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Adolescent Big Five Personality and Pubertal Development: Pubertal Hormone Concentrations and Self-Reported Pubertal Status

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In early adolescence, levels of conscientiousness and agreeableness have been found to temporarily decrease, with levels of neuroticism increasing, indicating a dip in personality maturation. It is unknown whether these changes are related to the process of puberty, a major developmental milestone with numerous changes for children. Here, we first replicated the dip in personality maturity in early adolescence (N = 2640, age range 8–18, 51% girls, 65% non-Hispanic white, 21% Hispanic/Latino, 10% African American, 9% other, roughly 33% of families received means-tested public assistance) and tested associations between the Big Five personality dimensions and pubertal development and timing across late childhood and adolescence (n = 1793). Pubertal development was measured using both hormonal assays (DHEA, testosterone, and progesterone) and self-reports of secondary sex characteristics. Of hormonal measures, only higher DHEA concentrations were associated with lower conscientiousness and openness. Nonparametric moderation analyses using LOSEM indicated Complex Age × Sex interactions involving all three hormones. Self-reported pubertal development was associated with lower extraversion, conscientiousness, agreeableness, and openness. More advanced pubertal timing was also related to lower levels of extraversion, conscientiousness, and agreeableness. All associations were small. As some evidence was found for small associations between pubertal development and lower levels of conscientiousness and agreeableness, a dip in personality maturation in these personality traits may be partly due to pubertal development in early adolescence. Overall, results did not indicate that pubertal development was the primary explanation of the maturity dip in adolescent personality. Many small influences likely accumulate to explain the dip in personality maturity in early adolescence.

Keywords: personality, puberty, testosterone, progesterone, DHEA

Big Five personality characteristics develop in the direction of increasing maturity across adulthood, with mean levels of agreeableness and conscientiousness increasing and neuroticism decreasing in the population (Roberts et al., 2006). However, during early adolescence these same personality traits appear to temporarily change in the opposite direction, becoming less mature before increasing in maturity again (Göllner et al., 2017; Luan et al., 2017; Soto et al., 2011; Van den Akker et al., 2014). These temporary declines in personality maturation have in turn been associated with adolescents' behavioral and emotional problems (Van den Akker et al., 2010). At present, it is unknown what causes this temporary disruption of personality maturation, but pubertal development is a strong candidate factor (Soto & Tackett, 2015). Here, we test whether we can replicate the temporary dip in personality maturation using a large (N = 2640), cross-sectional (age range primarily 8–18 years) sample. Next, we test whether markers of pubertal development, hormone concentrations and self-reports of secondary sex characteristics are associated with personality. As most pubertal development takes place between 10 and 15, it may explain a dip in personality maturation in this age range.

Pubertal Development and Personality Maturation: Hormonal Concentrations

Individual differences in characteristic ways of thinking, feeling, and behaving that are relatively stable across time and situations, or personality traits, can be captured by five overarching personality dimensions: Extraversion, Agreeableness, Conscientiousness, Neuroticism, and Openness to Experience (Goldberg,

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OSF link: https://osf.io/jgfqp/?view_only=d21e101898c64ab6b7478df003b40cf8.

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1990). The same "Big Five" dimensions describe personality traits in childhood and adolescence as in adulthood, allowing for the investigation of the development of these traits across the life span (Shiner & Caspi, 2003). Investigations of mean-level personality development across early and middle adulthood have converged on the finding that, for the population as a whole, levels of conscientiousness and agreeableness increase, whereas levels of neuroticism decrease (Roberts et al., 2005). To explain this phenomenon, it was hypothesized that taking on adult social roles (i.e. starting a paid job and entering a stable romantic relationship), something that most young adults do during this period, could explain why the population as a whole tended to increase in those characteristics that are necessary to be successful in these roles (Roberts et al., 2005). Mean-level development thus tends to be aimed at increasing maturity during early adulthood. As levels of extraversion and openness do not show a consistent pattern of maturation in adulthood, with openness remaining fairly stable and some aspects of extraversion increasing and others decreasing, they are not central to the maturity principle (Roberts et al., 2005).

When investigations of mean-level development of the Big Five personality dimensions were extended to earlier ages, several findings indicated trends in the opposite direction. Although similar trends to early adulthood were already visible in later adolescence, during early adolescence (between ages 10 and 15) several findings indicated that youths' personality traits were actually becoming less mature than they were before, with evidence for decreases in agreeableness (Göllner et al., 2017; Luan et al., 2017; Soto et al., 2011; Van den Akker et al., 2014) and conscientiousness (Borghuis et al., 2017; Göllner et al., 2017; Soto et al., 2011; Van den Akker et al., 2014) and increases in neuroticism for girls specifically (Borghuis et al., 2017; Luan et al., 2017; Soto et al., 2011; Van den Akker et al., 2014). As lower levels of conscientiousness and agreeableness are important predictors of externalizing problems, and neuroticism is a predictor for internalizing problems (Tackett, 2006), these changes have important implications for adolescents' psychological and behavioral adjustment. During this developmental period, incidence of problems such as delinquency (Moffitt, 1993) and depression (Bongers et al., 2003) increase, and the dip in personality maturation may explain these increases. Indeed, these changes have been found to be associated with increased adjustment problems in youth (Van den Akker et al., 2010). Therefore, it is important to understand what may be driving the disruption of personality maturation in early adolescence.

Although contemporary personality theories vary in the relative importance they place on intrinsic maturation versus social influences in explaining mean-level personality development (e.g., Costa & McCrae, 2006; Roberts et al., 2006), findings of small genetic influences on intraindividual personality changes for young adults (Hopwood et al., 2011) and adolescents (Kawamoto & Endo, 2019) indicate that biological processes do play a role. Important biological changes that coincide with the dip in personality maturation during the transition to adolescence are the hormonal changes associated with pubertal development. The onset of puberty in humans, typically occurring in childhood when children are between 6 and 8 years of age, is adrenarche. Adrenarche is characterized by a rise in the adrenal hormone dehydroepiandrosterone (DHEA), as a result of maturation of the hypothalamic-pituitary-adrenal (HPA) axis, causing pubic hair to grow and body odor to develop (Havelock et al., 2004). Approximately two years later, as children enter adolescence, gonadarche introduces the increase of gonadal hormones, including testosterone and progesterone (Hiort, 2002), which are responsible for the development of secondary sex characteristics (Dorn, 2006). The process of pubertal maturation is completed approximately four to five years later, around age 15 (Dahl et al., 2018).

Pubertal development could be related to a disruption in personality maturation because the rise in concentrations of pubertal hormones affects brain function and structure (Blakemore et al., 2010). These neurological changes produce changes in emotion, cognition, and behavior. These neurological changes produce changes in emotion, cognition, and behavior. DHEA associated neurological changes have been connected to emotional processing (Whittle et al., 2015). Similar findings have linked testosterone to increased risk-taking behavior (Braams et al., 2015) and progesterone to emotional processing and response inhibition (for a review, see Toffoletto et al., 2014). These changes are likely reflected in more stable changes in patterns of thinking, feeling, and behaving, rather than mere short-lived state changes. Therefore, we can expect these to be reflected in personality trait changes. The effects of rising concentrations of pubertal hormones can be expected to be especially likely to play a role in personality development in early adolescence as it has been proposed that youth likely adapt to the rises in hormonal concentrations after some time (Buchanan et al., 1992).

Although we know of no studies investigating pubertal hormones in relation to the broad Big Five personality dimensions, some evidence for the possibility of pubertal hormone concentrations impacting narrower traits than the Big Five are available. Testosterone has been associated with social dominance (Rowe et al., 2004; Tremblay et al., 1998), which is a facet of extraversion (John & Srivastava, 1999), as well as sensation seeking (Harden et al., 2018), which is related to both high extraversion and low conscientiousness (Mann et al., 2017), and irritability (Olweus et al., 1980), a facet of neuroticism (John & Srivastava, 1999).

Pubertal Development and Personality Maturation: Self-Reported Pubertal Development Status

Although changes in physical characteristics associated with pubertal development are initiated by hormonal changes, measures of pubertal development status derived from physical characteristics are only moderately associated with measures of hormonal concentrations (Shirtcliff et al., 2009). Pubertal development status derived from physical characteristics may be associated with personality changes over and above hormonal concentrations because physical characteristics are more closely tied to social experiences that accompany pubertal development (Blakemore et al., 2010). For instance, physical changes associated with pubertal development may indicate to the social environment that children are becoming more mature. With increased perceptions of maturity, expectations regarding mature (i.e. well regulated, independently planned and executed) behavior may also increase. Consequently, although adolescents' personalities may still be maturing, demands placed on them by their environment (e.g., parents, teachers) may increase even more strongly. The result of this discrepancy between adolescents' actual maturation on the one hand and expectations of their social environment on the other may be that

adolescents appear to be decreasing in maturity (Denissen et al., 2013). For instance, even though children might be becoming more conscientious, when they are suddenly expected to keep track of homework, clean their own rooms, and make sure they are on time for sports lessons, they may forget some tasks on their to-do list. Children may receive negative feedback from parents or teachers and may view themselves as becoming less conscientious. This maturation disparity, or the gap between expectations and underlying capabilities, may diminish as adolescents' underlying psychological capabilities develop to match their changing physical appearance. Therefore, more advanced pubertal development status derived from physical characteristics may be related to lower personality maturity especially in early adolescence.

