

Short Communication

Three-month cumulative exposure to testosterone and cortisol predicts distinct effects on response inhibition and risky decision-making in adolescents

Grant S. Shields^{a,*}, Susannah L. Ivory^b, Eva H. Telzer^{c,**}

^a Center for Mind and Brain, University of California, Davis, United States

^b Department of Psychology, Pennsylvania State University, University Park, United States

^c Department of Psychology and Neuroscience, University of North Carolina, Chapel Hill, United States



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ABSTRACT

Prior studies have established that cortisol and testosterone play a role in impulsive behavior, but little is known about how cumulative exposure to these hormones over a recent period influences cognitive processes that help to regulate impulsive behavior. We addressed this gap in the present study by examining how hair concentrations of testosterone and cortisol related to response inhibition and risky decision-making in adolescents. Adolescents provided 3 cm of hair cut as close as possible to the scalp from a posterior vertex position—indexing three months of hair growth—and completed two behavioral tasks, one that measures response inhibition and the second that measures risky decision-making. We found that greater three-month cumulative exposure to testosterone predicted better response inhibition but was unassociated with risky decision-making, whereas greater three-month cumulative exposure to cortisol predicted less risky decision-making but was unassociated with response inhibition. These results suggest that testosterone and cortisol may be associated with unique cognitive processes underpinning impulsive behavior, providing further evidence for their roles in contributing to complex impulsive behaviors in adolescence.

1. Introduction

Much work has established that testosterone and cortisol can contribute to behavioral aggression (for review, see [Montoya et al., 2012](#)). This work has prompted popular media to portray testosterone and cortisol as villains, contributing to undesirable behaviors (e.g., [Keating, 2018](#)). However, these hormones may have more than one effect on cognition and behavior, and the effects they have on cognitive processes that play a role in impulsivity are relatively unknown. We addressed this gap in the present study by examining how cumulative exposure to testosterone and cortisol over a three month period—measured using hair samples—predicted both response inhibition (i.e., the ability to stop oneself from acting in a habitual way, such as stopping oneself from reaching for a piece of food) and risky decision-making (i.e., a tendency to make high-risk, high-reward decisions).

Examining associations between testosterone or cortisol and cognitive performance can be difficult, as both cortisol and testosterone fluctuate in response to state factors, such as time of day (e.g., diurnal

rhythms; [Matchock et al., 2007](#)), acute stress ([Dickerson and Kemeny, 2004](#)), or even the mere presence of opposite-sex others ([Miller et al., 2012](#)). Therefore, associations based upon a single saliva or blood sample of testosterone or cortisol—given the extent to which they fluctuate—may fail to describe the true association between these hormones and cognitive processes. Hair hormone assessment offers a solution to this issue, as hair levels represent cumulative exposure to hormones over the assessed window ([McLennan et al., 2016](#); [Ronay et al., 2018](#)).

In adults, hair testosterone—indexing three-month cumulative exposure—is associated with better response inhibition in some individuals ([Hildebrandt et al., 2016](#)), and when hair cortisol levels are low, greater risky decision-making in men ([Ronay et al., 2018](#)). Hair cortisol, on the other hand, has not been associated with these or other cognitive processes in adults when hair testosterone was not also considered ([Ceccato et al., 2016](#); [McLennan et al., 2016](#)). Given that both testosterone and cortisol increase substantially during adolescence and that impulsive behaviors peak in adolescence ([Casey et al., 2008](#)),

* Corresponding author at: 1 Shields Ave, Davis, CA, 95616, United States.

** Corresponding author at: 235 E. Cameron Avenue, Chapel Hill, NC, 27514, United States.

E-mail addresses: gsshields@ucdavis.edu (G.S. Shields), ehetelzer@unc.edu (E.H. Telzer).

recent cumulative exposure to these hormones may be an important predictor of response inhibition and risky decision-making during this developmental period. To date, however, no study has examined how cumulative exposure to testosterone and cortisol relate to response inhibition and risky decision-making in adolescents.

Current theories of the psychological functions of testosterone and cortisol may help inform hypotheses regarding how they should relate to response inhibition and risky decision-making. Testosterone, for example, is thought to promote competitive and status-seeking behavior (Roney, 2016), which often enhance response inhibition relative to cooperative behavior (Ruissen and De Bruijn, 2016; Staiano et al., 2012). Cortisol, in contrast, due to its association with stress, may signal a relative lack of safety, and thereby confer a preference for safe decisions over high-risk, high-reward ones (e.g., Nesse et al., 2016). Therefore, the psychobiological functions of testosterone and cortisol offer some insights as to how they might relate to response inhibition and risky decision-making.

