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ORIGINAL ARTICLE

Estimating the Associations between Big Five Personality Traits, Testosterone, and Cortisol

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Abstract

Objective Hormones are often conceptualized as biological markers of individual differences and have been associated with a variety of behavioral indicators and characteristics, such as mating behavior or acquiring and maintaining dominance. However, before researchers create strong theoretical models for how hormones modulate individual and social behavior, information on how hormones are associated with dominant models of personality is needed. Although there have been some studies attempting to quantify the associations between personality traits, testosterone, and cortisol, there are many inconsistencies across these studies.

Methods In this registered report, we examined associations between testosterone, cortisol, and Big Five personality traits. We aggregated 25 separate samples to yield a single sample of 3964 (50.3% women; 27.7% of women were on hormonal contraceptives). Participants completed measures of personality and provided saliva samples for testosterone and cortisol assays.

Results The results from multi-level models and meta-analyses revealed mostly weak, non-significant associations between testosterone or cortisol and personality traits. The few significant effects were still very small in magnitude (e.g., testosterone and conscientiousness: $r = -0.05$). A series of moderation tests revealed that hormone-personality associations were mostly similar in men and women, those using hormonal contraceptives or not, and regardless of the interaction between testosterone and cortisol (i.e., a variant of the dual-hormone hypothesis).

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Conclusions Altogether, we did not detect many robust associations between Big Five personality traits and testosterone or cortisol. The findings are discussed in the context of biological models of personality and the utility of examining heterogeneity in hormone-personality associations.

Keywords Personality · Testosterone · Cortisol · Dual-hormone hypothesis · Registered report

Establishing a biological basis of human personality has been a goal of researchers for many years (Canli 2006; Hippocrates 460 BC/ 1978; Netter 2004). To date, many of the efforts to link personality to its biological origins have focused on issues related to heritability, brain structure and functioning, behavioral genetics, and non-human research (e.g., Canli 2008; Krueger and Johnson 2008; Weinstein et al. 2008). The examination of how variation in endogenous hormone levels is associated with variation in individual psychological characteristics also arises from these efforts (e.g., Schultheiss et al. 2005; Smeets-Janssen et al. 2015). Indeed, hormones are often conceptualized as biological markers of individual differences and have been found to be associated with a variety of behavioral indicators and characteristics, such as mating behavior or acquiring and maintaining dominance (e.g., Edelstein et al. 2011; Josephs et al. 2006; Mehta and Josephs 2010; Newman et al. 2005; Sellers et al. 2007; Slatcher et al. 2011). However, before researchers create strong theoretical models for how hormones modulate individual and social behavior, observational information on how hormones are associated with popular models of personality (e.g., the Five Factor Model; McCrae and Costa 2008) is needed. Although there have been some studies attempting to quantify the associations between personality traits, testosterone, and cortisol, there are many inconsistencies across these studies. In the current project, we examined associations between testosterone, cortisol, and Big Five personality traits in a pooled sample of nearly 4000 people.

Big Five Personality Traits

The most dominant taxonomy of characterizing individual differences in the field of personality is the Big Five taxonomy of personality traits. The Big Five traits are comprised of five broad, global traits—extraversion (traits like outgoing and lively), agreeableness (traits like helpful and sympathetic), neuroticism (traits like moody and worrying), conscientiousness (traits like hardworking and responsible), and openness to experience (traits like imaginative and curious). The Big Five traits were derived from a lexical approach to understanding individuals (Cattell 1945; Goldberg 1990). Specifically, early iterations of trait descriptors were derived from common linguistic expressions and words that could most succinctly be summarized as being organized under five superordinate factors. There are subordinate descriptors that fall under these five factors (e.g., facets; Costa Jr and McCrae 1995), but the majority of work has examined the five broad, global traits.

Why would one expect to see associations between personality traits, testosterone, and cortisol? Although some theory related to personality and physiological systems

exists (McCrae and Costa 2008), rarely are specific hypotheses made regarding the direction and magnitude of associations between personality and hormones. There have been efforts to link the origin of individual differences in personality to selection pressures, mutation, and fitness pay-offs and trade-offs over extended periods of time (de Vries et al. 2016; Nettle 2005, 2006). Although these reviews do not explicitly talk about hormone variation specifically, it is easy to see the many places in which personality, testosterone, and cortisol might be linked to one another in various contexts (see Nettle 2006). Most notably, many of the correlates of both personality and testosterone or cortisol reflect a similar strategy for reproductive fitness from an evolutionary perspective. For example, some of the benefits of extraversion include mating success, but some of the costs include more instability in maintaining long-term relationships, which would suggest that extraversion might be positively associated with testosterone. Likewise, some of the benefits of neuroticism include a vigilance to danger, but some of the costs include higher stress and depression, which would suggest that neuroticism might be positively associated with cortisol. These hypotheses constitute speculation about why personality, testosterone, and cortisol might be associated with one another. However, they illustrate that there may be reasons to expect personality and hormones to be associated with one another, partially because they present similar trade-offs for reproductive fitness. To date, unfortunately, empirical investigations linking personality to testosterone or cortisol have often produced more ambiguity about whether they are linked at all.

Current Evidence Linking Testosterone and Cortisol to Big Five Personality Characteristics

In the current project, we focused our attention on two hormones in particular—testosterone and cortisol—as they have the clearest theoretical and empirical linkages with Big Five personality traits. Testosterone is a major sex hormone found in men and women that is associated with a number of behaviors, including mating effort and dominance (Apicella et al. 2014; Slatcher et al. 2011; Stanton et al. 2011). Cortisol is the hormonal product of the hypothalamic-pituitary-adrenal (HPA) axis and is associated with psychological stress and behavioral inhibition (Dickerson and Kemeny 2004; Tops and Boksem 2011). Although there have been studies examining associations between testosterone and cortisol with Big Five-adjacent characteristics (e.g., the aforementioned facets of dominance, sensation seeking, anxiety, interpersonal closeness), there have been very few tests of associations between testosterone and cortisol with Big Five characteristics specifically. Below, we review the existing evidence that has examined links between testosterone and cortisol to Big Five personality traits.

Testosterone Testosterone has been found to be most reliably associated with extraversion-related traits, particularly characteristics related to social dominance (Archer 2006; Archer et al. 1998; Archer et al. 2005; Book et al. 2001; McCabe and Fleeson 2012). Traits such as dominance, aggression, assertiveness, and status-seeking are conceptualized as further facets of social dominance and have been studied in both humans and other animals—with many finding associations between these behaviors and testosterone (Archer 2006; Josephs et al. 2006; Mazur and Booth 1998; Mehta and

Josephs 2010; Slatcher et al. 2011; Soto and John 2017; Wingfield et al. 1990; Wingfield et al. 2000). For example, in human status-seeking, individuals with higher basal testosterone levels seek out higher social standing; those with lower testosterone prefer (or are relegated) to stay in lower social positions rather than ascend hierarchies (Newman et al. 2005). Likewise, testosterone and extraversion are both associated with dominance tendencies in mating contexts (Nettle 2005; Slatcher et al. 2011). In one particular study examining mating context competition, higher testosterone levels were associated with men's dominance behavior toward other men, their dislike for their male competitor afterwards, and how much the female confederate self-reportedly "clicked" (e.g., felt a connection) with them (Slatcher et al. 2011). Aside from the social dominance facets of extraversion, testosterone is also positively correlated with additional trait-like characteristics such as sensation seeking (an independent characteristic that has been linked to extraversion, [lower] conscientiousness, and openness to experience; Aluja et al. 2003; Aluja et al. 2002; Roberti 2004; Smeets-Janssen et al. 2015). Although these studies might suggest a positive association between extraversion and testosterone, it is worth noting that reliable links between extraversion (or its facets) and testosterone are not always found (Aluja and García 2007; Anderson et al. 1992; Archer et al. 1998; Archer et al. 2005; Doering et al. 1975; van Goozen et al. 1998).

Few studies have examined the relationship between testosterone and the remaining of the Big Five traits. In a study of 2093 participants (77% of whom had a history of psychopathology), lower levels of neuroticism and higher levels of extraversion and conscientiousness were positively related to testosterone, although the magnitude of the associations is generally small (Smeets-Janssen et al. 2015). Agreeableness was found to be negatively associated with testosterone in a sample of castrated males (who are thus deprived of testosterone/androgens; Treleaven et al. 2013). Testosterone levels have been found to be negatively associated with anxiety, stress, and depression (factors related to neuroticism; Francis 1981; Giltay et al. 2012). Testosterone has been positively associated with risk-taking, a facet of low conscientiousness (Apicella et al. 2014). Some studies have found a *negative* association between conscientiousness and testosterone, and occasionally this association differs between men and women (e.g., Reardon et al. 2016; Sellers et al. 2007; Smeets-Janssen et al. 2015). Testosterone appears to be largely unrelated to openness to experience.

Although these studies suggest some links between testosterone and Big Five traits, there is little to no consistency in these associations across other studies (Francis 1981; Sellers et al. 2007; Treleaven et al. 2013). Given the few studies examining associations between testosterone and Big Five personality traits (and the ambiguity of these few studies), we examined the links between testosterone and personality in an aggregated sample in which people completed personality measures and provided a way of assaying testosterone. Tentatively, we hypothesized that we would find a positive association between testosterone and extraversion, and negative associations between testosterone and agreeableness and neuroticism. Due to the little or conflicting research on openness and conscientiousness, we did not make hypotheses about these traits. We expected that, if there were any associations between personality and testosterone, the effect sizes of these associations would likely be small.

Cortisol Research examining associations between cortisol and personality traits is less common relative to work on testosterone. Commonly studied by researchers examining depression, stress, and anxiety, cortisol is most often conceptualized as a likely biological correlate of neuroticism. The consensus is that cortisol may be positively correlated with neuroticism through the activation of the HPA axis (Nater et al. 2010). For example, high levels of stress are a hallmark of both neuroticism (e.g., being moody, worrying) and cortisol. Indeed, higher levels of neuroticism are associated with higher levels of cortisol throughout the day, and elevated cortisol is one of the proposed mechanisms linking neuroticism to poorer health outcomes over time (Nater et al. 2010; Portella et al. 2005). However, work by Schommer et al. (1999) found no significant association between neuroticism and cortisol, and a number of studies have provided conflicting information about the size and even direction of associations between neuroticism and cortisol (see Vickers Jr et al. 1995). Thus, although there are theoretical reasons to expect associations between cortisol and neuroticism, empirical studies have yet to find a compelling link between the two.