Although we know of no studies examining associations between the Big Five dimensions and pubertal development status, a few studies regarding other personality traits are available. Pubertal development status at age 12 has been associated with both positive and negative urgency, traits that describe a tendency to react rashly in response to positive versus negative emotion respectively (Gunn & Smith, 2010). Both these traits are associated with high neuroticism and low conscientiousness and agreeableness, or a less mature personality (Cyders & Smith, 2008). Constraint, which can be considered a combination of traits associated with conscientiousness and openness to experience, (Church, 1994) has been found to be associated with pubertal development differently for boys and girls (Schissel et al., 2011). For girls, pubertal development was negatively related with constraint during earlier stages of puberty but unrelated at later stages. For boys however, pubertal development was positively associated with constraint during early stages of puberty, with no association thereafter. Planning and perseverance, two other subcomponents of conscientiousness (John & Srivastava, 1999), have been found to be unrelated to pubertal status (Gunn & Smith, 2010), as has impulse control (Castellanos-Ryan et al., 2013). Two other studies found that pubertal status was unrelated to traits related to positive emotionality (a facet of extraversion) and negative emotionality (a facet of neuroticism; Canals et al., 2005; Schissel et al., 2011).

Goals of the Current Study

Although pubertal development is a strong candidate factor in explaining decreases in personality maturity in early adolescence, no study has previously examined associations between pubertal development, as assessed either by hormonal concentrations or pubertal development status derived from physical characteristics, and Big Five personality dimensions. It is important to understand what is driving these personality changes to understand how to best support adolescents during this time.

In a preliminary step, we examined mean-level trends of self-reports of the Big Five personality dimensions in a large, cross-sectional sample with an age range from 8 to 18 years ($N = 2640$) to investigate whether they were in line with a temporary disruption in personality maturation in early adolescence. Next, we examined associations between the Big Five personality dimensions and pubertal development. First, we examined associations with pubertal hormone concentrations in hair samples (i.e. DHEA, testosterone, and progesterone, $n = 1793$). Hair sampling is a recently developed, noninvasive method of collecting longer-term free hormone output (Gao et al., 2016). If rising pubertal hormone concentrations play a role in explaining a dip in personality maturation in early adolescence, we would expect that hormone concentrations would be associated with lower personality maturity as evidenced by lower levels of agreeableness and conscientiousness and higher levels of neuroticism. These effects might be stronger for younger adolescents as pubertal development is a process that adolescents may adapt to over time. We also examined associations with Extraversion and Openness to Experience to gain a complete picture of associations with the Big Five. These analyses were exploratory. Next, we examined associations of the Big Five personality dimensions with pubertal development status as measured by youth self-report of physical characteristics. For pubertal development status as derived by physical characteristics, we expect similar associations with the personality dimensions as for the hormone concentrations. Finally, we examined whether either pubertal hormone concentrations or pubertal development status derived from physical characteristics were uniquely associated with the Big Five. Moderation by sex was examined for the associations.

Method

All analytic plans were preregistered on OSF (https://osf.io/t52k8/?view_only=75c8ef2395e6423ca36941f7788bb8fb).

Sample

The sample included 2640 participants from 1,102 families (49% boys) from the Texas Twin Project (Harden et al., 2013). Adolescent mean age was 13.64 years ($SD = 2.93$, range = 6.94–21.29 years). Over 94% of the sample was between the ages of 8 and 18 years, and we therefore base our inferences on this age range to avoid problems of overextrapolation. Sixty percent of the adolescents identified as non-Hispanic white, 21% as Hispanic/Latino, 10% as African American, and 9% as another race/ethnicity. Approximately a third of sibling pairs were monozygotic twins, with the remaining pairs being dizygotic twins. For the purposes of the current study, we did not perform any family based analyses. Instead, we analyzed the data at the individual-level and corrected for the nonindependence of drawing observations from the same family. A subset of the sample only provided self-reports on personality ($n = 847$). These participants were recruited prior to the introduction of hair sampling into the research protocol and typically completed mailed or online surveys rather than participating in the laboratory setting. The sampling frame was students in K-12 public schools for these participants. The rest of the sample provided both self-reports of personality and pubertal development, and pubertal hormone samples ($n = 1793$, from 771 families, 43% boys). The sampling frame was students in 3rd-12th grade public schools for these participants due to the in-lab nature of the data collection. Of this subsample, the average age was 12.45 years ($SD = 2.84$, range = 7.8–19.47 years). Participants who only had personality data and not hormone data tended to be younger due to the differences in the sampling frame but did not differ meaningfully on personality (average absolute value of Cohen's $d = .05$). This result is consistent with the missing data being due to the design of the study rather than systematically on the basis of key study variables. A total of 20 additional participants were omitted due to some sort of disorder that would affect

hormone levels (e.g., hypothyroidism), and an additional 51 participants were omitted due to use of hormonal birth control. The Texas Twin Project started recruiting participants from public schools in Austin, TX, Houston, TX, and surrounding areas in 2012, with data collection in Austin ongoing.

The Texas Twin Project subprojects were approved by the Institutional Review Board of the University of Texas as projects 2009–12-0040 ("A Sibling and Twin Study of Healthy Development in Children and Adolescents"), 2011–11-0066 ("A Twin Study of Healthy Development in Infants and Young Children"), 2011–11-0067 ("Genetic Influences on Adolescent Decision-Making and Alcohol Use"), 2013–02-0011 ("The Genes and Development Study"), 2014–11-0021 ("Cortisol, Socioeconomic Status, and Genetic Influence on Cognitive Development"), and 2016–01-0004 ("Genetic & Hormonal Influences on Adolescent Decision-Making").

Measures

Personality

Adolescents provided self-reports on the 44 items of the child version of the Big Five Inventory (BFI; John et al., 2008). Participants were asked to indicate on a 5-point Likert-type scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*) how much they agreed that the item described them. The BFI assesses extraversion with 8 items (example item: "is talkative"), neuroticism with 8 items (example item: "can be tense"), conscientiousness with 9 items (example item: "does a thorough job"), agreeableness with 9 items (example item: "starts quarrels with others"), and openness to experience with 10 items (example item: "has an active imagination"). Individual item responses were corrected for acquiescence by subtracting person-specific means, and extreme responding by dividing scores by person-specific standard deviations of responses to pairs of items with opposite implications for personality (e.g., "is talkative" vs. "tends to be quiet"), prior to computing mean scale scores (Soto et al., 2008). Acquiescence is reflected by participants' tendency to agree with items with differing implications for personality, and extreme responding is reflected by participants' tendency to use either pole of the scale. Cronbach's alphas in the current sample were: Extraversion = .80, Agreeableness = .75, Conscientiousness = .78, Neuroticism = .72, and Openness = .70.

Pubertal Hormones

DHEA, testosterone, and progesterone concentrations were derived from hair samples summing 3 mm in diameter from the posterior vertex of the scalp, representing an accumulation of hormones over 3 months. Participants were instructed not to use any hair products that were not rinsed out of the hair the day of the appointment. Hair samples were stored at room temperature before being shipped to Dr. Clemens Kirschbaum's laboratory at Technical University Dresden, where they were analyzed using liquid chromatography-tandem mass spectrometry (Gao et al., 2013). The lower limit of detection was 0.1 pg/mg. There were 459 samples below this threshold for testosterone, 365 for progesterone, and 172 for DHEA. A winsorizing procedure was used to replace extreme values by the highest observed score within 3 standard deviations of the sample mean. This procedure replaced a total of 12, 9, and 15 observations for testosterone, progesterone, and DHEA, respectively. As all hormones were positively skewed, these variables were log-transformed to approximate normal distributions and then standardized. These procedures match previous publications using this data (Grotzinger et al., 2018) and our preregistration plan.

Self-Reported Pubertal Development

Adolescents provided self-reports on the Pubertal Development Scale (PDS; Petersen et al., 1988). All adolescents rated five items on a 4-point scale ranging from 1 = *not yet begun to change* to 4 = *finished changing* with an option to respond *I do not know*, which was recoded as missing. Boys and girls all rated items about growth in height, growth of body hair, and changes in skin-appearance, with girls additionally indicating breast growth and menarche (1 = *no* and 4 = *yes* to maintain scaling with other items), whereas boys rated growth of facial hair and deepening of voice. The mean of these items was used as the final pubertal development score.