1.1. Current research

In the current study, we examined how three-month cumulative exposure to testosterone and cortisol relate to response inhibition and risky decision-making in adolescents. Drawing on prior work described above, we hypothesized that greater three-month levels of testosterone would predict better response inhibition. Although we did not have strong *a priori* hypotheses for cortisol, drawing on chronic stress literature, we expected greater three-month levels of cortisol to predict worse response inhibition (Mika et al., 2012). We did not have any hypotheses about interactions between these hormones with regards to response inhibition. As for risky decision-making, drawing on the psychological function of cortisol as well as the dual hormone hypothesis—which posits that cortisol buffers the effects of testosterone on aggression and status-seeking behaviors (Denson et al., 2013; but see Dekkers et al., 2019)—we hypothesized that greater three-month levels of cortisol would predict less risky decision-making, greater three-month levels of testosterone would predict more risky decision-making, and that cortisol and testosterone would interact, such that the association between testosterone and risky decision-making would be stronger in individuals with low cortisol.

2. Method

Additional information on each section of the method is provided in the Supplemental Material.

2.1. Participants

Participants in this study were 55 adolescents (52.7% female, $M_{\text{age}} = 13.39$ years, $SD = 1.11$, range = 12.01–15.92).

2.2. Cognitive tasks

Response inhibition was assessed using the stop-signal task, which is an extensively validated response inhibition task (Verbruggen et al., 2013). The primary index of response inhibition in this task is the stop-signal reaction time (SSRT), which quantifies the time a participant requires to inhibit an activated response. We calculated SSRT using the recommended integration method (Verbruggen et al., 2013). Greater SSRTs indicate poorer response inhibition.

Risky decision-making was assessed using the yellow light game (YLG), which is a risky decision-making task embedded in a driving simulation (Op de Macks et al., 2018). In this task, “go” (as opposed to

“stop”) decisions at intersections with yellow lights represent risky decision-making, as such decisions risk a crash with oncoming cars.

2.3. Hair sampling and assays

Three hair segments approximately 3 mm in diameter were collected from the posterior vertex position of the scalp. Testosterone and cortisol concentrations were determined using the first 3 cm of hair most proximal to the scalp (therefore indexing three-month hormone concentrations).

2.4. Data analysis

Some participants did not have enough hair to provide the standard sample, so all analyses controlled for hair length. Age and sex were included as additional covariates in our primary analyses. We log transformed hair hormone values to correct for skewness.

3. Results

As a preliminary analysis, we examined whether hair testosterone and hair cortisol differed by sex. Consistent with expectations, we found that males had significantly greater hair testosterone ($M = 1.49$, $SE = 0.33$) than females ($M = 0.75$, $SE = 0.10$), $t(43) = 2.20$, $p = .034$, $d = 0.65$. We found no differences in hair cortisol by sex, $t(43) = 0.14$, $p = .887$. Hair testosterone was not significantly associated with hair cortisol, $r = .054$, $p = .722$. Additional preliminary analyses, including the association of age with each of these variables as well as analyses of potential sex difference in cognitive task performance, are presented within the Supplemental Material.

Next, we examined how hair testosterone and hair cortisol related to inhibitory control. We found that hair testosterone significantly predicted inhibitory control, such that greater hair testosterone predicted lower SSRT (i.e., better response inhibition), $\beta = -.337$, $p = .039$ (Fig. 1a), and hair testosterone remained a significant predictor of better inhibitory control when controlling for hair cortisol, $\beta = -.326$, $p = .045$. In contrast to hair testosterone, hair cortisol was unassociated with inhibitory control, $\beta = -.194$, $p = .233$ (Fig. 1b). Hair cortisol and hair testosterone did not interact to predict inhibitory control, $\beta = -.143$, $t(38) = -0.83$, $p = .413$, and the association between hair testosterone and response inhibition was not moderated by sex, $\beta = .137$, $t(39) = 0.63$, $p = .532$.

We then examined how hair testosterone and cortisol related to risky decision-making (i.e., percent of go decisions). Hair testosterone was unassociated with risky decision-making, $\beta = .143$, $p = .398$ (Fig. 2a). However, hair cortisol predicted fewer risky decisions, $\beta = -.393$, $p = .015$ (Fig. 2b), and hair cortisol remained a significant predictor of less risky decision-making when controlling for hair testosterone, $\beta = -.404$, $p = .012$. Hair cortisol and hair testosterone did not interact to predict risky decision-making, $\beta = .271$, $t(38) = 1.62$, $p = .115$, and the association between hair cortisol and risky decision-making was not moderated by sex, $\beta = .194$, $t(38) = 0.82$, $p = .419$.