Very little work has examined associations between cortisol and the remaining Big Five traits. In one study, interpersonal closeness (a construct most closely related to some facets of extraversion and agreeableness [depending on the taxonomy used]) was found to be associated with lower cortisol (Ketay et al. 2017). Agreeableness is occasionally positively correlated with cortisol (Tops et al. 2006; Vickers Jr et al. 1995). Cortisol is sometimes found to be negatively correlated with conscientiousness (Vickers Jr et al. 1995), but this association is not always found (e.g., Nater et al. 2010). Patients with an oral condition (burning mouth syndrome) known to increase cortisol report higher levels of neuroticism and lower levels of openness to experience relative to control patients (de Souza et al. 2015). This study is one of few to test patients with elevated cortisol reporting on all Big Five traits, but with the small sample ($N = 60$; 97% female) and specialized population/design, it is difficult to generalize these findings to a broader, healthy population.

Given the few studies examining associations between cortisol and Big Five personality traits (and the ambiguity of these few studies), we examined the links between cortisol and personality in a large sample in which people completed personality measures and provided a way of assaying cortisol. Tentatively, we hypothesized that we would find positive associations between cortisol and neuroticism and agreeableness, and negative associations between cortisol and extraversion and openness to experience. We expected that, if there were any associations between personality and cortisol, the effect sizes of these associations would likely be small.

Limitations of Previous Research

Although there have been some examinations of the links between hormones and Big Five personality traits, many limitations restrict our understanding of how and which personality traits are associated with testosterone and cortisol. The ambiguity regarding personality-hormone associations likely originates from at least three sources.

First, we may not have much understanding about personality-hormone associations because of the methodological and reporting choices that researchers make. For example, many of the studies examining personality-hormone associations recruit too

small sample sizes (e.g., Anderson et al. 1992; de Souza et al. 2015; Doering et al. 1975), often with fewer than 20 participants. Small samples and the increased likelihood that only significant results are published may overestimate the number of associations between personality and hormones (Simmons et al. 2011; Van Elk et al. 2015). Likewise, this file drawer problem (i.e., that null and/or inconsistent results are not published) may have left many samples that contain personality and hormone information undetectable (Rosenthal 1979).

Second, and relatedly, some studies measure (or only report) associations with one hormone and/or one or two personality traits (Nater et al. 2010; Sellers et al. 2007). For example, a study might only report a correlation between conscientiousness and testosterone without reporting any information on the remaining four Big Five traits. In some cases, this information may not have been available, measured, or analyzed. In other cases, this information may not have been reported on because the authors believed it was not relevant to that particular empirical article. As a result, part of the gap in our knowledge about personality-hormone associations can be attributable to researchers not testing or not reporting all associations of the Big Five personality traits with testosterone and cortisol. In the current project, we examined associations between all Big Five traits and two hormones often studied (i.e. testosterone and cortisol) to provide this descriptive information for the fields of personality and neuroendocrinology.

Finally, many of the current studies examine special or restricted populations (e.g., those with a history of psychopathology, castrated individuals, men only; de Souza et al. 2015; Smeets-Janssen et al. 2015; Vickers Jr et al. 1995). Few large studies report personality-hormone associations in samples of relatively healthy participants.

Ancillary Questions Regarding Personality-Hormone Associations

A separate but related issue to how personality and hormones are associated is whether these associations are the same across different subsets of a population. In addition to providing basic descriptive information linking hormones and personality, we sought to shed light on three additional factors—gender, hormonal contraceptives, and the dual-hormone hypothesis (i.e., whether combinations of testosterone and cortisol are differentially associated with personality traits).

Are the same personality-hormone associations found in both women and men (Reardon et al. 2016; Sellers et al. 2007; Smeets-Janssen et al. 2015)? How important are hormonal contraceptives in suppressing (or enhancing) personality-hormone associations (Josephs 2009)? Unfortunately, along with the aforementioned limitations, researchers rarely or inconsistently test moderation by these variables. Oftentimes, these variables are used as justification for excluding participants entirely (e.g., the lack of research on testosterone in women; van Anders et al. 2014). This approach is unfortunate in that it contributes to the lack of knowledge about how personality-hormone associations differ across groups. The few studies that tested how these associations vary across different groups have provided useful information. For example, Sellers et al. (2007) found that, among women, conscientiousness is negatively associated with testosterone but, among men, conscientiousness was not significantly related to testosterone. In the

current project, we tested the moderating effects of gender on the links between personality and hormones.

Some researchers advocate for excluding women on hormonal contraceptives entirely from analyses (van Anders et al. 2014); others suggest including women on contraceptives but checking for moderation effects (Josephs 2009; Wardecker et al. 2018). Some of the reasons for excluding women on contraceptives exist because contraceptives are a synthetic form of estrogen and progesterone that decrease the endogenous production of these hormones—and testosterone—in most women (Fleischman et al. 2010). Other reasons include findings regarding opposing effects of testosterone among those on or not on hormonal contraceptives. Including women on hormonal contraceptives and testing for differences can reveal several insights into how psychological and biological processes differ between the two groups. Importantly, these tests can be modeled through moderation, irrespective of the aforementioned exclusionary reasons (Josephs 2009). Although contraceptive use is most often implicated as a confounder in the study of sex hormones (Goldey and van Anders 2011), it is also possible that contraceptive use might influence circulating levels of cortisol, affecting personality-cortisol associations. Some studies find that contraceptives suppress cortisol levels (Meulenberg et al. 1987); other studies find no suppression (Nickelsen et al. 1989). There is also some evidence that contraceptive use does not moderate personality-cortisol associations, as seen in a study examining narcissism and cortisol associations (Wardecker et al. 2018). To our knowledge, no studies have examined the moderating role of hormonal contraceptive use on links between Big Five personality traits and hormones. In the current project, we tested the moderating effects of hormonal contraceptives on the link between personality and hormones.

Finally, the dual-hormone hypothesis dictates that testosterone will only be positively correlated with dominance among individuals lower in cortisol (Mehta and Josephs 2010). Hormone interactions increase the complexity of how individual differences in personality are regulated by biological markers. A recent study of collegiate athletes found evidence for the dual-hormone hypothesis by suggesting that female athletes were judged to hold higher status among teammates when they possessed higher testosterone and lower cortisol (Casto and Edwards 2016; Edwards and Casto 2013). Behaviors such as aggression, dominant leadership behavior, empathy, and risk-taking have all been tested in the context of the dual-hormone hypothesis, suggesting that this interaction is critical to examine in future work using hormones as biological markers (Mehta and Prasad 2015; Mehta et al. 2015b; Zilioli et al. 2015). Some recent work has critically evaluated the evidence for the dual-hormone hypothesis (Grebe et al. 2019), through p-curve analyses (Simonsohn et al. 2014) and collaborative efforts similar to ours. This recent work revealed that previous examinations are often underpowered (~16% power), and hormonal associations with personality traits rarely emerged in a relatively large sample ($N = 436$). Although the review and examination by Grebe et al. (2019) provided an important step in evaluating evidence for the dual-hormone hypothesis using personality trait outcomes, we also examined the utility of this hypothesis in our data of approximately 4000 individuals to see if there were significant interactions between testosterone and cortisol in predicting each of the Big Five personality traits.

The Current Project

In the current project, along with examining associations between personality traits and hormones, we examined the moderating effects of gender, hormonal contraceptives, and the dual-hormone hypothesis. For our main effects, we hypothesized that (a) testosterone would be positively associated with extraversion and negatively associated with agreeableness and neuroticism, and (b) cortisol would be positively associated with neuroticism and agreeableness, and negatively associated with extraversion and openness to experience. Given the lack of evidence or competing findings from previous studies, we were agnostic about the remaining traits and how they are related to testosterone and cortisol. We did not make hypotheses or predictions about the potential moderators of gender, hormonal contraceptive use, or the dual-hormone hypothesis given either the lack of prior evidence and recent work re-evaluating the dual-hormone hypothesis.

Method

The current project brought together a consortium of researchers who broadly study personality and hormonal variation. These data come from both published and unpublished studies in which Big Five personality trait-hormone associations were not the primary question of interest and some portions of a dissertation (e.g., Edelstein et al. 2011; Slatcher et al. 2011; Wardecker et al. 2018). The current project is a registered report of a pre-registered secondary data analysis[1] of 3964 participants (50.3% women; 27.7% on hormonal contraceptives; see Table 1 for sample descriptives). Additional demographic characteristics and assay procedures, as well as details for the 25 studies, are available for reference in the original studies linked in Table 1 or by request to the corresponding author. Many samples did not collect information on age or other characteristics (but most studies were comprised of college-aged students from large universities in the United States). Three samples (Samples 12, 21, and 25) did not collect cortisol data, so there were 446 fewer observations for cortisol overall. Because some studies did not collect cortisol data and were entirely comprised of men or women, the forest plots occasionally appear to have "holes" in them. However, this is merely meant to communicate which samples did not have data for that particular estimate in the meta-analysis. Because a few of the datasets were proprietary, we are unable to share the entirety of the data. However, copies of the syntax, analytic output, and the original Stage 1 manuscript have been uploaded to the OSF site.

With an $\alpha = .05$, we were able to estimate effects as small as $f^2 = .002$ at 80% power and $f^2 = .004$ at 95% power. This sample size enabled us to estimate similar size effects of previous research (Smeets-Janssen et al. 2015) and to conduct strong tests of the

[1] We used the secondary data pre-registration template. A blinded copy of this document can be found on the OSF page for this project (https://osf.io/z8xfu/). We faithfully executed all of the specified analyses outlined in the Stage 1 manuscript with one exception—due to some missing data on study variables, the sample size fell just below 4000 participants. The pre-registration and Stage 1 manuscript predicted "at least 4000 participants" and our actual sample size was 3964 for testosterone (and 3518 for cortisol); we note the deviation here but view this as a minor problem given that we had approximately the same statistical power to estimate small effects.