Analysis Plan

First, to examine nonlinearities in mean-level age trends of the Big Five, indicating a disruption in personality maturation, we used nonparametric local structural equation models (LOSEM; Briley et al., 2015; Hildebrandt et al., 2016) to provide a nonparametric picture of age-trends in the key outcomes considered in this report (see participants section for details). The use of LOSEM is similar to the use of LOESS plots as an extension of regression analysis (Cleveland & Devlin, 1988). We fit locally weighted models with different focal ages from age 8 to 18 years in .1 increments. For example, when a model with age 8 years is the focal age, data near age 8 years is weighted most strongly, and data near age 18 years is weighted less strongly. Importantly, all models make full use of the entire dataset, and no arbitrary subsetting of the data is necessary. We chose 18 years as the upper bound of our analysis frame because very few observations with age greater than 18 were included in the dataset, and we did not want to extrapolate beyond our data coverage. All personality measures were standardized relative to the full sample mean and standard deviation to provide a more intuitive metric, and only for these models, the variables were not ipsatized to maintain the between-person metric of the scales.

To examine if more advanced pubertal development is associated with lower personality maturity, especially in early adolescence, we first examined associations between pubertal hormones and the Big Five personality dimensions, including hormone by sex interactions. To examine whether the associations were stronger in early adolescence than in later adolescence, we again estimated nonparametric LOSEM. In these models, effects of pubertal hormone concentrations, as well as interactions between pubertal hormone concentrations and sex, were tested for separate points across the age range in the sample (ages 8 to 18, with .1 year intervals). Given the marked discontinuities of pubertal development in this age range, we anticipated that nonlinear trends may be found. Next, we examined associations between self-reported pubertal development and Big Five personality dimensions. Sex and self-reported pubertal development by sex interactions were included in this model. To examine pubertal development by age

interactions, we estimated regression models including linear and quadratic effects of age and pubertal development status by age interaction. It is important to note that including main effects of age necessarily changes the interpretation of the pubertal development status to mean pubertal development status relative to same-age peers, or "pubertal timing" (Marshall & Tanner, 1969). Therefore, for both the hormone concentrations and the pubertal development status, we also report results of models that do not include age. Finally, to examine whether pubertal hormones and pubertal development status derived from physical characteristics were uniquely associated with the personality dimensions, we included all variables in a single model.

All models were estimated in M*plus* Version 7.31 (Muthén & Muthén, 1998–2015), with estimation type = complex to account for the nested structure of the data with individual twins nested within families. Missing data were handled using the WLSMV estimator. To deal with the left-censoring in the hormone variables, because of the samples that did not reach the lower limit of detection, we estimated Tobit regression models. These models controlled for the year hair samples were analyzed, as well as race of the participant. The Benjamini-Hochberg procedure was applied simultaneously to all regression coefficients tested in all the models to correct for increased false discovery rate due to multiple testing, using a spreadsheet available online (www.biostathandbook.com). The false discovery rate was set to .05.

Results

Evidence for Disruption of Personality Maturation

We expected that mean-levels of agreeableness, conscientiousness, and neuroticism, would show temporary dips in typical maturational trends. Figure 1 plots mean-level trends of the Big Five dimensions, separately for boys and girls. The cross-sectional evidence for agreeableness and conscientiousness was largely consistent with the temporary disruption in early adolescence of the normative trend toward a more mature personality. For girls, mean-levels of agreeableness and conscientiousness increased with increasing age up until age 10 but decreased between age 10 and age 14. For boys, the trends in agreeableness were similar to those for girls but lagged about a year behind. Rather than first increasing, conscientiousness already decreased from age 8 for boys. For both boys and girls, mean-level trends for agreeableness and conscientiousness turned positive between age 14 and 16, with the upturn for boys lagging about a year behind that of girls. For neuroticism, we did not find that the association with age temporarily changed direction. Rather, levels increased across the entire age range for girls, increasing roughly .4 SDs, whereas for boys, levels decreased across the entire age range.

Mean levels of extraversion increased up to around age 11 for both boys and girls and then decreased across the rest of the age range for boys but started increasing again around age 16 for girls. Mean levels of openness increased up to age 12 for both boys and girls. After age 12, levels of openness decreased with age, with 16 to 18 year-old children at similar levels as 8 year-olds. Importantly, these age-trends are based on cross-sectional data, and therefore, we cannot make any inferences about change or longitudinal trajectories.

Pubertal Development and Adolescent Personality

Pubertal Hormones

To examine associations between pubertal development and personality, we first examined associations between the five personality dimensions and pubertal hair hormones, see Table 1. In line with expectations, higher concentrations of DHEA were related to lower levels of conscientiousness for both boys and girls. However, concentrations of DHEA were unrelated to agreeableness and neuroticism. Unexpectedly, DHEA was also related to lower openness to experience. Progesterone and testosterone were unrelated to the personality dimensions. There were no significant sex by hormone interactions.

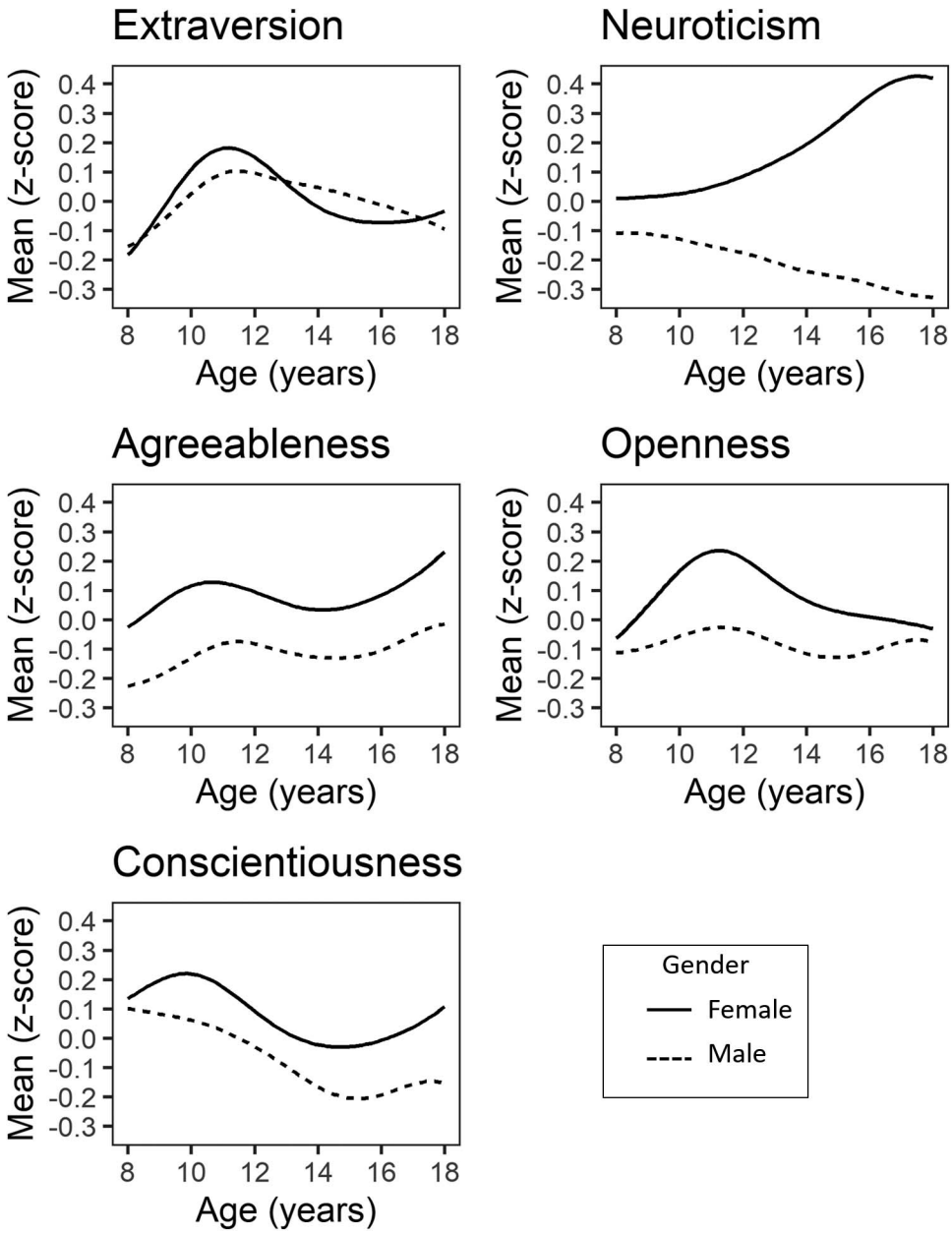
To examine whether the hormonal effects were especially pronounced across early adolescence, we estimated LOSEM models. Figure 2 presents these results for each of the Big Five dimensions and pubertal hormones. In these graphs, the *y*-axis reflects the correlation between a personality dimension and pubertal hormone. The *x*-axis reflects age, from 8 to 18 years. The age-trends were estimated separately for male and female participants.

