

# Collective hormonal profiles predict group performance

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**Prior research has shown that an individual's hormonal profile can influence the individual's social standing within a group. We introduce a different construct—a collective hormonal profile—which describes a group's hormonal make-up. We test whether a group's collective hormonal profile is related to its performance. Analysis of 370 individuals randomly assigned to work in 74 groups of three to six individuals revealed that group-level concentrations of testosterone and cortisol interact to predict a group's standing across groups. Groups with a collective hormonal profile characterized by high testosterone and low cortisol exhibited the highest performance. These collective hormonal level results remained reliable when controlling for personality traits and group-level variability in hormones. These findings support the hypothesis that groups with a biological propensity toward status pursuit (high testosterone) coupled with reduced stress-axis activity (low cortisol) engage in profit-maximizing decision-making. The current work extends the dual-hormone hypothesis to the collective level and provides a neurobiological perspective on the factors that determine who rises to the top across, not just within, social hierarchies.**

testosterone | cortisol | groups | status | performance

Humans have always worked collaboratively in small groups to accomplish goals. In modern organizations, group work is increasing because of the growing competitive and technological demands placed on organizations and the belief that a greater variety of perspectives and approaches will lead to more innovative solutions (1–3). As a result, decades of research have focused on understanding the factors that can enhance group performance and allow some groups to outperform others. Not surprisingly, groups with structures, processes, and norms that facilitate collaboration and coordination tend to perform well (4, 5). Additionally, group composition can influence performance; groups composed of members that vary in diversity, skills, and intelligence outperform others when the appropriate structures, processes, and norms are in place (3, 6–10).

Past research on the effects of group composition on performance has focused primarily on the demographic and psychological characteristics of group members without taking into consideration the biological make-up of groups. This omission is particularly surprising because there is evidence that hormonal profiles can influence performance among individuals within a group. Indeed, past research has found that a hormonal profile characterized by high testosterone and low cortisol predicts an individual's performance and status attainment (11). Just as individuals have a hormonal profile that affects their individual performance and social status, we suggest that groups likewise can be characterized by a particular hormonal profile—their collective hormonal profile—which will influence group performance. We define a collective hormonal profile as the hormonal make-up of a group of individuals. Here, we test the hypothesis that groups with a collective hormonal profile characterized by high testosterone and low cortisol outperform and attain higher social standing among a collection of groups.

Across humans and various animal species, elevated testosterone, a steroid hormone released as the end product of the

hypothalamic–pituitary–gonadal (HPG) axis, is positively related to social dominance and behaviors that foster the achievement or maintenance of high status (12, 13). Individuals high in testosterone tend to outcompete others (14) and rise to the top of their social hierarchies, particularly in studies of nonhuman animals (15, 16). Recently, a more nuanced perspective on the link between testosterone and status attainment in humans has begun to emerge. There is growing evidence that the HPG axis acts in concert with the hypothalamic–pituitary–adrenal (HPA) stress axis to regulate status attainment within groups (11, 17). The HPA axis secretes the steroid hormone cortisol in response to stress and anxiety; thus interactions between the HPG and HPA axes can be observed by measuring testosterone and cortisol simultaneously. Specifically, the dual-hormone hypothesis posits that testosterone has a positive impact on status-attaining behavior only among individuals with low levels of cortisol (18). This hypothesis is informed by evidence that high levels of cortisol can suppress the neurobiological pathway through which testosterone impacts behavior; thus high levels of cortisol may inhibit testosterone's positive effect on dominance and status attainment (18).

The hypothesis that testosterone and cortisol interact to predict status-related behaviors for individuals has received strong empirical support in numerous contexts. For instance, individuals high in testosterone and low in cortisol have a greater number of subordinates, a measure of attained status (17); are perceived as more dominant leaders (18); are more respected by their peers (19); are more popular within their social networks (20); and engage in more competitive behavior as well as risk-taking (18, 21), a behavioral strategy associated with the attainment of social status (22, 23).

The current work explores whether the hormonal profile of a group predicts its standing among groups. We test whether the hormonal profile of high testosterone and low cortisol at the

## Significance

Past research has focused primarily on demographic and psychological characteristics of group members without taking into consideration the biological make-up of groups. Here we introduce a different construct—a group's collective hormonal profile—and find that a group's biological profile predicts its standing across groups and that the particular profile supports a dual-hormone hypothesis. Groups with a collective hormonal profile characterized by high testosterone and low cortisol exhibit the highest performance. The current work provides a neurobiological perspective on factors determining group behavior and performance that are ripe for further exploration.

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(31–34). To rule out the possibility that within-group hormonal variability was a key driver of our performance effects, we calculated each group's SD in testosterone and cortisol and tested whether within-group variability in testosterone, cortisol, or their interaction was related to group performance. When included in the main regression model, there were no significant effects of within-group variability in either hormone or their interaction on group performance. Further, the interaction between mean levels of testosterone and cortisol on group performance remained significant when within-group hormone levels were included in the model ( $b = -2.84$ ,  $SE = 1.17$ ,  $r = -0.29$ ,  $P = 0.02$ ) (Table 3, model 2). We also conducted exploratory analysis to test whether testosterone and cortisol unbiased means and SDs interacted to predict group performance and found no significant effects (*Supporting Information*). Additionally, we examined each group's concentration of individuals with the high-testosterone and low-cortisol profile to test whether greater concentrations of this collective hormonal profile predicted performance. We found no reliable effects of group concentration on group performance (*Supporting Information*), suggesting that the relationship between collective hormonal profiles and group performance is an emergent process that is not simply a reflection of individuals' hormonal profiles (Table S2).