Table 1 Description of Samples

Study Number	N	% Female	% Contraceptives	Big 5 Measure	Sample	Published?
Study 1	120	54.52	32.31	BFI	Community	No
Study 2	129	63.36	20.73	TIPI	Business leaders	No
Study 3	136	52.24	41.43	TIPI	College	No
Study 4	161	55.28	48.31	TIPI	College	No
Study 5	160	56.05	0	TIPI	College	No
Study 6	152	100	55.63	BFI	College	No
Study 7	106	56	0	BFI	Adolescents	(Reardon et al. 2016; Tackett et al. 2014a, b, 2015)
Study 8	300	53.5	0	ICID-S	Children	(Brandes et al. 2019; Tackett et al. 2017; Turan et al. 2015)
Study 9	276	52.2	0	BFI-2	Adolescents	No
Study 10	165	0	0	BFI	College	(Bird et al. 2016; Mehta et al. 2015b; Roy et al. 2019; Welker et al. 2015, 2019)
Study 11	213	55.9	20.2	BFI	College/community	(Roy et al. 2019)
Study 12	147	52.4	14.3	TIPI	College	No
Study 13	168	82.1	17.26	TIPI	College	(Ketay and Beck 2017; Ketay et al. 2017, 2019)
Study 14	94	0	0	BFI	College	(Slatcher et al. 2011)
Study 15	214	54	0	BFI	College/community	No
Study 16	116	52.6	0	BFI	College	No
Study 17	142	100	0	BFI	College	(Jünger et al. 2018a, b; Stern et al. 2020)
Study 18	60	0	0	BFI	College/community	(Knight et al. 2017)
Study 19	176	51.1	0	TIPI	College	(Mehta and Josephs 2010)
Study 20	98	57.14	0	TIPI	College	(Mehta et al. 2017)

Table 1 (continued)

Study Number	N	% Female	% Contraceptives	Big 5 Measure	Sample	Published?
Study 21	115	53	0	BFI	College/community	(Mehta et al. 2015a, b)
Study 22	164	0	0	BFI	College/community	(Kordsmeyer et al. 2018, 2019a, b, c, d; Kordsmeyer & Penke 2019; von Borell et al. 2019)
Study 23	258	50.8	15.5	BFI	College	(Edelstein et al. 2011; Edelstein et al. 2012; Wardecker et al. 2018)
Study 24	104	81.7	61.2	BFI	College	No
Study 25	190	0	0	NEO-FFI	Community	(Asendorpf et al. 2011)

. Contraceptive use was only measured in women and only in some samples. BFI: Big Five Inventory; BFI-2: Big Five Inventory v. 2; TIPI: Ten Item Personality Inventory; ICID-S: Inventory of Child Individual Differences-Short Form; NEO-FFI: NEO Five-Factor Inventory

moderating effects of gender, hormonal contraceptives, and the dual-hormone hypothesis.

We used two criteria to make inferences about hormone-personality links. First, we considered effects that were below $p = .05$ to be significant. However, we were also attentive to the effect sizes that the project would yield and viewed a better estimation of these effects as a major contribution of the current work. In the context of our sample size, we considered effect sizes that are below $r = |.05|$ to be of little practical significance and would not be discussed at length (Funder and Ozer 2019).[2]

Measures

Personality Measures In each study, a measure of the Big Five personality traits was administered. These measures included both the original and translated version of the Big Five Inventory (BFI; John and Srivastava 1999), the Big Five Inventory-2 (BFI-2; Soto and John 2017), the Ten Item Personality Inventory (TIPI; Gosling et al. 2003), the Inventory of Child Individual Differences-Short Form (ICID-S; Deal et al. 2007), and the German NEO-FFI (Borkenau and Ostendorf 1993). Because of the overrepresentation of short-form measures (which often consisted of two items), the alphas were occasionally low to moderate for extraversion ($M = .80$, range: .66–.89), agreeableness ($M = .62$, range: .19–.85), conscientiousness ($M = .69$, range: .33–.87), neuroticism ($M = .77$, range: .50–.90), and openness to experience ($M = .63$, range: .20–.83). Because the use of short-form measures was so frequent, we examined the personality—hormone correlations accounting for the unreliability of the personality measures in a supplementary analysis.[3]

Salivary Hormone Assessment In each study, participants provided a saliva sample and completed the measure of personality. Although many of these studies had additional assessments of each hormone (e.g., following an experimental manipulation or weeks

[2] There is some controversy over the correct effect size to quantify the magnitude of fixed effects in the content of multi-level modeling (Lorah 2018). We chose partial correlation coefficients derived from the estimates in the multi-level model. We did so because of their intuitive nature and the ease with which they could be subjected to a meta-analysis. However, there is also the perspective that computing correlation coefficients in this manner does not adequately account for the Level-2 unit measurement (in this case, study membership). Partial standardization also relies on sample characteristics (e.g., the standard deviation of each variable), which might also vary across samples. Rather, it is recommended to use an index like f^2 because it is measure of variance explained that has clearer benchmarks of interpretation (Aiken et al. 1991; Cohen 1992). By using an effect size conversion based on the critical estimate from the models, the pseudo-partial-r's presented in the tables account for the Level-2 membership. However, upon estimating the f^2 measure for the substantive effects of interest, we also found that the effect sizes present were very small ($f^2 \leq .003$), consistent with the inferences made using correlation coefficients as effect sizes. For a full report of the magnitude of the effects across different effect size indices, please contact the second author for more details.

[3] The use of alpha reliabilities is far from the ideal solution to correct for measurement unreliability in personality-hormone associations. Internal consistencies are not a good reflection of the reliability of short-form measures of personality. Correcting for unreliability using these indices likely leads to an overestimation of the association between personality traits and hormones. As a result, under this likely possibility, the corrected associations should be viewed with skepticism, particularly when they depart from the results found in other analyses. The results did not dramatically differ across analyses in the current project, but future research can more closely examine this question using different criteria than those that we pre-registered. For example, a better index for reliability might be test-retest correlations, which have been shown to be adequate when using these short-form scales (Gosling et al. 2003).

later), we elected to use only the baseline sample given that experimental manipulations, random fluctuations, or genuine longitudinal change might have altered the levels of hormones. Also, this approach allowed for standardization across all studies given the different designs (see Table 1 for more details). Saliva samples were collected via passive drool with the occasional use of aids like sugarless gum or oral swabs.

Saliva was assayed for testosterone and cortisol using chemiluminescence-immunoassay, liquid chromatography-mass spectrometry, enzyme-linked immunosorbent assay, or radioimmunoassay using commercially available kits or standardized protocols (see linked papers for more details). To maximize the use of all available data, hormone values that were larger than three standard deviations above the mean within each sample were replaced (i.e., values greater than 3SD were given the score of 3SD) with values corresponding to three standard deviations above the mean (i.e., Winsorized; Reifman and Keyton 2010). Further, both testosterone and cortisol levels were log-transformed within each sample to reduce skewness and kurtosis and to apply a common transformation method across all the samples.

Single Assessments of Hormones For each study, each analysis included only one assessment of testosterone and/or cortisol. Having only one assessment of each hormone might raise concerns about whether we adequately assessed individual differences in endogenous hormone levels given the many factors purported to affect hormone levels (van Anders et al. 2014). However, it is worth noting that single assessments of testosterone and cortisol are likely still useful for characterizing between-subject differences in hormones. Evidence for this claim comes from studies examining the rank-order stability of hormones (and that stability is often the same across many contexts, gender, and hormonal contraceptive use; Liening et al. 2010). For instance, testosterone ($r = .73–.93$) and cortisol ($r = .65–.78$) are stable over a period of 2 weeks. In other words, between-subject differences in a single assessment of testosterone and cortisol are at least somewhat reliable indicators of individual differences (and that is primarily what our analyses examined). Indeed, these stability coefficients are similar in magnitude to those of personality measures (e.g., the Big Five Inventory, the Five-Item Personality Inventory, and the Ten-Item Personality Inventory; Gosling et al. 2003) over 2 weeks. Nevertheless, we do acknowledge that, even in a project as large as this one, there are limitations to having only one assessment of testosterone and cortisol.

Analytic Plan

Our analytic plan consisted of two main analyses: (1) a multi-level model approach in which participants' personality and hormone assessments are nested within each sample and (2) a local meta-analysis of the samples to quantify the heterogeneity of the effects across study characteristics. See our pre-registration document for full details (https://osf.io/z8xfu/).

Main Analyses Based on our previous research on replications of personality-hormone associations (Wardecker et al. 2018), a survey of the samples to be included, and our

review of the literature, we concluded that there is considerable variability in the assay kits/labs/procedures (e.g., enzyme immunoassays (EIAs) and tandem mass spectrometry; Welker et al. 2016), study designs and settings, and Big Five personality measures. In our multi-level modeling approach (Peugh and Enders 2005), we accounted for any non-independence based on study source/location/design. Specifically, we combined all of the samples into one data file. Then, we nested participants' personality assessments within samples predicted from testosterone and cortisol with random intercepts estimated. These analyses controlled for gender and time of day.

For the meta-analysis, separate linear regressions within each sample were conducted (controlling for gender and time of day), and standardized effect sizes were used in a subsequent meta-analysis. For each regression analysis, testosterone and cortisol were jointly entered as predictors of each standardized (within-sample) personality trait separately (i.e., testosterone and cortisol predicting extraversion).[4]

Supplementary Analyses A series of pre-registered supplementary analyses were also conducted. For example, interactions between testosterone and cortisol (and their further interaction with gender) predicting each personality trait were modeled as an ancillary test of the dual-hormone hypothesis in which the effects of testosterone on a criterion (often status-relevant behavior) depends on cortisol (see Mehta and Josephs 2010; Mehta and Prasad 2015).

The comparability of effects across men and women and women on and off oral contraceptives were tested with moderation by gender and hormonal contraceptive use, respectively. Because hormonal contraceptive usage is limited to women, these moderation tests were only conducted among women.

In a supplementary meta-analysis, separate estimates for men and women were utilized given the large differences in the mean-levels and distributional properties of some hormones between men and women.