DHEA showed the most heterogeneity in terms of associations with personality. Overall, we did not find that effects were most pronounced in early adolescence. For girls, near zero negative correlations were found across all of the Big Five, across the entire age range. For males, on the other hand, relatively larger positive associations ($r \sim .15$) with DHEA were found for extraversion, agreeableness, conscientiousness, and openness across early adolescence. For each of these dimensions, the positive association slowly faded, reaching zero by approximately age 13. Near the upper limit of the observed age range, negative associations were found with relatively large magnitudes ($r \sim -.2$). Rather than being more pronounced (and negative) in early adolescence than at later ages, effects were approximately equally strong, but in the opposite direction. Effects for boys were also in the opposite direction as expected in early adolescence, with higher DHEA concentrations associated with higher agreeableness and conscientiousness during this time. For neuroticism, there was a near zero effect for boys until age 14, with an increasing effect from then onward.

In line with expectations, testosterone was negatively associated with conscientiousness ($r \sim -.1$) and agreeableness ($r \sim -.07$), and positively associated with neuroticism ($r \sim .1$) among males. For neuroticism, effects were indeed stronger in early adolescence, decreasing in magnitude to zero by approximately age 16. The effects for conscientiousness and agreeableness were not stronger at earlier ages but remained quite stable across the entire age range. Results were similar for extraversion. Openness was the only personality dimension to show an opposite pattern, with a null relation at early ages and a positive association of approximately .1 by late adolescence. As expected, we found fewer associations with testosterone for girls. For girls, testosterone was positively correlated ($r \sim .1$) with extraversion and openness at early ages, with these associations shifting to essentially null by age 14. All other associations were essentially null across the age range for them.

Turning toward progesterone, most of the associations were essentially flat and null across the age range. The most prominent age trend for females was in line with expectations: the association

Figure 1
Mean-Level Age Trends in Personality Using LOSEM (N = 2640)



Note. All variables were standardized relative to the full sample mean and standard deviation and were not ipsatized.

between progesterone and conscientiousness strengthened modestly across early adolescence, from a null association at early ages to −.1 by age 14. The association increased toward zero again across later ages. For agreeableness, there was a small negative association with agreeableness up to age 14, with this effect increasing to essentially null by age 17. Although associations were also mostly null for boys, the strongest association between progesterone and adolescent personality occurred for boys rather than girls. Progesterone was negatively correlated with male neuroticism at early ages ($r \sim -.15$), shifting slowly to a null relation by age 14.

Self-Reported Pubertal Development

Next, we investigated associations between self-reported pubertal development and the five personality dimensions. Results indicated that more advanced self-reported pubertal development predicted lower levels of extraversion, agreeableness, conscien-

Table 1
Results From the Regression Analyses Predicting the Big Five Dimensions by Pubertal Hormones, Sex, and Their Interaction (n = 1793)

Predictor	Extraversion	Agreeableness	Conscientiousness	Neuroticism	Openness
	b (*SE*)	*b* (*SE*)	*b* (*SE*)	*b* (*SE*)	*b* (*SE*)
Sex	−.00 (.06)	−.17 (.06)*	−.12 (.06)	−.44 (.05)*	−.14 (.06)*
Testosterone	.06 (.04)	−.04 (.04)	.01 (.04)	.05 (.05)	.03 (.04)
Progesterone	−.09 (.05)	−.05 (.05)	−.07 (.05)	.08 (.05)	.02 (.04)
DHEA	−.07 (.04)	−.07 (.04)	−.10 (.04)*	−.06 (.05)	−.11 (.03)*
Testosterone × Sex	−.12 (.06)	−.03 (.06)	−.12 (.06)	−.01 (.06)	−.01 (.06)
Progesterone × Sex	.13 (.07)	.03 (.06)	.12 (.07)	−.10 (.07)	.02 (.06)
DHEA × Sex	.04 (.05)	.07 (.05)	.10 (.05)	.02 (.05)	.07 (.04)

Note. Age was centered prior to analyses, and sex was coded as (0 = female, 1 = male). All models also controlled for batch year for the hormone sample and participant race/ethnicity.
* $p < .014$.

tiousness, and openness, see Table 2. For neuroticism, there was an interaction between self-reported pubertal development and sex, indicating that more advanced pubertal development was related to lower levels of neuroticism for boys (b (SE) = −.21(.04), $p < .000$) but was unrelated to neuroticism for girls (b (SE) = .01(.03), $p = .716$).

To examine whether associations were stronger in early than late adolescence, we included interactions with age, including linear and quadratic main effects of age. To accomplish this, self-reported pubertal development was first residualized for linear and quadratic age effects, with the residuals included in the models. For estimated coefficients, see Table 3. Self-reported pubertal development status did not interact with age or sex in predicting any of the Big Five personality dimensions. As we had to control for main effects of age, the interpretation of the pubertal development status variable now changed to pubertal development relative to same age peers, or pubertal timing. Pubertal timing was related to lower levels of agreeableness and conscientiousness, as well as extraversion.

Unique Effects of Self-Reported Pubertal Development and Hormones

Finally, we examined unique effects of self-reported pubertal development (again residualized for age effects, thus representing pubertal timing) and pubertal hormones by including both predictors in the same model (see Table 4). In this model, the associations between self-reported pubertal development and lower agreeableness and conscientiousness remained approximately equally strong. Higher levels of DHEA relative to same-age peers were associated with lower openness but slightly less strongly so than in the model that did not include self-reported pubertal development and age. The association of concentrations of DHEA with conscientiousness decreased by about a third and was no longer significant. The association between self-reported pubertal development and extraversion that was found in the model not including the hormones decreased by about half and was no longer significant.

Discussion

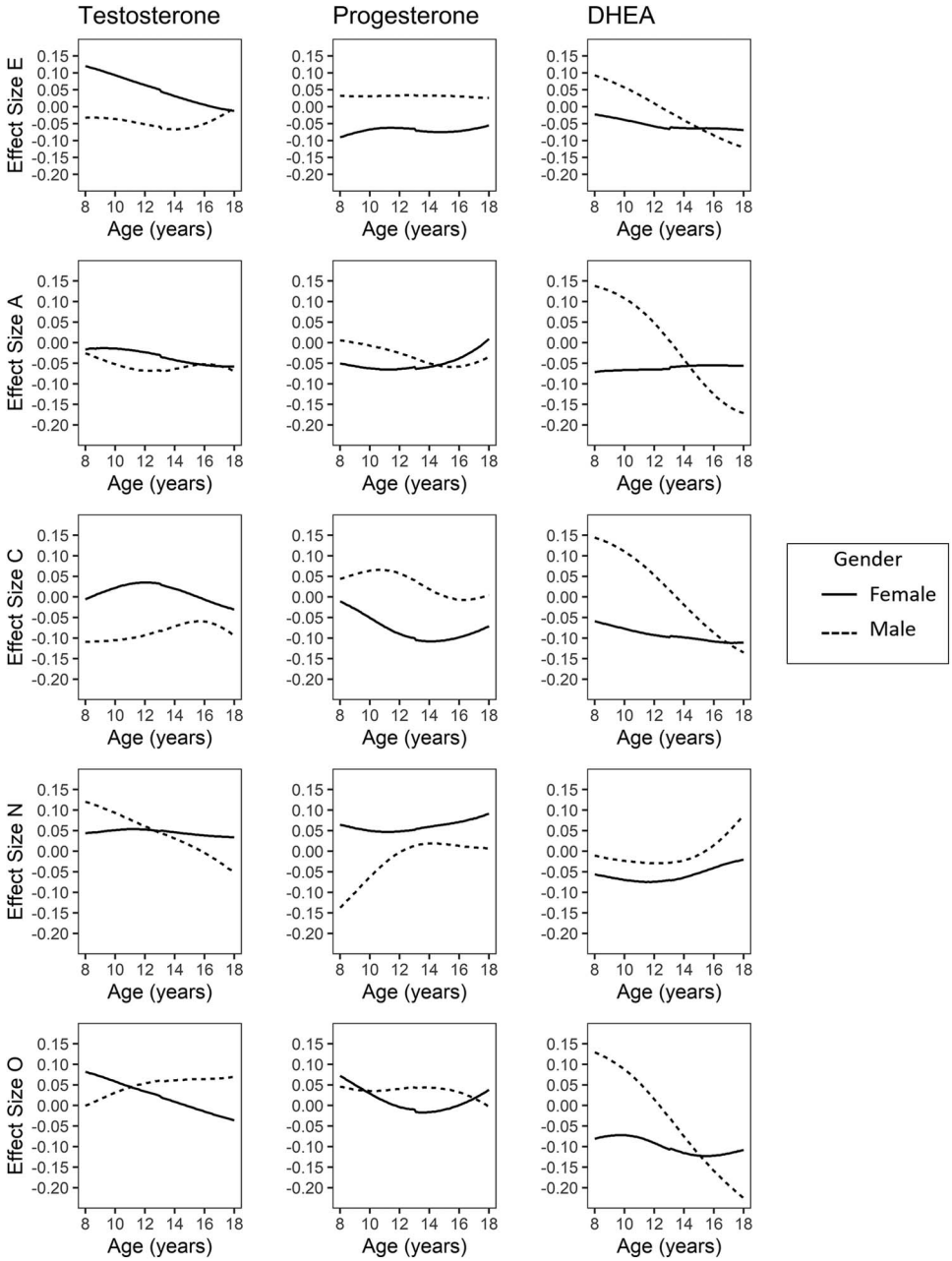
The main aim of this study was to examine whether pubertal development may explain a temporary disruption of maturation of Big Five personality characteristics in early adolescence. Mean-level age trends for the Big Five traits in the Texas Twin Project were in line with a disruption of personality maturation in early adolescence, with higher levels of conscientiousness and agreeableness for older children until around age 10, lower levels for children up until age 14, and again higher levels for older children thereafter. For neuroticism, older girls had higher levels than younger girls across the entire age range, whereas older boys had lower levels than younger boys across the entire age range. We found some evidence for negative associations with higher levels of hormonal concentrations, in line with these mean-level trends, for conscientiousness only. More advanced self-reported pubertal development and earlier pubertal timing were related to lower levels of both conscientiousness and agreeableness for both boys and girls. These associations were not stronger in early adolescence relative to later adolescence. Overall, all associations were relatively small in magnitude. Taken as a whole, pubertal development may explain some portion of the dip in personality maturation due to the mean-level increases in pubertal hormones during the age period, but there are likely many other contributing factors.