The results demonstrate that groups collectively high in testosterone and low in cortisol outperform others, attaining higher standing. This finding is consistent with the dual-hormone hypothesis: Groups collectively high in testosterone may have a heightened status drive, but this status drive results in optimal decision-making only when coupled with low cortisol, a potential indicator of reduced stress and attenuated behavioral inhibition. Indeed, recent evidence suggests that increased testosterone combined with reduced cortisol may elevate an individual's status by promoting rational decision-making focused on maximizing financial profits (35). Our findings extend this research to the group level and suggest that groups with a propensity for status attainment, but without inhibition, engage in profit-maximizing decision-making strategies.

Our findings offer several avenues for future research. For instance, future studies should try to capture the emergent process through which an individual's neurobiology is transformed in an adaptively synergistic way to affect group performance. It is also critical to consider other neurobiological profiles that might influence group performance. Because anabolic hormones, such as dehydroepiandrosterone (DHEA), can counterregulate catabolic hormones (e.g., cortisol) and are indicative of an adaptive, thriving response during acute stress (36), we may expect to find that the interaction of group-level DHEA and cortisol predicts group performance under acute stress. This example, combined with our findings, highlights the importance of examining both the linear and interactive effects of collective hormones on group outcomes to capture the context-dependent nature of hormones (18), particularly as they relate to HPA and HPG axis activation. Additionally, although here we focus on resting hormone levels, examining hormonal reactivity and hormonal covariation among group members is another important direction for future research.

Our theorizing focuses on status attainment motivation as the key mechanism underlying our group performance effect; however, future studies should examine group-process measures to advance our knowledge of how status attainment motivations manifest themselves in group dynamics. There is evidence that the combination of elevated testosterone and reduced cortisol produces greater social rapport in interdependent decision-making tasks (35). This past finding suggests that groups in the present study with a collective hormonal profile of high testosterone and low cortisol may have experienced greater intragroup cohesion. Because intragroup cohesion is a critical determinant of group performance (37–40), we suspect that high testosterone/

low cortisol groups produced more favorable performance outcomes partly because they were more cohesive.

The current research goes beyond past work that has focused on observable behaviors of the group or on psychological characteristics of individuals within the group as predictors of group performance without paying attention to biological factors at the collective level. By showing that groups collectively high in testosterone and low in cortisol outperform other groups, we provide a broader perspective on the processes at play in determining which groups rise to the top across and not just within social hierarchies. In doing so, we both establish evidence in support of the dual-hormone hypothesis at the collective level and open up additional questions regarding the neurobiology of group behavior and performance.

## Materials and Methods

**Participants.** Participants were 370 Master in Business Administration (MBA) students (63.8% male; 36.2% female) enrolled in an introductory organizational behavior course and an operations management course at a business school in the northeastern United States. The average age of the sample was 27.44 y ( $SD = 1.93$  y); 157 participants (42.4%) were born outside the United States. The ethnic composition of our sample was diverse: 54.9% white, 16.5% Asian, 10.8% Hispanic, 9.4% South Asian, 4.6% black, 1.4% Southeast Asian, and 2.4% other. Participants provided informed consent, and the Institutional Review Board of Columbia University approved all materials and procedures in our study.

**Procedure.** Participants were randomly assigned to 74 groups ranging in size from three to six people. These groups met regularly during the semester (6 wk) and were required to work on a variety of tasks together outside of class. There were no formally assigned positions or roles within the groups, allowing groups to develop roles and form status hierarchies naturally over time (41). Additionally, there was little variance across groups in gender composition, because the MBA sample was predominantly male. Specifically, 1.4% of the groups had no women, 18.9% of the groups had one woman, and the remaining 79.7% had two women. Furthermore, gender composition did not moderate our observed effects [ $b = 0.15$ ,  $SE = 4.47$ ,  $t(64) = 0.03$ ,  $r < 0.01$ ,  $P = 0.85$ ]. The lower-level interaction between mean levels of testosterone and cortisol was still a significant predictor of group performance when gender was considered as a moderator instead of as a covariate [ $b = -2.74$ ,  $SE = 1.28$ ,  $t(64) = -2.14$ ,  $r = -0.26$ ,  $P = 0.04$ ].

At the start of the semester, during their organizational behavior course, participants completed a survey assessing trait dominance. Two weeks later, they provided a saliva sample and completed a survey assessing trait anxiety. One week after providing the saliva sample, participants engaged in a competitive group decision-making task in their operations management course in which their performance was measured relative to other groups in the class at two time points.