Finally, a supplementary analysis computed the correlations between each hormone and each personality trait disattenuated for measurement reliability (Schmidt and Hunter 1996; Schmitt 1996). This analysis was conducted because the measures of personality varied considerably in their reliability. Thus, an adjustment was made to examine the personality-hormone correlations accounting for the unreliability of the personality measures. These disattenuated correlations were then subjected to a meta-analysis (with the caveat that the disattenuation is unable to account for the aforementioned covariates).

[4] In our experience and a review of the literature, there is some ambiguity with respect to how we should have standardized the hormone values. Some studies did little or no standardizing beyond log-transformations, depending on the distribution of the hormone values. Other studies have standardized the hormone values within gender, given the different distributions between men and women (Zilioli et al. 2015). Yet others have standardized within a sample (across gender) to test questions related to mediation of gender differences (Schultheiss et al. 2020). One immediate implication is that the different standardization approaches affect the rank-ordering of men (who have higher and more variable testosterone values) and women, which has implications for the estimation of a gender difference and possibly estimations of personality-hormone associations. In a series of exploratory supplementary analyses, we examined how robust our findings were to different standardization procedures (e.g., standardizing hormones within a sample, standardizing hormones within men and women, within a sample). The findings were robust across all of these methods—the association between testosterone and cortisol was reproduced and all other effects were non-significant or did not surpass our pre-registered effect size cut-off.

Results

Are Hormones Associated with Big Five Personality Traits?

Our main analysis tested whether testosterone and cortisol were associated with each of the Big Five traits. The results of this multi-level analysis of the aggregated data set can be found in Table 2. Across all models, traits, and hormones, only two significant effects emerged: testosterone was negatively associated with extraversion ($r = -.046$, $p = .013$) and conscientiousness ($r = -.050$, $p = .004$). However, only the conscientiousness-testosterone association met our inference criteria of significance and effect size ($r > |.05|$, $p < .05$); however, even this association did not *surpass* this effect size.

Table 2 Multi-level model predicting personality

					95% Confidence Interval		
	B	*SE*	*t*	*p*	LB	UB	*r*
Extraversion							
Testosterone	−.057	.023	−2.484	.013	−.102	−.012	.046
Cortisol	−.022	.028	−.793	.428	−.077	.033	.020
Sex/Gender	.031	.025	1.246	.213	−.018	.079	.022
Time of Day	<.001	<.001	−.635	.526	<.001	<.001	.011
Agreeableness							
Testosterone	−.033	.018	−1.814	.070	−.070	.003	.032
Cortisol	.028	.023	1.228	.220	−.017	.072	.027
Sex/Gender	.087	.020	4.395	<.001	.048	.126	.076
Time of Day	<.001	<.001	2.016	.044	<.001	<.001	.035
Conscientiousness							
Testosterone	−.057	.020	−2.891	.004	−.096	−.018	.050
Cortisol	−.002	.024	−.081	.935	−.050	.046	.002
Sex/Gender	.094	.021	4.444	<.001	.052	.135	.077
Time of Day	<.001	<.001	−.511	.610	<.001	<.001	.009
Neuroticism							
Testosterone	.010	.020	.495	.621	−.030	.050	.017
Cortisol	.012	.022	.539	.591	−.031	.055	.047
Sex/Gender	.199	.023	8.739	<.001	.155	.244	.193
Time of Day	<.001	<.001	−.371	.710	<.001	<.001	.008
Openness to Experience							
Testosterone	.008	.018	.457	.648	−.027	.044	.008
Cortisol	−.014	.023	−.612	.541	−.058	.031	.011
Sex/Gender	.003	.019	.165	.869	−.035	.041	.003
Time of Day	<.001	<.001	.933	.351	<.001	<.001	.016

LB lower bound of 95% confidence interval of b, *UB* upper bound of 95% confidence interval of b. Sex/Gender: −1 = men; 1 = women

The meta-analyses yielded similar findings, and findings were consistent for both fixed effects and random effects meta-analyses (see Table 3 and Figs. 1, 2, 3, 4 and 5). Testosterone was again negatively correlated with conscientiousness, and this association became larger after adjusting for measurement error. Testosterone and cortisol were largely unrelated to Big Five personality traits. Further, these associations varied little across the studies, as indicated by non-significant Q tests and low I^2 values.

Worth noting, upon adjusting for measurement error in the personality measures, some indicators of heterogeneity became significant. Specifically, despite the largely non-significant associations between personality and hormones overall, the effect sizes between testosterone and extraversion, agreeableness, neuroticism, and openness varied significantly across studies (as did the association between cortisol and openness to experience). However, upon inspecting the forest plots in Figs. 1, 2, 3, 4 and 5, the vast majority of the individual studies reported non-significant effects. This pattern suggests that, although the magnitude of the associations varied across studies and could potentially be attributable to some methodological differences between studies (e.g., assay procedures), it is likely that the heterogeneity indices are distinguishing between relatively small effects. However, a larger sample of studies with more varied methodological characteristics in the future can help test for sources of heterogeneity. We return to this possibility in the Discussion.

Moderators of Hormone-Personality Associations

We next tested three moderation questions: whether testosterone and cortisol interacted to predict personality traits (i.e., the dual-hormone hypothesis), whether the effects varied depending on whether women were on hormonal contraceptives, and whether the effects differed across men and women. To test each of these questions, we ran separate analyses that each extended the model presented in Table 2. Specifically, (1) the interaction term between testosterone and cortisol was entered to test the dual-hormone hypothesis, (2) interaction terms between hormonal contraceptive use and testosterone and cortisol were entered to test for differences based on women's hormonal contraceptive use, and (3) interaction terms between gender and testosterone and cortisol were entered to test for gender differences. A supplementary meta-analysis was also conducted to test for gender differences in the associations between testosterone, cortisol, and Big Five personality traits.

The results from these moderation analyses can be found in Table 4. Across all models, the interaction between testosterone and cortisol was not significant, suggesting that the dual-hormone hypothesis is not robustly associated with broad personality traits like the Big Five. In exploratory follow-up analyses, the dual hormone hypothesis test also did not differ between men and women (i.e., testosterone × cortisol × gender interactions were all $ps > .223$) as is occasionally found in previous studies (Welker et al. 2014). Also, hormonal contraceptive use did not moderate any of the associations between women's hormones and the personality traits in women. Finally, gender largely did not moderate the association between the hormones and the personality traits. The only exception was a significant gender × testosterone interaction predicting conscientiousness. However, the size of this interaction did not meet our inference criteria of significance and effect size ($r > .05$, $p < .05$). Further, upon decomposing this interaction, it was revealed that the effect of testosterone was not significant among

Table 3 Results for meta-analytic associations between personality and testosterone and cortisol

						Measures of Heterogeneity			
Trait	Type	Fixed effects *r*	Mixed effects *r*	*Z*	*p*	Q	df	*p*	I^2 (%)
Testosterone									
Extraversion	Overall	−.025 (−.057–.008)	−.027 (−.066–.013)	−1.500	.134	34.829	24	.071	31.09% (0.00–57.77)
Extraversion	Disattenuated	−.028 (−.060–.0004)	−.031 (−.076–.013)	−1.690	.091	**43.435**	**24**	**.009**	**44.74% (11.44–65.52)**
Extraversion	Men	.007 (−.039–.053)	.007 (−.039–.053)	.299	.765	20.500	22	.552	0.00% (0.00–41.41)
Extraversion	Women	**−.048 (−.094–.002)**	**−.048 (−.095–-.001)**	**−2.032**	**.042**	19.490	19	.426	2.49% (0.00–49.28)
Agreeableness	Overall	.005 (−.027–.038)	.005 (−.027–.038)	.316	.752	21.901	24	.585	0.00% (0.00–38.53)
Agreeableness	Disattenuated	.005 (−.028–.037)	.002 (−.048–.051)	.283	.777	**54.053**	**24**	**<.001**	**55.60% (30.41–71.67)**
Agreeableness	Men	.024 (−.022–.070)	.024 (−.022–.070	1.039	.299	14.950	22	.864	0.00% (0.00–19.65)
Agreeableness	Women	−.024 (−.070–.022)	−.024 (−.072–.025)	−1.014	.310	20.626	19	.358	7.88% (0.00–42.62)
Conscientiousness	Overall	**−.046 (−.078–-.014)**	**−.046 (−.078–-.014)**	**−2.778**	**.005**	19.453	24	.727	0.00% (0.00–30.80)
Conscientiousness	Disattenuated	**−.058 (−.090–-.026)**	**−.057 (−.097–-.018)**	**−3.521**	**<.001**	34.890	24	.070	31.22% (0.00–57.85)
Conscientiousness	Men	−.011 (−.056–.035)	−.011 (−.057–.036)	−.449	.653	22.165	22	.450	0.74% (0.00–45.80)
Conscientiousness	Women	**−.058 (−.104–-.012)**	**−.058 (−.105–-.010)**	**−2.448**	**.014**	20.049	19	.392	5.23% (0.00–37.86)
Neuroticism	Overall	−.013 (−.045–.019)	−.012 (−.048–.024)	−.785	.432	29.355	24	.207	18.24% (0.00–49.88)
Neuroticism	Disattenuated	−.013 (−.045–.019)	−.011 (−.052–.031)	−.787	.431	**38.489**	**24**	**.031**	**37.64% (0.00–61.52)**
Neuroticism	Men	−.001 (−.047–.045)	.006 (−.051–.064)	−.028	.978	32.253	22	.073	31.79% (0.00–58.98)
Neuroticism	Women	−.016 (−.062–.030)	−.016 (−.062–.030)	−.679	.497	18.336	19	.500	0.00% (0.00–46.10)
Openness to Experience	Overall	.018 (−.015–.050)	.018 (−.015–.050)	1.060	.289	17.700	24	.817	0.00% (0.00–23.94)
Openness to Experience	Disattenuated	.027 (−.006–.059)	.031 (−.013–.074)	1.608	.108	**42.401**	**24**	**.012**	**43.40% (9.07–64.77)**
Openness to Experience	Men	.041 (−.005–.087)	.041 (−.005–.089)	1.750	.080	21.000	22	.521	0.00% (0.00–42.80)
Openness to Experience	Women	−.012 (−.058–.035)	−.012 (−.058–.035)	−.489	.625	11.478	19	.907	0.00% (0.00–13.90)