Pubertal Development and Personality Maturation

Similar to several previous studies (Göllner et al., 2017; Luan et al., 2017; Soto et al., 2011; Van den Akker et al., 2014), we found temporary lower levels of conscientiousness and agreeableness in early adolescents for both boys and girls and higher levels of neuroticism for older girls across the whole of adolescence. It has been suggested that these changes are partly explained by hormonal changes associated with pubertal development (Soto & Tackett, 2015). For conscientiousness we indeed found some evidence for this possibility. First, the regression models indicated a negative association between DHEA and conscientiousness. Examination of nonlinear trends for this association indicated that this effect was the same at all ages for girls, but not for boys. According to the LOSEM results (see Figure 2), for boys, DHEA was positively associated with conscientiousness up to age 13, and the effect became negative thereafter. This would indicate that lower conscientiousness in early adolescence could be partly explained by DHEA increases for girls, but not for boys. Importantly, the parametric results (see Table 1) did not indicate that the DHEA by gender interaction was statistically significant after our correc-

Figure 2

LOSEM Results Displaying Age-Related Shifts in the Association Between Pubertal Hormones and Personality (n = 1793)



Note. The *y*-axis reflects the effect size, which is a correlation coefficient. The *x*-axis reflects age from 8 to 18 years. The first column displays results for testosterone. The second column displays results for progesterone. The third column displays results for DHEA. E = extraversion; A = agreeableness; C = conscientiousness; N = neuroticism; O = openness.

tion for multiple testing ($p = .042$), and therefore, these novel findings should be replicated in an independent sample prior to interpreting strongly. Most similar to our current finding, an investigation of the related personality characteristic of constraint (a trait that can be considered a combination of conscientiousness and openness to experience) in association to pubertal development status reported a similar moderation by sex (Schissel et al., 2011).

With regard to the other hormones, we also found some evidence pointing to associations with lower conscientiousness in early adolescence. Whereas the regression models did not indicate

Table 2

Results From the Regression Analyses Predicting the Big Five Dimensions by Self-Reported Pubertal Development, Sex, and Their Interaction (n = 1727)

Predictor	Extraversion	Agreeableness	Conscientiousness	Neuroticism	Openness
	b (*SE*)	*b* (*SE*)	*b* (*SE*)	*b* (*SE*)	*b* (*SE*)
Sex	−.06 (.06)	−.27 (.06)**	−.24 (.05)**	−.47 (.05)**	−.20 (.05)**
Self-reported pub. dev.	−.16 (.03)**	−.14 (.03)**	−.18 (.03)**	.01 (.03)	−.12 (.03)**
Self-Reported Pub. Dev. × Sex	−.04 (.06)	−.04 (.06)	−.09 (.05)	−.22 (.05)**	−.05 (.05)

Note. Age was centered prior to analyses, and sex was coded as (0 = female, 1 = male). All models also controlled for batch year for the hormone sample and participant race/ethnicity.
** $p < .014$.

significant associations between conscientiousness and testosterone or progesterone, the LOSEM models showed a small negative effect of progesterone on conscientiousness for girls, and a negative effect of testosterone on conscientiousness for boys, that became less strong from mid-adolescence onward.

Findings regarding the association with conscientiousness could be explained by decreased cognitive control that has been posited as one of the effects of pubertal hormones on functional brain development, through effects on activity in areas in the frontal and parietal cortex (Luna, 2009). However, it should be noted that a recent review of the literature indicates that there is less support for a link of pubertal hormone concentrations with neural activation related to cognitive control processes than with neural activation related to perspective taking and sensitivity to reward for instance, as most studies on cognitive control processes have reported null findings (Vijayakumar et al., 2018). An alternative explanation for the association between DHEA and conscientiousness is that it is due to the changes in physical characteristics as a result of pubertal development. A more mature appearance may result in expectations of mature behavior (e.g., more planful and organized) increasing more quickly than adolescents underlying capabilities, or a maturation disparity effect (Denissen et al., 2013). This interpretation is in line with our finding that self-reported pubertal development based on physical characteristics was also associated with lower conscientiousness, and that the association with DHEA disappeared in the model including self-reported pubertal development.

With regard to agreeableness, we did not find associations between pubertal hormones and lower agreeableness in the regression models. We did find that more advanced self-reported pubertal development was related to lower levels of agreeableness, again pointing to the possibility of a maturation disparity effect. Interestingly, perhaps the most expected association, that is, an association between puberty and neuroticism for girls, was the only one that we did not find any evidence at all for. Based on findings that link depression in adolescent girls to pubertal development (Joinson et al., 2012; Lewis et al., 2018), a link with neuroticism could be expected, as neuroticism represents a trait disposition to experience negative affect such as depressed mood (Widiger & Oltmanns, 2017). However, we did not find an association between pubertal hormones and neuroticism for either boys or girls, nor did we find an association between self-reported pubertal development and neuroticism for girls. We did find an association between self-reported pubertal development and neuroticism, but for boys only, with more advanced pubertal developmental status associated with lower (rather than higher) levels of neuroticism. This association was no longer significant when we controlled for age, which may indicate either that this effect is not especially strong for earlier maturing boys or that it merely reflects the overall age trends of decreasing neuroticism for boys. Replication of this unexpected finding is needed. A previous study that also found decreasing levels of neuroticism for boys did not find an effect of self-reported pubertal development for either boys or girls (Canals et al., 2005).

Table 3

Results From the Regression Analyses Predicting the Big Five Dimensions by Pubertal Timing (i.e. Self-Reported Pubertal Development, Controlling for Age), Sex, and Their Interaction (n = 1727)

Predictor	Extraversion	Agreeableness	Conscientiousness	Neuroticism	Openness
	b (*SE*)	*b* (*SE*)	*b* (*SE*)	*b* (*SE*)	*b* (*SE*)
Age	−.04 (.01)*	−.02 (.01)	−.04 (.01)*	−.00 (.01)	−.04 (.01)*
Age^2	−.02 (.00)*	−.01 (.00)	−.00 (.00)	.01 (.00)	−.01 (.00)
Sex	−.03 (.06)	−.27 (.06)*	−.24 (.06)*	−.46 (.05)*	−.13 (.06)
Self-reported pub. dev.	−.09 (.03)*	−.14 (.04)*	−.15 (.03)*	.02 (.03)	−.04 (.03)
Age × Sex	.01 (.02)	−.01 (.02)	−.05 (.02)	−.08 (.02)*	−.02 (.02)
Self-Reported Pub. Dev. × Sex	.08 (.05)	.01 (.06)	.02 (.05)	−.11 (.05)	.06 (.05)
Self-Reported Pub. Dev. × Age	.01 (.01)	.01 (.01)	−.01 (.01)	−.02 (.01)	.02 (.01)

Note. Age was centered prior to analyses, and sex was coded as (0 = female, 1 = male). All models also controlled for batch year for the hormone sample and participant race/ethnicity.
* $p < .014$.