Results were similar using a different approach to adjust for unequal hair length. Additionally, results were similar both when hormone values were not log transformed and regardless of whether or not covariates were included (e.g., sex, age; see Supplemental Material).

4. Discussion

Despite hypothesized effects of testosterone and cortisol on inhibitory control and risky decision-making in humans, to date no study has examined how cumulative recent exposure to these hormones is

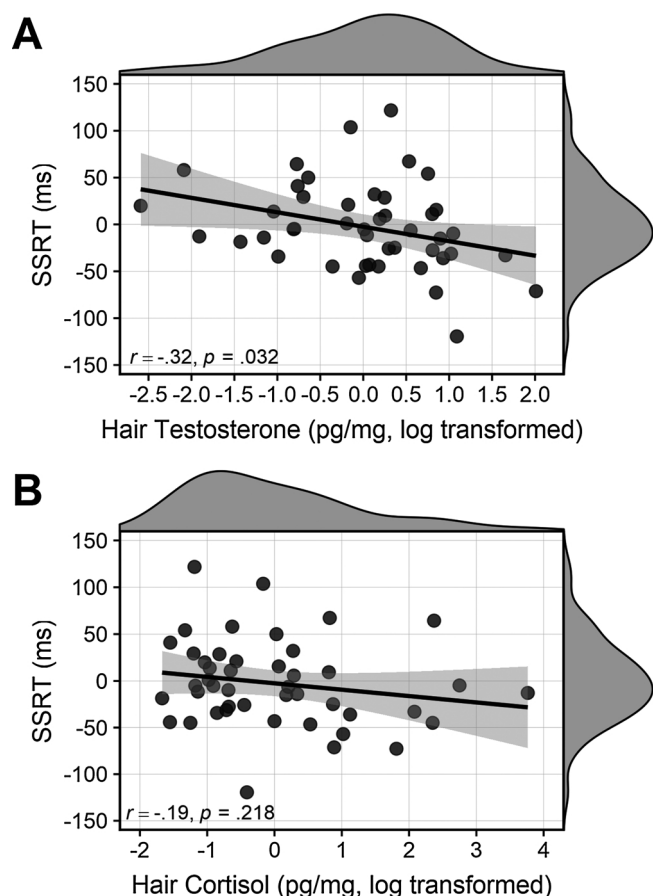


Fig. 1. Associations between hair concentrations of hormones and response inhibition (stop signal reaction time—higher values represent worse performance), controlling for hair sample length, age, and sex (associations without covariates are depicted in Supplemental Material). Panel A depicts the association with testosterone, whereas panel B depicts the association with cortisol. The shaded area above each scatterplot displays the density plot of the variable on the x-axis (e.g., testosterone), whereas the shaded area to the right of each scatterplot displays the density plot of the variable on the y-axis (i.e., SSRT). Testosterone was associated with better response inhibition (A), whereas cortisol was unassociated with response inhibition (B). These results held when both hormones were included in a single model.

related to both of these cognitive processes in adolescents. Because adolescence is a time of both substantial hormonal increases and undeveloped inhibitory control coupled with heightened risky decision-making (Casey et al., 2008), understanding how testosterone and cortisol relate to cognitive processes during this developmental window is important. Additionally, these potential associations may have important implications: Better response inhibition in adolescence is a strong predictor of mathematics and science achievement (Latzman et al., 2010), and risky decision-making in adolescence is a risk factor for adolescent substance use and other unsafe behaviors (Aklin et al., 2005). In the present study, we examined how three-month hair concentrations of testosterone and cortisol predicted inhibitory control and risky decisions. Somewhat surprisingly, we found that greater hair testosterone predicted better inhibitory control but was unassociated with risky decision-making, whereas greater hair cortisol predicted less risky decision-making but was unassociated with inhibitory control. Unlike what might have been predicted from the Dual Hormone

Hypothesis, we also found no interactions between testosterone and cortisol in predicting either of these outcomes (see also Grebe et al., 2019, who found no empirical support for the Dual Hormone Hypothesis). Although these results are correlational, this double dissociation could be taken to suggest independent roles of testosterone and cortisol in contributing to inhibitory control and risky decision-making, respectively.

Our finding that testosterone predicted better response inhibition but was unassociated with risky decision-making is similar to findings from prior studies in human adults: One study found that circulating levels of testosterone were associated with fewer errors in an emotional response inhibition task (Hildebrandt et al., 2016), and another found that hair testosterone levels were unassociated with risky decision-making (Ronay et al., 2018). In contrast, these prior findings and our results differ from the conceptual results of one study in rodents, which found that rats that were administered testosterone for four weeks showed greater tolerance for risk but no differences in motor impulsivity (Cooper et al., 2014).