Table 3 (continued)

Trait	Type	Fixed effects *r*	Mixed effects *r*	*Z*	*p*	Measures of Heterogeneity			
						Q	df	*p*	I^2 (%)
Cortisol									
Extraversion	Overall	−.030 (−.064–.005)	−.030 (−.064–.005)	−1.702	.089	17.102	21	.705	0.00% (0.00–33.95)
Extraversion	Disattenuated	−.033 (−.068–.001)	−.033 (−.068–.001)	1.889	.059	21.084	21	.454	.40% (0.00–46.42)
Extraversion	Men	.006 (−.045–.056)	.006 (−.045–.056)	.221	.825	8.900	19	.975	0.00% (0.00–0.00)
Extraversion	Women	**−.055 (−.102–.006)**	**−.054 (−.110–.002)**	**−2.221**	**.026**	22.823	17	.156	25.51% (0.00–57.91)
Agreeableness	Overall	.015 (−.019–.149)	.015 (−.019–.049)	.853	.394	14.454	21	.849	0.00% (0.00–21.85)
Agreeableness	Disattenuated	.027 (−.008–.061)	.028 (−.012–.068)	1.530	.126	27.222	21	.164	22.86% (0.00–54.20)
Agreeableness	Men	.036 (−.014–.086)	.036 (−.014–.086)	1.400	.161	10.573	19	.937	0.00% (0.00–6.53)
Agreeableness	Women	.009 (−.039–.058)	.009 (−.039–.058)	.382	.702	15.954	17	.527	0.00% (0.00–46.74)
Conscientiousness	Overall	−.005 (−.039–.030)	−.005 (−.039–.030)	−.258	.796	14.177	21	.862	0.00% (0.00–20.32)
Conscientiousness	Disattenuated	−.002 (−.036–.033)	−.002 (−.034–.033)	−.095	.924	21.248	21	.444	1.17% (0.00–46.84)
Conscientiousness	Men	.006 (−.044–.056)	.006 (−.044–.056)	.228	.820	7.830	19	.988	0.00% (0.00–0.00)
Conscientiousness	Women	−.008 (−.056–.041)	−.007 (−.058–.045)	−.309	.757	19.256	17	.314	11.72% (0.00–48.01)
Neuroticism	Overall	.023 (−.012–.057)	.023 (−.012–.057)	1.280	.201	15.930	21	.774	0.00% (0.00–29.09)
Neuroticism	Disattenuated	.023 (−.011–.057)	−.011 (−.011–.057)	1.316	.188	20.945	21	.462	0.00% (0.00–46.07)
Neuroticism	Men	.027 (−.023–.078)	.027 (−.023–.078)	1.065	.287	16.883	19	.598	0.00% (0.00–41.46)
Neuroticism	Women	.008 (−.040–.057)	.008 (−.040–.057)	.345	.730	13.219	17	.721	0.00% (0.00–35.71)
Openness to Experience	Overall	−.013 (−.048–.021)	−.013 (−.048–.021)	−.757	.449	19.468	21	.555	0.00% (0.00–41.98)
Openness to Experience	Disattenuated	−.025 (−.059–.010)	−.023 (−.068–.022)	−1.401	.161	**35.068**	**21**	**.028**	**40.12% (0.30–64.03)**
Openness to Experience	Men	−.005 (−.055–.046)	−.005 (−.055–.046)	−.181	.857	11.883	19	.891	0.00% (0.00–16.83)
Openness to Experience	Women	−.014 (−.063–.034)	−.014 (−.063–.034)	−.587	.557	10.199	17	.895	0.00% (0.00–16.68)

Z tests are from the fixed effects meta-analysis. Significant effects are also bolded. Disattenuated effect sizes correct for measurement error in the personality measures

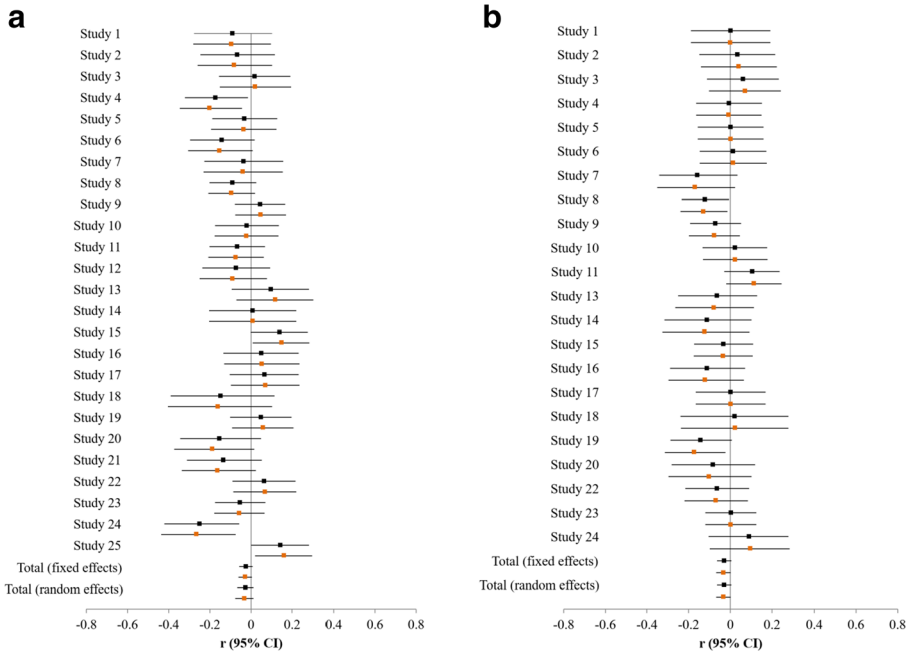

Fig. 1 Associations between extraversion and testosterone (**a**; left) and cortisol (**b**; right). Black markers are uncorrected estimates; orange markers are estimates corrected for measurement error

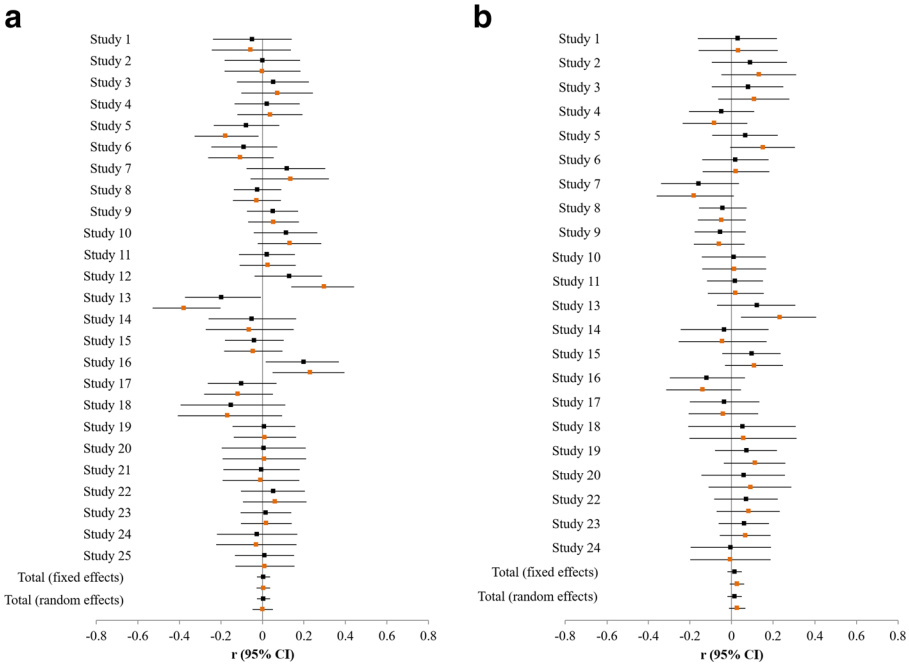

Fig. 2 Associations between agreeableness and testosterone (**a**; left) and cortisol (**b**; right). Black markers are uncorrected estimates; orange markers are estimates corrected for measurement error

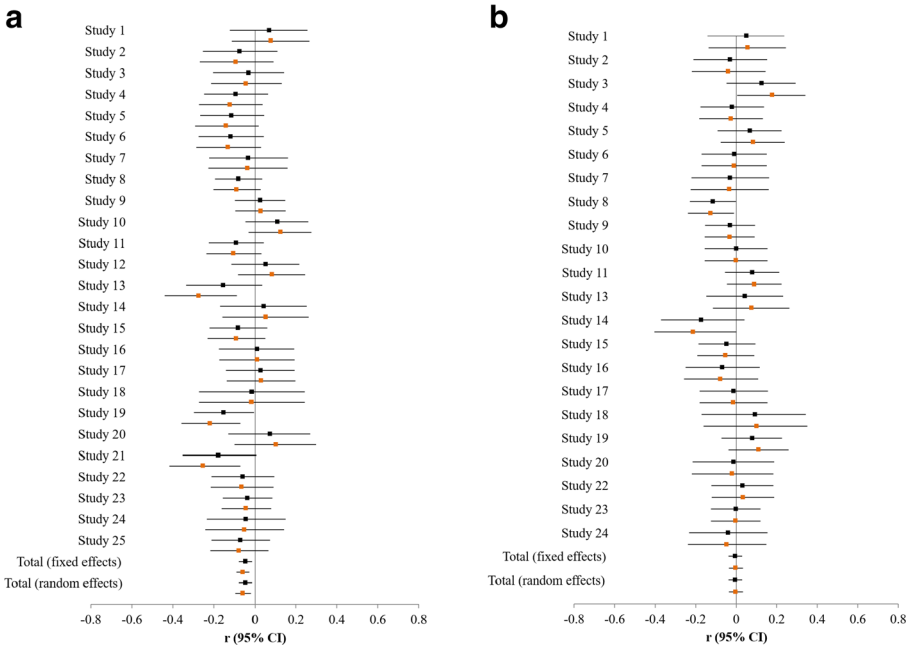

Fig. 3 Associations between conscientiousness and testosterone (**a**; left) and cortisol (**b**; right). Black markers are uncorrected estimates; orange markers are estimates corrected for measurement error