Table 4

Results From the Regression Analyses Predicting the Big Five Dimensions by Pubertal Hormones, Sex, Age, and Their Interaction (n = 1793)

Predictor	Extraversion	Agreeableness	Conscientiousness	Neuroticism	Openness
	b (*SE*)	*b* (*SE*)	*b* (*SE*)	*b* (*SE*)	*b* (*SE*)
Age	−.04 (.01)*	−.02 (.01)	−.03 (.01)	−.01 (.01)	−.03 (.01)*
Age^2	−.01 (.00)*	−.01 (.00)	.00 (.00)	.01 (.00)	−.01 (.00)
Sex	−.02 (.06)	−.24 (.07)*	−.23 (.07)*	−.50 (.08)*	−.14 (.07)
Self-reported pub. dev.	−.08 (.03)	−.14 (.04)*	−.14 (.04)*	.02 (.05)	−.05 (.04)
Testosterone	.04 (.04)	−.05 (.04)	−.01 (.04)	.06 (.05)	.01 (.04)
Progesterone	−.04 (.05)	−.02 (.05)	−.04 (.05)	.05 (.05)	.04 (.04)
DHEA	−.02 (.04)	−.05 (.04)	−.07 (.04)	−.05 (.05)	−.09 (.03)*
Self-Reported Pub. Dev × Age	.01 (.01)	.01 (.01)	−.01 (.01)	−.02 (.02)	.02 (.01)
Testosterone × Age	−.01 (.01)	−.00 (.01)	.00 (.01)	−.02 (.01)	.00 (.01)
Progesterone × Age	.01 (.01)	−.00 (.01)	−.01 (.01)	.02 (.01)	−.01 (.01)
DHEA × Age	.05 (.05)	.00 (.01)	−.01 (.01)	.01 (.01)	−.02 (.01)
Self-Reported Pub. Dev. × Sex	.08 (.06)	.01 (.05)	.01 (.06)	−.11 (.06)	.07 (.05)
Testosterone × Sex	−.07 (.06)	.01 (.06)	−.07 (.06)	−.01 (.06)	.05 (.06)
Progesterone × Sex	.07 (.07)	.00 (.06)	.07 (.07)	−.08 (.07)	.02 (.06)
DHEA × Sex	.05 (.05)	.07 (.05)	.12 (.05)	.07 (.05)	.09 (.04)
Sex × Age	.02 (.02)	−.02 (.02)	−.05 (.02)	−.07 (.03)	−.02 (.02)

Note. Age was centered prior to analyses, and sex was coded as (0 = female, 1 = male). All models also controlled for batch year for the hormone sample and participant race/ethnicity.

* $p < .014$.

We also examined links between pubertal development and extraversion and openness to experience. Self-reported pubertal development was related to lower extraversion, whereas hormonal concentrations were not. Interestingly, the most robust association between pubertal hormone concentrations and any of the personality dimensions was found for DHEA and openness to experience. This association was the only one that remained after controlling for self-reported pubertal development. Unexpectedly, both higher concentrations of DHEA and more advanced self-reported pubertal development were associated with lower openness to experience. The main links of pubertal hormones to behavioral tendencies that have been proposed to date, such as increased sensitivity to reward and increased perspective taking (Vijayakumar et al., 2018), would suggest links to higher rather than lower openness to experience. The LOSEM models showed that the association was actually quite different for boys and girls: For boys, DHEA was positively associated with openness across early adolescence and only became negative from mid-adolescence onward. For girls, the association was essentially null but slightly negative across the entire age range.

As we examined interactions with age, we controlled for main effects of age. Separating effects of puberty from age effects is problematic as they are highly confounded. Controlling for age effects changes the interpretation of the pubertal development status variable to pubertal development relative to same age peers, or pubertal timing (Marshall & Tanner, 1969). Earlier pubertal timing is also proposed to have negative consequences for adolescent development due to a maturation disparity effect (Ge & Natsuaki, 2009; Harden, 2014). Results indicated that earlier self-reported pubertal timing was related to lower levels of extraversion, agreeableness, and conscientiousness. When examining unique effects of pubertal timing indexed by self-report and by pubertal hormone concentrations, earlier self-reported pubertal timing was related to lower levels of conscientiousness and agreeableness, and higher concentrations of DHEA relative to same age peers were uniquely predictive of lower levels of openness. These associations were all similar for boys and girls. These findings are in line with a large body of evidence indicating that early maturation is equally associated with risk for adjustment problems in boys and girls (Ullsperger & Nikolas, 2017).

Effects of Pubertal Development by Age and Sex

We hypothesized that pubertal hormones would be more strongly related to the personality dimensions in early adolescence than in later adolescence, as adolescents may adapt to the changes over time. We did not find any pubertal hormone by age interactions in our regression models, and the LOSEM models also did not provide much evidence for these types of effects. For testosterone, three out of 10 associations showed this type of effect, and one association showed the opposite effect (i.e. the association becoming stronger over time). For progesterone, one association of this type was found, as well as one association in the opposite direction. The LOSEM models showed similar sex by age trends for associations between DHEA and all the personality dimensions except neuroticism, with positive associations becoming negative for boys, and quite stable, slightly negative associations for girls. Replicating this finding in an independent sample would be desirable. Interestingly, a previous investigation of mean-level changes in DHEA in this sample (Grotzinger et al., 2018) showed that mean levels of DHEA were more stable for boys than for girls up to mid-adolescence. Findings of the present study indicate that even though mean levels were more stable for boys, the association of higher concentrations of these hormones with all personality dimensions except neuroticism changed from positive to negative for them. Additionally, although mean levels were increasing for girls, the effect of higher concentrations was quite stable for them. This could indicate that the adolescent habituates to the rising

DHEA concentrations, such that DHEA only produces the same effects if concentrations increase (and effects decrease when concentrations remain stable). For future studies into DHEA concentrations in youth, these findings indicate that, although adrenarche is marked by a rise in DHEA for both boys and girls, it is still important to examine associations for boys and girls separately.

Strengths and Limitations

The present study has several strengths. First, the large sample size ensures power to detect the small effects that can be expected for hormone-personality associations. Second, the Texas Twin Project was designed to maximize representativeness with regards to socioeconomic status and ethnicity, with 40% of participants having an ethnic minority status (Harden et al., 2013). Third, we examined both concentrations of three pubertal hormones as well as self-reports of pubertal development simultaneously, allowing us to investigate their unique effects. Fourth, the broad age range spanning 8 to 18 years allowed us to investigate whether puberty and personality associations differ across ages. Related to this, LOSEM modeling allowed us to examine nonlinear trends in the puberty–personality interactions across ages. In addition to these strengths, it should be noted that the study is limited by its cross-sectional nature. To disentangle pubertal development from more general age effects, we controlled for age. However, doing so necessarily changes the interpretation of the pubertal development variables to indices of pubertal timing. A longitudinal study would allow for further disentangling of these effects, as well as examination of whether pubertal development is associated with personality development within persons over time. Additionally, we did not include estradiol in the current investigation, a pubertal hormone that drives important pubertal changes in girls and also increases in boys during this phase (Bidlingmaier et al., 1973). A recent review provides evidence for the notion that this long overlooked hormone may be critically implicated in the development of cognitive brain structures and function (Beltz & Moser, 2020). Further, even though our sample size was quite large by conventional standards, complex nonlinear interaction models place high demands on the data. It is important to replicate these findings in an independent sample prior to strongly interpreting the age-moderation results. Additionally, results from twin samples may not generalize to samples of singletons, as twins are more often born prematurely and at low birth weight for instance, which may impact their further development. With regards to behavioral problem development for instance, there is some evidence of differences in internalizing, but not externalizing, problems emerging by adolescence (Robbers et al., 2010). At the same time, twins and singletons do not differ substantially on numerous measures of personality (Johnson et al., 2002), which implies the current results likely generalize. Finally, it should be noted that we included only self-reports of personality. Although self-reports provide access to the stable patterns of thoughts and affect that are an important part of personality and that are mostly internal to the person, other-reports (e.g., parent-, teacher-, or peer-reports) may provide an interesting additional perspective, especially with regards to the behavioral component of personality.

Conclusion

This study investigated associations of pubertal hormone concentrations and self-reported pubertal development to the Big Five personality dimensions across adolescence. We found evidence for a temporary decline in maturation in mean-level trends of conscientiousness, agreeableness, and neuroticism for girls. For conscientiousness and agreeableness, we found some evidence for small effects of pubertal development that could explain these mean-level trends. Overall there were more associations between the personality dimensions and self-reported pubertal development than with pubertal hormone concentrations. Further research is necessary to examine whether neural development and expectations of more mature behavior from the environment are indeed mechanisms that may explain these associations.