## Measures.

**Testosterone and cortisol.** Participants provided one saliva sample at the start of class during their assigned class time of 9:00 AM (early morning session), 10:45 AM (late morning session), 2:15 PM (early afternoon session), or 4:00 PM (late afternoon session). Participants first completed informed consent and biological questionnaires and then, after a 15-min rest period, provided a saliva sample that was later assayed for testosterone and cortisol. Saliva samples were frozen until the study was completed and then were shipped overnight on dry ice to a laboratory in College Park, PA. Saliva samples were assayed for testosterone and cortisol using a highly sensitive enzyme immunoassay (Salimetrics). Average intra- and interassay coefficients of variation were 2.5% and 5.6%, respectively, for testosterone and 3.5% and 5.1%, respectively, for cortisol. Before analysis, both hormone measures were log-transformed to account for significant positive skew, and mean levels were centered around their grand means (see *Supporting Information* and Table S3 for raw hormone values). Finally, group-level testosterone and cortisol profiles were calculated from the best linear unbiased predictors of testosterone and cortisol levels within each group (see *Data Analysis Strategy*), because groups varied in size from three to six members. We also calculated group-level SDs in testosterone and cortisol for each group.

**Group performance.** The group decision-making task was a computerized exercise (Littlefield Labs, Responsive Learning Technologies) simulating the supply-chain process of a series of laboratories providing blood testing to its

customers. Groups were told that they were employees at the blood-testing laboratory and that they would compete with the other groups in the class in managing several aspects of the laboratory (e.g., buying and selling capacity, adjusting lead-time quotes, changing lot sizes and inventory-ordering parameters, and selecting scheduling rules). Specific instructions were as follows:

The lab has been running for 50 days, and management has hired a high-powered operations team (you) to manage the capacity, scheduling, purchasing, and contract quotations to maximize the cash generated by the lab over its lifetime. You will have control of the lab from day 50 to day 218. At 1 hour per simulated day, this translates to 7 real days. At day 218, you lose control of the lab, and the simulation will quickly run another 97 days of simulation. When you lose control of the lab, management expects you to leave the lab parameters set to maximize the lab's cash position when the lab shuts down later on day 315.

Groups were required to make decisions in response to historical records of inventory levels, queues, utilization, lead times, cash flows, and the group's standing relative to the other competing groups. Each group simultaneously received the same information through the computer interface. For example, new orders arrived at each group's fictional factory at exactly the same time. Our key dependent variable was a composite of the key group performance measures produced by the Littlefield Labs simulation: profitability in millions of dollars, number of contracts secured, number of reorders on existing contracts, and group rank relative to other groups in the class. Because these measures had different scales, they were first standardized and then averaged to create the aggregated group performance metric ( $\alpha = 0.86$ ). Performance was assessed at two time points: 5 d into the simulation (simulating 170 d of laboratory operations) and 7 d into the simulation (simulating 315 d of laboratory operations). It is important to note that there was no normative solution or decision-making model in the decision-making exercise. Groups could use a variety of strategies to optimize financial performance.

**Self-report measures.** Participants completed an online survey assessing trait dominance using the Revised Interpersonal Adjective Scales (IAS-R) (42). Three items—dominant, assertive, and forceful—were rated on a scale ranging from 1 (does not describe me at all) to 7 (describes me very well) to assess dominance. These three items have demonstrated high correlations with the full eight-item Dominance Scale (43) and thus are considered suitable measures of trait dominance. The three items were intercorrelated ( $\alpha = 0.79$ ) and therefore were combined into one overall index of trait

dominance. Two weeks later, participants completed the Positive and Negative Affect Schedule (PANAS) (44) and rated their feelings on 20 emotional states (10 positive and 10 negative) using five-point scales ranging from 1 (not at all) to 5 (a great deal). We were particularly interested in the anxiety subscale of the PANAS (nervous, afraid, scared;  $\alpha = 0.84$ ), given that cortisol increases in situations that evoke psychological stress and anxiety (45).

**Data Analysis Strategy.** The primary analyses reported in the main text examine the final results (i.e., day 7 of the exercise) using a multilevel model (46). Specifically, our dependent variable, group performance, was collected at the group level, but we wanted to predict this group-level outcome from the hormones that were collected at the individual level. Therefore, we conducted a multilevel model that accounted for the nesting of individuals (level 1) within groups (level 2) by estimating the collective group hormones from the best linear unbiased predictor for all group aggregates of variables measured at the individual level. This approach is known to be superior to simply using group means as predictors, and the multilevel model corrects the slope SEs to account for heteroscedasticity caused by unequal group sizes. In the *Supporting Information* we also modeled group performance as a function of time of performance (day 5 or day 7, which simulated days 170 and 315 of laboratory operations, respectively); group unbiased means and group SDs for testosterone and cortisol; the three-way interaction between time of performance, group testosterone, and group cortisol; and all three possible two-way interactions between time of performance, group testosterone, and group cortisol using a multilevel model controlling for time of day, gender composition, and group size. All predictors were mean centered before analysis. All analyses were conducted using R 3.2.2 (47). The full data and analysis script that reproduces the numbers reported in the main text and in *Supporting Information* are provided on the Open Science Framework (<https://osf.io/jg5z4>).

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