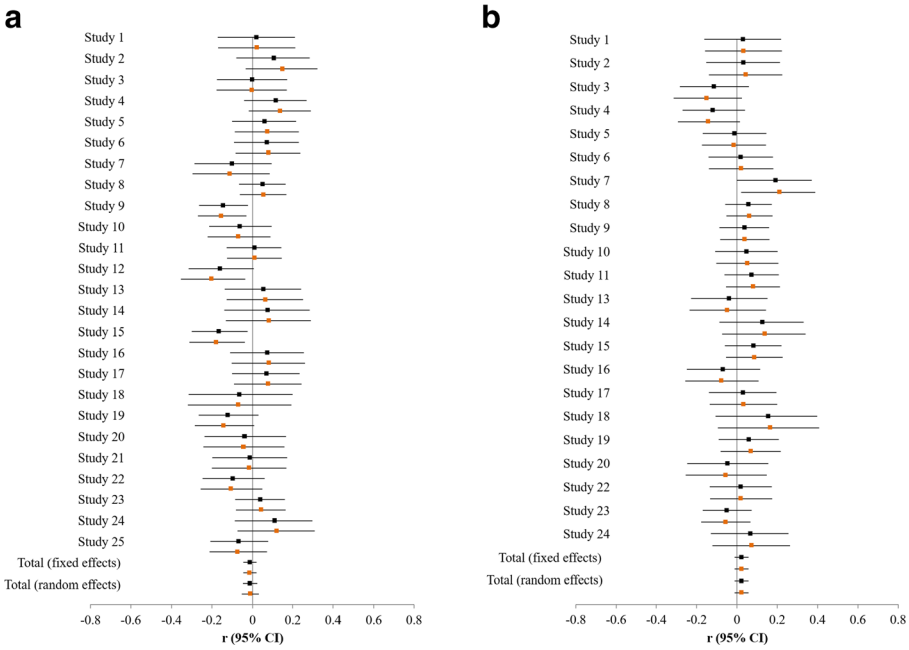

Fig. 4 Associations between neuroticism and testosterone (**a**; left) and cortisol (**b**; right). Black markers are uncorrected estimates; orange markers are estimates corrected for measurement error

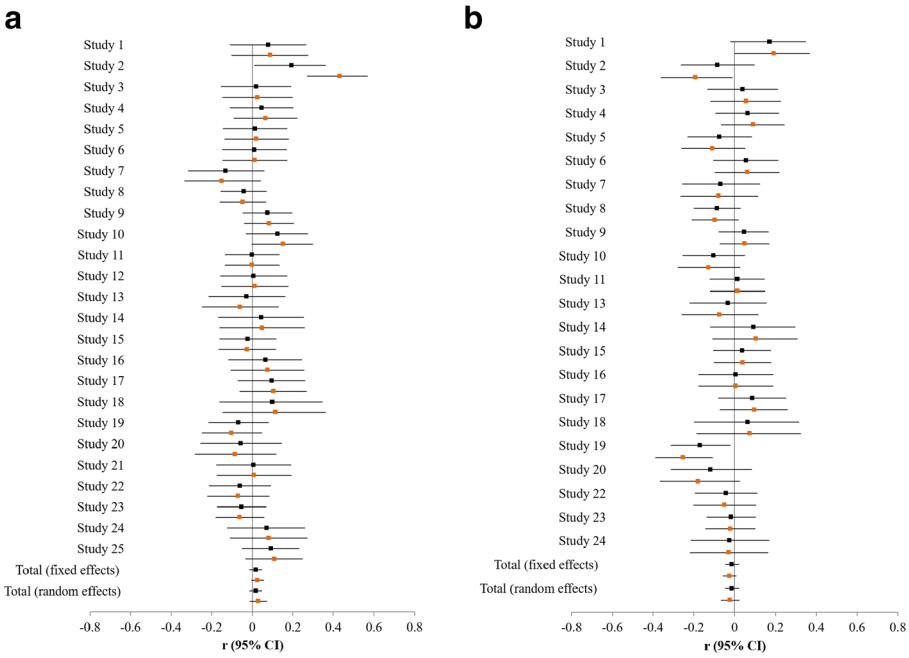

Fig. 5 Associations between openness to experience and testosterone (**a**; left) and cortisol (**b**; right). Black markers are uncorrected estimates; orange markers are estimates corrected for measurement error

men ($b = -.042$, SE = .026, $t = -1.598$, $p = .110$) or women ($b = -.034$, SE = .026, $t = -1.323$, $p = .186$). Thus, altogether, there was little evidence for moderating effects of the dual-hormone hypothesis, hormonal contraceptives, and gender.

Results from the supplementary meta-analysis for gender revealed a few significant effects that were not present in the multi-level analyses (see Table 3; Figs. 6, 7, 8, 9 and 10). Among women, cortisol was negatively associated with extraversion, and testosterone was negatively associated with conscientiousness. The other effects did not surpass our pre-registered effect size threshold for discussion ($r > .05$). Thus, for women, there were some additional associations between their hormones and personality, but these effects were still relatively small and only found in the context of the meta-analysis which pools studies rather than analyzes one aggregated sample (e.g., via multi-level modeling). The discrepancies in the findings between the two approaches are likely attributable to the analysis conducted and the control variables included in each (e.g., time of day versus none).

Across all these analyses, the small and largely non-significant effects suggest that testosterone and cortisol are largely unrelated or very weakly related to personality traits, in men and women (mostly equally), for those using hormonal contraceptives and not, and regardless of how testosterone and cortisol interact with one another.

Discussion

In the current project, we aggregated 25 different data sets to examine associations between testosterone, cortisol, and Big Five personality traits among 3964 people.

Table 4 Results for the moderation tests for each personality trait

DV	Estimate	*B*	*SE*	*t*	*p*	95% Confidence Interval		*r*
						LB	UB	
Dual Hormone Hypothesis								
Extraversion	Testosterone × Cortisol	.001	.011	.129	.897	−.020	.023	.002
Agreeableness	Testosterone × Cortisol	.000	.009	−.022	.982	−.018	.017	.000
Conscientiousness	Testosterone × Cortisol	.011	.009	1.181	.238	−.007	.030	.020
Neuroticism	Testosterone × Cortisol	−.009	.010	−.829	.407	−.029	.012	.020
Openness to Experience	Testosterone × Cortisol	.003	.009	.326	.744	−.014	.020	.006
Hormonal Contraceptives Moderation								
Extraversion	Testosterone × HC	.005	.029	.185	.854	−.051	.062	.005
Extraversion	Cortisol × HC	.029	.021	1.422	.155	−.011	.070	.041
Agreeableness	Testosterone × HC	.001	.022	.042	.967	−.042	.043	.001
Agreeableness	Cortisol × HC	.008	.015	.509	.611	−.022	.038	.015
Conscientiousness	Testosterone × HC	−.042	.024	−1.727	.084	−.089	.006	.050
Conscientiousness	Cortisol × HC	.001	.017	.039	.969	−.033	.035	.001
Neuroticism	Testosterone × HC	.041	.029	1.414	.158	−.016	.098	.041
Neuroticism	Cortisol × HC	.026	.021	1.260	.208	−.014	.066	.037
Openness to Experience	Testosterone × HC	−.033	.022	−1.555	.120	−.076	.009	.045
Openness to Experience	Cortisol × HC	.012	.015	.794	.428	−.018	.042	.023
Gender Moderation								
Extraversion	Testosterone × Gender	−.013	.017	−.759	.448	−.047	.021	.013
Extraversion	Cortisol × Gender	−.015	.013	−1.168	.243	−.041	.010	.020
Agreeableness	Testosterone × Gender	.021	.014	1.532	.126	−.006	.048	.027
Agreeableness	Cortisol × Gender	.002	.010	.197	.844	−.018	.022	.003
Conscientiousness	Testosterone × Gender	−.032	.015	−2.193	.028	−.060	−.003	.038
Conscientiousness	Cortisol × Gender	−.019	.011	−1.695	.090	−.040	.003	.029
Neuroticism	Testosterone × Gender	.020	.016	1.228	.219	−.012	.052	.022
Neuroticism	Cortisol × Gender	.003	.012	.270	.788	−.021	.028	.005
Openness to Experience	Testosterone × Gender	−.019	.013	−1.418	.156	−.045	.007	.025
Openness to Experience	Cortisol × Gender	−.003	.010	−.322	.748	−.023	.017	.006

Note. The effects listed here are the Testosterone × Cortisol interaction predicting each personality trait. Models were extensions of those found in Table 2, so main effects and control variables are all included. LB: lower bound of 95% confidence interval of b; UB: upper bound of 95% confidence interval of b. Gender: −1 = men; 1 = women. HC: Hormonal Contraceptives (−1 = not using HC; 1 = using HC)

Testosterone was negatively associated with conscientiousness ($r = -0.05$), reaching our pre-registered effect size criteria but not surpassing it. All other effects were smaller and did not meet our inference criteria of significance and effect size. These hormone-personality associations were mostly invariant across gender with two exceptions found in the meta-analyses but not the multi-level models: Among women only, cortisol was negatively associated with extraversion, and testosterone was negatively associated with conscientiousness; these associations were not significant for men. Testosterone