Overall, results of this study do not point to pubertal development as the main factor in explaining the dip in personality maturation in adolescence. The adolescent social and biological environment is perhaps the most complex in human development, and a comprehensive biopsychosocial model of the "maturity dip" in personality development may include many causal factors of small effect. Other factors that may for instance play a role, in addition to other hormones such as estradiol, are experiences of stress associated with the transitions that children go through during this time, such as transitioning to secondary education and needing to make new friends. Stressful life events have previously been shown to predict decreases in conscientiousness, agreeableness, and increases in neuroticism in adults (Hutteman et al., 2014), and the experience of stress may also play a role for adolescents. The large sample in the current study sheds light on one piece of the puzzle by highlighting the small effect of both self-reported pubertal development and pubertal hormones on personality development and how these associations vary with age.

References

Beltz, A. M., & Moser, J. S. (2020). Ovarian hormones: A long overlooked but critical contributor to cognitive brain structures and function. *Annals of the New York Academy of Sciences*, *1464*(1), 156–180. https://doi.org/10.1111/nyas.14255

Bidlingmaier, F., Wagner-Barnack, M., Butenandt, O., & Knorr, D. (1973). Plasma estrogens in childhood and puberty under physiologic and pathologic conditions. *Pediatric Research*, *7*, 901–907. https://doi.org/10.1203/00006450-197311000-00006

Blakemore, S., Burnett, S., & Dahl, R. E. (2010). The role of puberty in the developing adolescent brain. *Human Brain Mapping*, *31*(6), 926–933. https://doi.org/10.1002/hbm.21052

Bongers, I. L., Koot, H. M., van der Ende, J., & Verhulst, F. C. (2003). The normative development of child and adolescent problem behavior. *Journal of Abnormal Psychology*, *112*(2), 179–192. https://doi.org/10.1037/0021-843X.112.2.179

Borghuis, J., Denissen, J. J. A., Oberski, D., Sijtsma, K., Meeus, W. H. J., Branje, S., Koot, H. M., & Bleidorn, W. (2017). Big Five personality stability, change, and codevelopment across adolescence and early adulthood. *Journal of Personality and Social Psychology*, *113*(4), 641–657. https://doi.org/10.1037/pspp0000138

Braams, B. R., Van Duijvenvoorde, A. C. K., Peper, J. S., & Crone, E. (2015). Longitudinal changes in adolescent risk-taking: A comprehensive study of neural responses to rewards, pubertal development, and risk-taking behavior. *The Journal of Neuroscience*, *35*(18), 7226–7238. https://doi.org/10.1523/JNEUROSCI.4764-14.2015

Briley, D. A., Harden, K. P., Bates, T. C., & Tucker-Drob, E. M. (2015). Nonparametric estimates of gene × environment interaction using local structural equation modeling. *Behavior Genetics*, *45*, 581–596. https://doi.org/10.1007/s10519-015-9732-8

Buchanan, C. M., Eccles, J. S., & Becker, J. B. (1992). Are adolescents the victims of raging hormones: Evidence for activational effects of hormones on moods and behavior at adolescence. *Psychological Bulletin*, *111*(1), 62–107. https://doi.org/10.1037/0033-2909.111.1.62

Canals, J., Vigil-Colet, A., Chico, E., & Martí-Henneberg, C. (2005). Personality changes during adolescence: The role of gender and pubertal development. *Personality and Individual Differences*, *39*(1), 179–188. https://doi.org/10.1016/j.paid.2004.12.012

Castellanos-Ryan, N., Parent, S., Vitaro, F., Tremblay, R. E., & Séguin, J. R. (2013). Pubertal development, personality, and substance use: A 10-year longitudinal study from childhood to adolescence. *Journal of Abnormal Psychology*, *122*(3), 782–796. https://doi.org/10.1037/a0033133

Church, A. T. (1994). Relating the Tellegen and five-factor models of personality structure. *Journal of Personality and Social Psychology*, *67*(5), 898–909. https://doi.org/10.1037/0022-3514.67.5.898

Cleveland, W. S., & Devlin, S. J. (1988). Locally-weighted regression: An approach to regression analysis by local fitting. *Journal of the American Statistical Association*, *83*(403), 596–610. https://doi.org/10.1080/01621459.1988.10478639

Costa, P. T., & McCrae, R. R. (2006). Age changes in personality and their origins: Comment on Roberts, Walton, and Viechtbauer. *Psychological Bulletin*, *132*(1), 26–28. https://doi.org/10.1037/0033-2909.132.1.26

Cyders, M. A., & Smith, G. T. (2008). Emotion-based dispositions to rash action: Positive and negative urgency. *Psychological Bulletin*, *134*(6), 807–828. https://doi.org/10.1037/a0013341

Dahl, R. E., Allen, N. E., Wilbrecht, L., & Ballonoff Suleiman, A. (2018). Importance of investing in adolescence from a developmental science perspective. *Nature*, *554*, 441–450. https://doi.org/10.1038/nature25770

Denissen, J. J. A., Van Aken, M. A. G., Penke, L., & Wood, D. (2013). Self-regulation underlies temperament and personality: An integrative developmental framework. *Child Development Perspectives*, *7*(4), 255–260. https://doi.org/10.1111/cdep.12050

Dorn, L. D. (2006). Measuring puberty. *Journal of Adolescent Health*, *39*(5), 625–626. https://doi.org/10.1016/j.jadohealth.2006.05.014

Gao, W., Kirschbaum, C., Grass, J., & Stalder, T. (2016). LC-MS based analysis of endogenous steroid hormones in human hair. *Journal of Steroid Biochemistry*, *162*, 92–99. https://doi.org/10.1016/j.jsbmb.2015.12.022

Gao, W., Stalder, T., Foley, P., Rauh, M., Deng, H., & Kirschbaum, C. (2013). Quantitative analysis of steroid hormones in human hair using a column-switching LC–APCI–MS/MS assay. *Journal of Chromatography B*, *928*, 1–8. https://doi.org/10.1016/j.jchromb.2013.03.008

Ge, X., & Natsuaki, M. N. (2009). In search of explanations for early pubertal timing effects on developmental psychopathology. *Current Directions in Psychological Science*, *18*(6), 327–331. https://doi.org/10.1111/j.1467-8721.2009.01661.x

Goldberg, L. R. (1990). An alternative "description of personality": The Big-Five factor structure. *Journal of Personality and Social Psychology*, *59*(6), 1216–1229. https://doi.org/10.1037/0022-3514.59.6.1216

Göllner, R., Roberts, B. W., Damian, R. I., Lüdtke, O., Jonkmann, K., & Trautwein, U. (2017). Whose storm and stress is it? Parent and child reports of personality development in the transition to early adolescence. *Journal of Personality*, *85*(3), 376–387. https://doi.org/10.1111/jopy.12246

Grotzinger, A. D., Briley, D. A., Engelhardt, L. E., Mann, F. D., Patterson, M. W., Tackett, J. L., Tucker-Drob, E. M., & Harden, K. P. (2018). Genetic and environmental influences on pubertal hormones in human hair across development. *Psychoneuroendocrinology*, *90*, 76–84. https://doi.org/10.1016/j.psyneuen.2018.02.005

Gunn, R. L., & Smith, G. T. (2010). Risk factors for elementary school drinking: Pubertal status, personality, and alcohol expectancies concurrently predict 5th grade alcohol consumption. *Psychology of Addictive Behaviors*, *24*(4), 617–627. https://doi.org/10.1037/a0020334

Harden, K. P. (2014). Genetic influences on adolescent sexual behavior: Why genes matter for environmentally oriented researchers. *Psychological Bulletin*, *140*(2), 434–465. https://doi.org/10.1037/a0033564

Harden, K. P., Mann, F. D., Grotzinger, A. D., Patterson, M. W., Steinberg, L., Tackett, J. L., & Tucker-Drob, E. M. (2018). Developmental differences in reward sensitivity and sensation seeking in adolescence: Testing sex-specific associations with gonadal hormones and pubertal development. *Journal of Personality and Social Psychology*, *115*(1), 161–178. https://doi.org/10.1037/pspp0000172

Harden, K. P., Tucker-Drob, E. M., & Tackett, J. L. (2013). The Texas twin project. *Twin Research and Human Genetics*, *16*(1), 385–390. https://doi.org/10.1017/thg.2012.97

Havelock, J. C., Auchus, R. J., & Rainey, W. E. (2004). The rise in adrenal androgen biosynthesis: Adrenarche. *Seminars in Reproductive Medicine*, *22*(4), 337–347. https://doi.org/10.1055/s-2004-861550

Hildebrandt, A., Lüdtke, O., Robitzsch, A., Sommer, C., & Wilhelm, O. (2016). Exploratory factor model parameters across continuous variables with local structural equation models. *Multivariate Behavioral Research*, *51*(2–3), 257–258. https://doi.org/10.1080/00273171.2016.1142856

Hiort, O. (2002). Androgens and puberty. *Best Practice & Research Clinical Endocrinology & Metabolism: Clinical and Experimental*, *16*(1), 31–41. https://doi.org/10.1053/beem.2002.0178

Hopwood, C. J., Donnellan, M. B., Blonigen, D. M., Krueger, R. F., McGue, M., Iacono, W. G., & Burt, S. A. (2011). Genetic and environmental influences on personality trait stability and growth during the transition to adulthood: A three wave longitudinal study. *Journal of Personality and Social Psychology*, *100*(3), 545–556. https://doi.org/10.1037/a0022409

Hutteman, R., Bleidorn, W., Keresteš, G., Brković, I., Butković, A., & Denissen, J. J. A. (2014). Reciprocal associations between parenting challenges and parents' personality development in young and middle adulthood. *European Journal of Personality*, *28*(2), 168–179. https://doi.org/10.1002/per.1932

John, O. P., Naumann, L. P., & Soto, C. J. (2008). Paradigm shift to the integrative Big-Five trait taxonomy: History, measurement, and conceptual issues. In O. P. John, R. W. Robins, & L. A. Pervin (Eds.), *Handbook of personality: Theory and research* (pp. 114–158). Guilford Press.