We found that hair cortisol was related to less risky decision-making but unassociated with response inhibition. The lack of association with response inhibition is consistent with one prior study (McLennan et al., 2016), but the observed unmoderated association with less risky decision-making differs from two prior studies (Ceccato et al., 2016; Ronay et al., 2018). Sample differences (e.g., adolescents vs. adults) may have contributed to this difference, as sex hormones are high during adolescence and one of these two studies did find that hair cortisol predicted lower risky decision-making when hair testosterone was high (Ronay et al., 2018). Alternatively, the association between hair cortisol and risky decision-making may be task-specific. Our data cannot determine which of these potential explanations best accounts for this discrepancy. Although this is not a comprehensive overview of the literature on steroid hormones and decision-making behavior in humans and animals, we highlight a few studies to underscore the ambiguity in the literature around testosterone, cortisol, and relevant cognitive processes.

This study has limitations that should be noted. First, although a strength of our study is its examination of adolescents (in that adolescence is a time when both impulsive behaviors and their consequences are high), it is unknown whether these results would generalize to different populations. Second, the relatively small sample size limited our power to detect effects, potentially precluding our ability to detect testosterone by cortisol interaction effects. Finally, our data are unable to determine the relative contribution of acute versus chronic levels of these hormones to the cognitive processes of interest.

In sum, we found that cumulative exposure to testosterone over a three-month period predicted better response inhibition but was unassociated with risky decision-making, whereas cumulative exposure to cortisol over a three-month period predicted less risky decision-making but was unassociated with response inhibition in a sample of healthy adolescents. These results have intriguing implications for our understanding of how testosterone and cortisol shape inhibitory control and impulsivity. Within a sample of adolescents, testosterone and cortisol may not be the villains that popular media portrays them to be, and instead are associated with better response inhibition and less risky decision-making, respectively.

Author note

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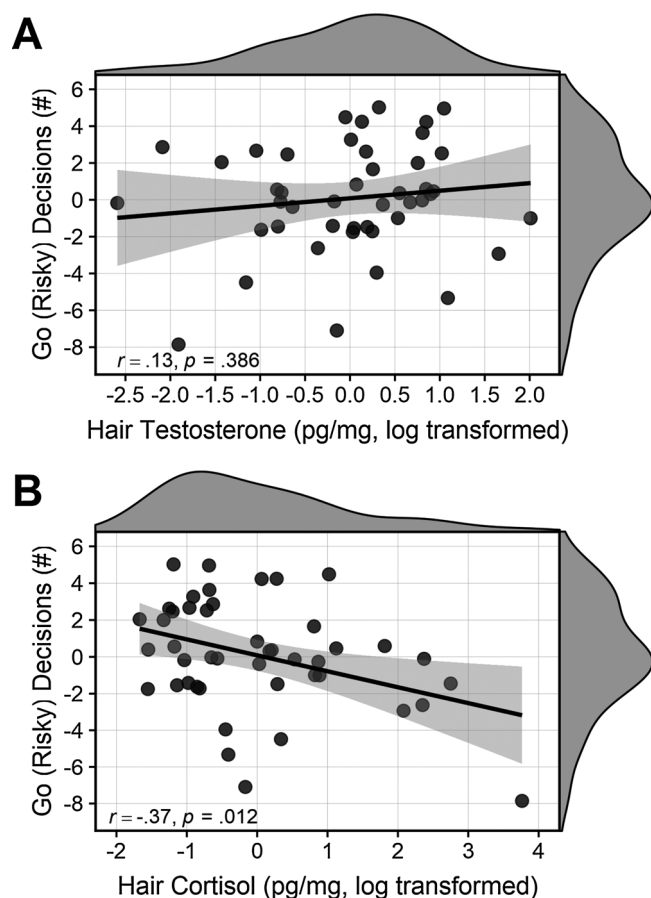


Fig. 2. Associations between hair concentrations of hormones and risky decision-making (“Go” decisions in the yellow light game—higher values indicate more risky decision-making), controlling for hair sample length, age, and sex (associations without covariates are depicted in Supplemental Material). Panel A depicts the association with testosterone, whereas panel B depicts the association with cortisol. The shaded area above each scatterplot displays the density plot of the variable on the x-axis (e.g., testosterone), whereas the shaded area to the right of each scatterplot displays the density plot of the variable on the y-axis (i.e., “go” decisions). Testosterone was unassociated with risky decision-making (A), whereas cortisol was significantly associated with less risky decision-making (B). These results held when both hormones were included in a single model.

Declaration of Competing Interest

The authors declare no conflict of interest in this work.

Appendix A. Supplementary material

Supplementary material related to this article can be found, in the online version, at <https://doi.org/10.1016/j.psyneuen.2019.104412>.

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