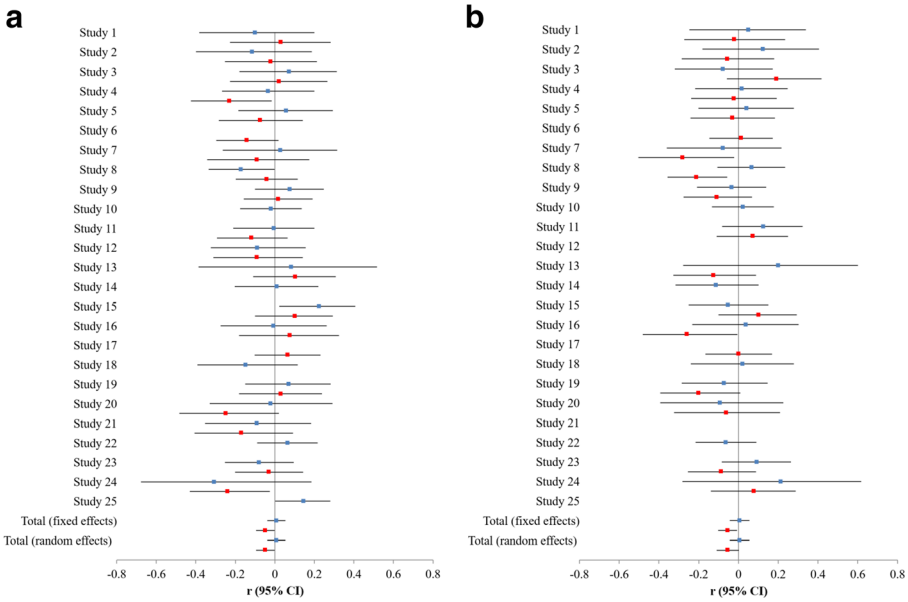

Fig. 6 Associations between extraversion and testosterone (**a**; left) and cortisol (**b**; right). Blue markers are estimates for men; Red markers are estimates for women

and cortisol did not significantly interact to predict personality traits (i.e., a test of the dual-hormone hypothesis), and hormonal contraceptive use did not moderate hormone-personality associations among women. Altogether, Big Five personality traits were

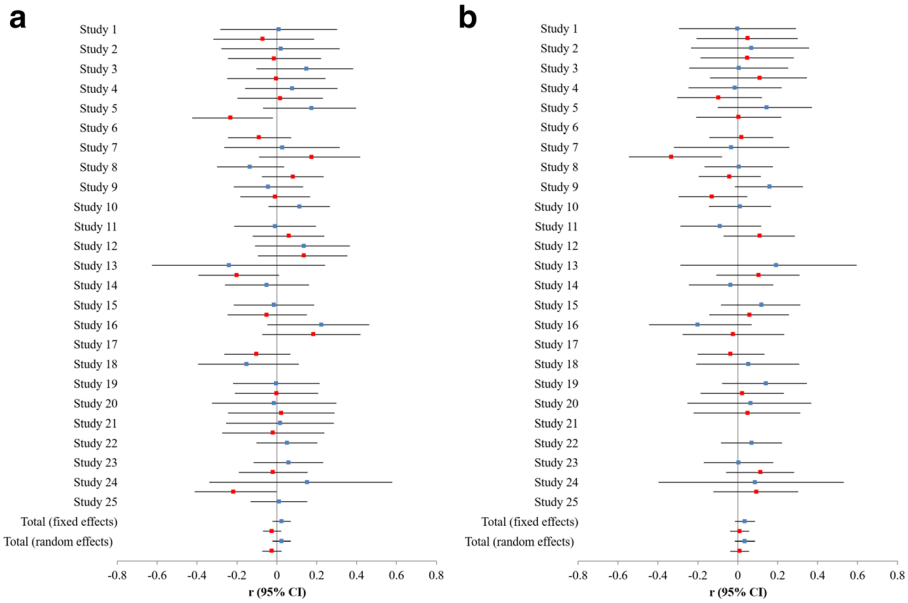

Fig. 7 Associations between agreeableness and testosterone (**a**; left) and cortisol (**b**; right). Blue markers are estimates for men; Red markers are estimates for women

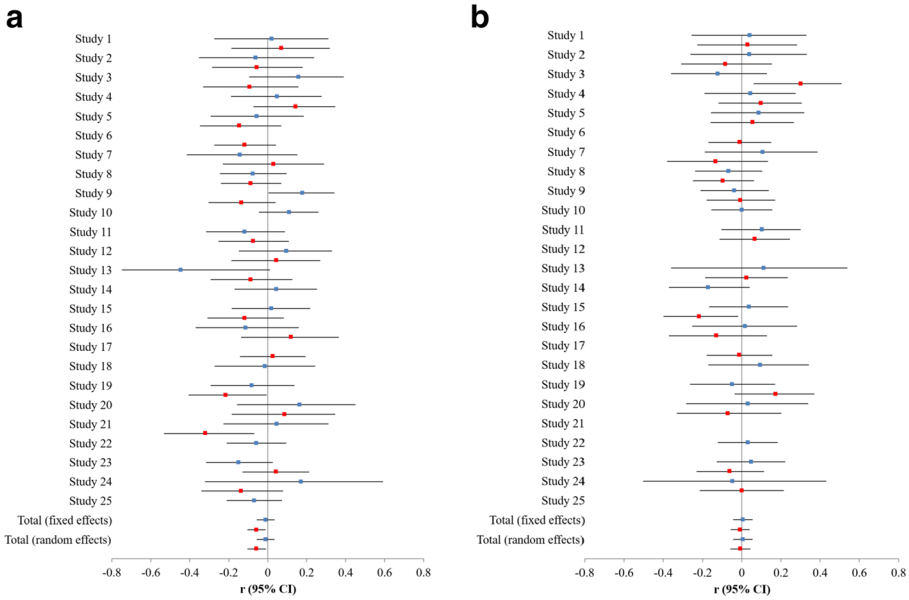

Fig. 8 Associations between conscientiousness and testosterone (**a**; left) and cortisol (**b**; right). Blue markers are estimates for men; Red markers are estimates for women

largely unrelated or very weakly related to testosterone and cortisol and across various moderation tests. The few exceptions were relatively small in magnitude, suggesting few robust links between interindividual personality and these particular hormones.

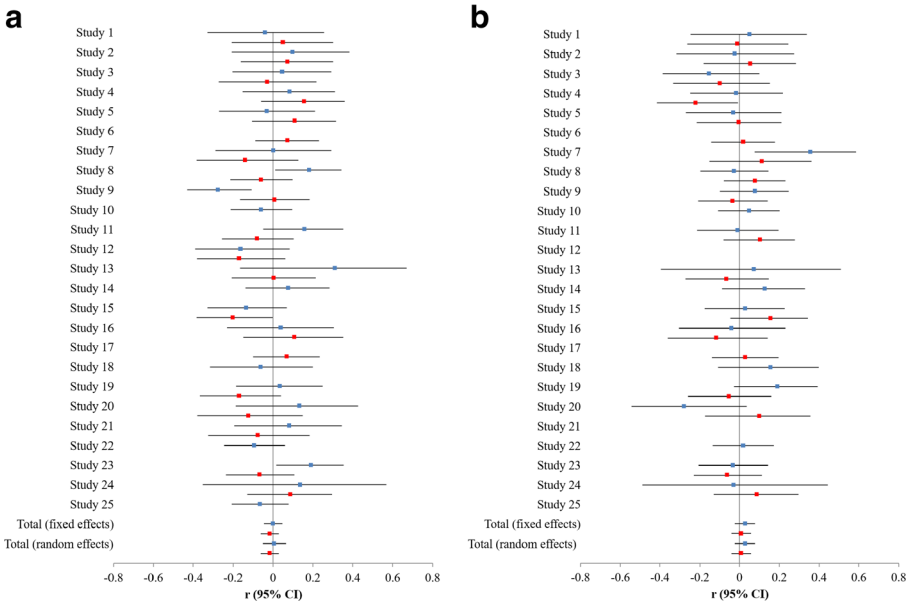

Fig. 9 Associations between neuroticism and testosterone (**a**; left) and cortisol (**b**; right). Blue markers are estimates for men; Red markers are estimates for women

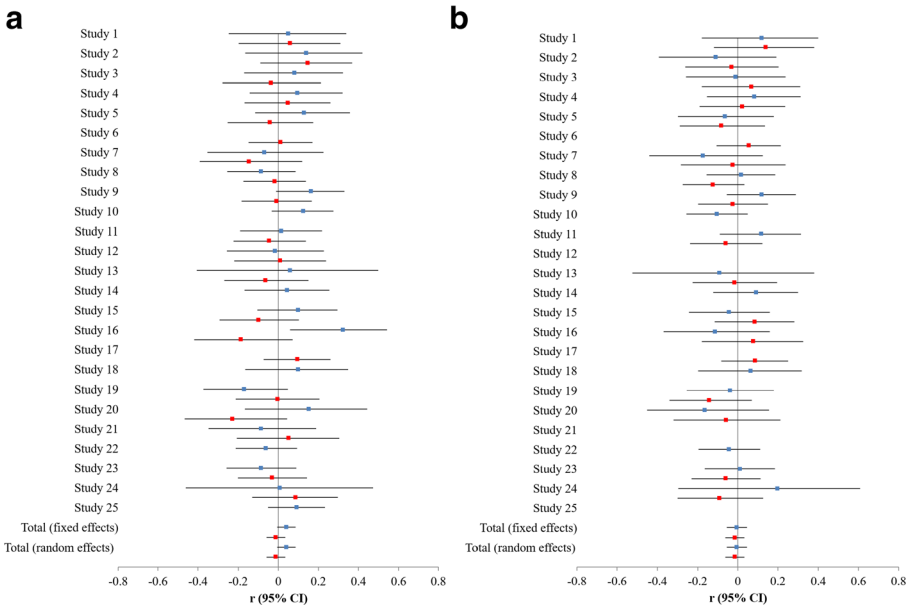

Fig. 10 Associations between openness to experience and testosterone (**a**; left) and cortisol (**b**; right). Blue markers are estimates for men; Red markers are estimates for women

Associations of Big Five Personality Traits with Testosterone and Cortisol

A great deal of theorizing and effort has been dedicated to establishing a biological basis of human personality (Canli 2006; Hippocrates 460 BC/ 1978; Netter 2004). Among these efforts are attempts to link variation in endogenous hormone levels with variation in individual psychological characteristics, like personality (e.g., Schultheiss et al. 2005; Smeets-Janssen et al. 2015). Based on our review of these efforts, we had hypothesized that testosterone would be positively associated with extraversion and negatively associated with agreeableness and neuroticism. We also hypothesized that cortisol would be positively associated with neuroticism and agreeableness, and negatively associated with extraversion and openness to experience. Despite these hormones being associated with behavioral indicators and characteristics in past research, we did not detect many robust associations between endogenous levels of testosterone or cortisol and Big Five personality traits. The only association that we did find (i.e., testosterone being negatively correlated with conscientiousness) was inconsistent with our hypotheses, consistent with some past research (e.g., Reardon et al. 2016; Sellers et al. 2007), but inconsistent with other past research (but somewhat consistent with the healthy functioning sample of Smeets-Janssen et al. 2015). Because testosterone has been linked to increased risk-taking in experiments and meta-analyses of correlational studies (Kurath and Mata 2018; Stenstrom and Saad 2011; Wu et al. 2020), this finding is relatively intuitive—risk-taking behavior and impulsivity are often hallmarks of lower levels of conscientiousness (Chopik 2016; Roberts et al. 2005). Again, worth noting, this association met our cut-off but did not surpass it, suggesting that even this association was relatively small. The remaining small and null effects are less intuitive and did not align with our hypotheses.

Why were testosterone and cortisol so consistently unrelated or very weakly related to Big Five personality traits? Hormones serve many different functions, and the specific functions they serve may vary across the lifespan. For example, circulating levels of hormones during the perinatal period and early life are thought to aid in organizing the development of the body and brain (Breedlove 1994). Later in life, hormones are often thought to mediate behaviors through the activation of neural systems that are tied to behavior more broadly (Arnold and Breedlove 1985). Related, hormones are often considered reciprocal and dynamic in their links to behavior—both causing and resulting from behavior and situations (Mazur and Booth 1998). For example, context-specific increases in testosterone and cortisol (e.g., in times of competition or stress, respectively) and post-situation elevations characterize how hormones and behavior interact with one another in a reciprocal way. Worth noting, many models detailing links between hormones and behavior are primarily concerned with situations in which the activation of biological systems and recruitment of these hormones are needed. Basal levels of testosterone and cortisol might only partially be related to these processes (and may also reflect many other processes; Knowles et al. 2008; Witbracht et al. 2012). Salivary measures of testosterone and cortisol measured in these samples in relatively neutral settings might be too far removed from the mechanisms and functions that these hormones serve for humans. Despite this, many previous studies have documented personality-hormone links outside of contexts of competition and stress. Nevertheless, it could be the case that Big Five personality traits might be more closely linked to individual differences in hormonal reactivity to specific situations rather than decontextualized measurements of personality and hormones (Edelstein et al. 2010b; Wardecker et al. 2018; Zilioli and Bird 2017). It could also be the case that Big Five personality traits are too broad, and that testosterone and cortisol might be more closely linked to more specific facets of the Big Five (e.g., dominance; Schwaba et al. 2020). Although this project, in conjunction with other studies (Smeets-Janssen et al. 2015), suggests that endogenous hormones may be largely unrelated to Big Five personality traits, future research can examine if personality-hormone associations may be more robust using facet-level measures or in situations that elicit reactivity.

Moderation Tests of Personality-Hormone Associations

In the current project, we also examined a number of moderating tests of the associations between testosterone, cortisol, and Big Five personality traits. We found that the effects were mostly consistent across gender and hormonal contraceptive use. Although there is literature documenting mean level and distributional differences between men and women (and those using and not using hormonal contraceptives; Liening et al. 2010), our project extends previous research by showing that associations between Big Five personality traits and testosterone or cortisol largely do not significantly differ based on these characteristics. This should provide some guidance for understanding inconsistent gender differences found in previous work (Smeets-Janssen et al. 2015) and affirms some of the differences (e.g., conscientiousness and testosterone being negatively associated among women) found in other work (Sellers et al. 2007). There are most certainly contexts in which hormone-personality/behavior associations vary across sex/gender (Edelstein et al. 2011; Edelstein et al. 2012). However, the

associations examined here may not be large or reliable enough to make strong claims about the existence of sex/gender differences in links between broad personality traits and endogenous levels of testosterone and cortisol.

Hormone-personality associations did not vary based on hormonal contraceptive use in women. This is also a particularly important finding because contraceptive use is often used as an exclusionary criterion in studies of hormones, especially sex hormones like testosterone (van Anders et al. 2014). Previous research trying to quantify the influence of hormonal contraceptives on personality-hormone associations yielded mixed findings. In some studies, hormonal contraceptive use was thought to suppress the magnitude of associations, particularly because contraceptives provide synthetic substitutes for some hormones from which testosterone is aromatized (Fleischman et al. 2010; Liening et al. 2010; Meulenberg et al. 1987; Nickelsen et al. 1989). However, based on the results of the current project, we encourage researchers to think critically about whether hormonal contraceptive use (or the exclusion of either men or women) is necessary for their study designs. Our results suggest that at least these associations do not vary much between men and women and those using and not using hormonal contraceptives. Future research should ensure that there are adequate proportions of each of these groups in large sample studies. Specifically, recruiting equitable numbers of men and women (and those who use hormonal contraceptives) would reduce the likelihood that any possible differences found between these groups cannot be attributable to false positives that result from low power and small sample sizes (Simmons et al. 2011).

Finally, our data provided an opportunity to test a variant of the dual-hormone hypothesis. The dual-hormone hypothesis proposes that testosterone is most often associated with dominance-related behavior and traits for individuals within the context of lower cortisol. The hypothesis has been extended to link the interaction of testosterone and cortisol to dominance-adjacent traits, like aggression, leadership behavior, empathy, risk-taking, and many others (e.g., Dekkers et al. 2019; Mehta and Prasad 2015; Mehta et al. 2015b; Zilioli et al. 2015). A recent review by Grebe et al. (2019) found that an appropriate test of the dual-hormone hypothesis often requires much greater statistical power than what has been found in previous research (Knight et al. 2020; Sarkar et al. 2019). They also found little evidence for the dual-hormone hypothesis while examining a wide range of outcomes, some of which (e.g., extraversion and agreeableness [Ns = 436 for the testosterone × cortisol interaction test]) were included in the current report (also see Dekkers et al. 2019 for a recent meta-analysis). We revisited this question with a sample size nearly nine times as large and found support for their conclusion—the dual-hormone hypothesis does not readily apply to the study of Big Five personality traits, and the main effects of testosterone and cortisol are also few and far between. Grebe et al. provide numerous points of discussion for why the dual-hormone hypothesis might not predict variation in trait-like characteristics. For example, hormones may be more likely to have effects on behavior or implicit measures of personality (Edelstein et al. 2010a) and may not be present when exclusively using self-reports of personality. Specifically, personality measures that do not specifically rely on self-reports, such as through the Implicit Association Test or the Picture Story Exercise, may be particularly worthwhile (Schönbrodt et al. 2020; Vianello et al. 2013). Future research should examine this and other possibilities to find the exact circumstances under which the dual-hormone hypothesis might affect individual and social behavior.

Strengths and Limitations

The current project had many strengths. It was the largest examination of personality-hormone associations conducted to date and was a registered report, so opportunities for analytic flexibility and deviations were reduced. The large sample size afforded us with a great deal of statistical power for strong tests of gender moderation, hormonal contraceptive moderation, and the dual-hormone hypothesis (Schultheiss and Mehta 2019).

Nevertheless, there are limitations that must be acknowledged. First, statistical power is not only determined by sample size. Measurement can also have a large influence on the ability to detect personality-hormone associations. For instance, a number of the studies here used abbreviated versions of personality instruments, which necessarily have trade-offs between measurement reliability and coverage on one hand and convenience and validity on the other hand (Gosling et al. 2003). We tried to alleviate this concern by applying a correction for measurement unreliability (Schmitt 1996). Using these corrected associations yielded similar estimates to uncorrected associations. One crucial difference was that, for some traits and some hormones, additional heterogeneity was found—suggesting that the magnitude of associations across studies might be attributable to methodological differences between the studies; this brings us to our next point.

In addition to the wide variety of personality measures used, there was a great deal of heterogeneity in study design, sample composition, and assay procedure. One byproduct of a collaboration this large is that there is a great deal of heterogeneity in the studies. Each sample differed from another in at least some way—no two studies used identical procedures, sample sources, measures, and assay approaches. Although we had a large number of participants, our small number of studies and, as a result, a small number of studies that consistently used a particular method (e.g., mass spectrometry, the NEO-FFI) precluded us from running analyses examining the sources of this heterogeneity. There is some evidence that, particularly for testosterone in women, methods like mass spectrometry provide more precise estimates of hormone levels (Welker et al. 2016). The exact implications this insight has for the types of questions we examined here are a little uncertain (see Grebe et al. 2019). For example, the vast majority of the studies reported null associations between personality traits, testosterone, and cortisol. Thus, finding that some samples using a particular assay procedure yield an effect that is slightly larger than the near-zero effect found using another assay procedure may not have been useful for our particular data set. However, study and methodological characteristics could have enormous effects in other contexts and examining other hormone-behavior associations (Corker 2020). Also, even within the same experimental procedures and assay kits, significant heterogeneity can be found (Prasad et al. 2019). Future research should examine a larger pool of studies that more consistently use a wider variety of personality measures and assay techniques. These future efforts should also assess hormones more than once during a baseline experimental session, examine alternative ways of assessing hormones (e.g., through more chronic measures, like hair; Grotzinger et al. 2018), and study the more proximal mechanisms hypothesized to link hormones to personality and behavior.

In light of these strengths and limitations, we would also like to convey that we do not view our project as providing the final word on whether personality traits are related

to testosterone and cortisol; our efforts do not generalize to explain all hormone-trait associations that can be examined (Simons et al. 2017). We tested these associations in a relatively narrow way: using single assessments of hormones among samples comprised primarily of college students who mostly completed self-report, short-form personality measures in a neutral context. Future research can examine whether testosterone, cortisol, and personality are reliably linked using more diverse samples and better measures of both personality and hormones.

Conclusion

To close, this registered report examined whether testosterone and cortisol were associated with Big Five personality traits. Our analyses included a multi-level aggregation of the samples and a series of meta-analyses. In general, we did not detect robust associations of testosterone and cortisol with Big Five personality traits, though there was some weak evidence for a negative association between testosterone and conscientiousness. Gender and hormonal contraceptive use did not moderate personality-hormone associations, and the dual-hormone hypothesis was not supported for these particular traits. Future research can more carefully select measures and assay procedures to examine the exact contexts in which personality is linked to testosterone and cortisol (e.g., studies of reactivity). Quantifying associations between hormones and personality can move the field closer to a more comprehensive understanding of the biological basis of personality.

Compliance with Ethical Standards

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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