John, O. P., & Srivastava, S. (1999). The Big-Five trait taxonomy: History, measurement, and theoretical perspectives. In L. A. Pervin & O. P. John (Eds.), *Handbook of personality: Theory and research* (Vol. 2, pp. 102–138). Guilford Press.

Johnson, W., Krueger, R. F., Bouchard, T. J., Jr., & McGue, M. (2002). The personalities of twins: Just ordinary folks. *Twin Research and Human Genetics*, *5*(2), 125–131. https://doi.org/10.1375/twin.5.2.125

Joinson, C., Heron, J., Araya, R., Paus, T., Croudace, T., Rubin, C., Marcus, M., & Lewis, G. (2012). Association between pubertal development and depressive symptoms in girls from a U. K. cohort. *Psychological Medicine*, *42*(12), 2579–2589. https://doi.org/10.1017/S003329171200061X

Kawamoto, T., & Endo, T. (2019). Sources of variances in personality change during adolescence. *Personality and Individual Differences*, *141*, 182–187. https://doi.org/10.1016/j.paid.2019.01.018

Lewis, G., Ioannidis, K., Van Harmelen, A., Neufeld, S., Stochl, J., Lewis, G., Jones, P. B., & Goodyer, I. (2018). The association between pubertal status and depressive symptoms and diagnoses in adolescent females: A population-based cohort study. *PLoS ONE*, *13*(6), Article e0198804. https://doi.org/10.1371/journal.pone.0198804

Luan, Z., Hutteman, R., Denissen, J. J. A., Asendorpf, J. B., & Van Aken, M. A. G. (2017). Do you see my growth? Two longitudinal studies on personality development from childhood to young adulthood from multiple perspectives. *Journal of Research in Personality*, *67*, 44–60. https://doi.org/10.1016/j.jrp.2016.03.004

Luna, B. (2009). Developmental changes in cognitive control through adolescence. *Advances in Child Development and Behavior*, *37*, 233–278. https://doi.org/10.1016/S0065-2407(09)03706-9

Mann, F. D., Engelhardt, L., Briley, D. A., Grotzinger, A. D., Patterson, M. W., Tackett, J. L., Strathan, D. B., Heath, A., Lynskey, M., Slutske, W., Martin, N. G., Tucker-Drob, E. M., & Harden, K. P. (2017). Sensation seeking and impulsive traits as personality endophenotypes for antisocial behavior: Evidence from two independent samples. *Personality and Individual Differences*, *105*, 30–39. https://doi.org/10.1016/j.paid.2016.09.018

Marshall, W. A., & Tanner, J. M. (1969). Variations in pattern of pubertal changes in girls. *Archives of Disease in Childhood*, *44*, 291–303. https://doi.org/10.1136/adc.44.235.291

Moffitt, T. E. (1993). Adolescence-limited and life-course-persistent antisocial behavior: A developmental taxonomy. *Psychological Review*, *100*, 674–701. https://doi.org/10.1037/0033-295X.100.4.674

Muthén, L. K., & Muthén, B. O. (1998–2015). *Mplus user's guide* (7th ed.).

Olweus, D., Mattsson, A., Schalling, D., & Low, H. (1980). Testosterone, aggression, physical, and personality dimensions in normal adolescent males. *Psychosomatic Medicine*, *42*, 253–269. https://doi.org/10.1097/00006842-198003000-00003

Petersen, A. C., Crockett, L., Richards, M., & Boxer, A. (1988). A self-report measure of pubertal status: Reliability, validity, and initial norms. *Journal of Youth and Adolescence*, *17*, 117–133. https://doi.org/10.1007/BF01537962

Robbers, S. C. C., Bartels, M., Van Oort, F. V. A., Van Beijsterveldt, C. E. M., Van der Ende, J., Verhulst, F. C., Boomsma, D. I., & Huizink, A. C. (2010). A twin-singleton comparison of developmental trajectories of externalizing and internalizing problems in 6- to 12-year-old children. *Twin Research and Human Genetics*, *13*(1), 79–87. https://doi.org/10.1375/twin.13.1.79

Roberts, B. W., Walton, K. E., & Viechtbauer, W. (2006). Patterns of mean-level change in personality traits across the life course: A meta-analysis of longitudinal studies. *Psychological Bulletin*, *132*(1), 1–25. https://doi.org/10.1037/0033-2909.132.1.1

Roberts, B. W., Wood, D., & Smith, J. L. (2005). Evaluating Five Factor Theory and social investment perspectives on personality trait development. *Journal of Research in Personality*, *39*(1), 166–184. https://doi.org/10.1016/j.jrp.2004.08.002

Rowe, R., Maughan, B., Worthman, C. M., Costello, E. J., & Angold, A. (2004). Testosterone, antisocial behavior, and social dominance in boys: Pubertal development and biosocial interaction. *Biological Psychiatry*, *55*(5), 546–552. https://doi.org/10.1016/j.biopsych.2003.10.010

Schissel, A. M., Olson, E. A., Collins, P. F., & Luciana, M. (2011). Age-independent effects of pubertal status on behavioral constraint in healthy adolescents. *Personality and Individual Differences*, *51*(8), 975–980. https://doi.org/10.1016/j.paid.2011.08.001

Shiner, R., & Caspi, A. (2003). Personality differences in childhood and adolescence: Measurement, development, and consequences. *Journal of Child Psychology and Psychiatry*, *44*(1), 2–32. https://doi.org/10.1111/1469-7610.00101

Shirtcliff, E. A., Dahl, R. E., & Pollak, S. D. (2009). Pubertal development: Correspondence between hormonal and physical development. *Child Development*, *80*(2), 327–337. https://doi.org/10.1111/j.1467-8624.2009.01263.x

Soto, C. J., John, O. P., Gosling, S. D., & Potter, J. (2008). The developmental psychometrics of Big Five self-reports: Acquiescence, factor structure, coherence, and differentiation from ages 10 to 20. *Journal of Personality and Social Psychology*, *94*(4), 718–737. https://doi.org/10.1037/0022-3514.94.4.718

Soto, C. J., John, O. P., Gosling, S. D., & Potter, J. (2011). Age differences in personality traits from 10 to 65: Big Five domains and facets in a large cross-sectional sample. *Journal of Personality and Social Psychology*, *100*(2), 330–348. https://doi.org/10.1037/a0021717

Soto, C. J., & Tackett, J. L. (2015). Personality traits in childhood and adolescence: Structure, development and outcomes. *Current Directions in Psychological Science*, *24*(5), 358–362. https://doi.org/10.1177/0963721415589345

Tackett, J. L. (2006). Evaluating models of the personality-psychopathology relationship in children and adolescents. *Clinical Psychology Review*, *26*(5), 584–599. https://doi.org/10.1016/j.cpr.2006.04.003

Toffoletto, S., Lanzenberger, R., Gingnell, M., Sundström-Poromaa, I., & Comasco, E. (2014). Emotional and cognitive functional imaging of estrogen and progesterone effects in the female human brain: A systematic review. *Psychoneuroendocrinology*, *50*, 28–52. https://doi.org/10.1016/j.psyneuen.2014.07.025

Treloar, S. A., Heath, A. C., & Martin, N. G. (2002). Genetic and environmental influences on premenstrual symptoms in an Australian twin sample. *Psychological Medicine*, *32*(1), 25–38. https://doi.org/10.1017/S0033291701004901

Tremblay, R. E., Schaal, B., Boulerice, B., Arseneault, L., Soussignan, R. G., Paquette, D., & Laurent, D. (1998). Testosterone, physical aggression, dominance, and physical development in early adolescence. *International Journal of Behavioral Development*, *22*(4), 753–777. https://doi.org/10.1080/016502598384153

Ullsperger, J. M., & Nikolas, M. A. (2017). A meta-analytic review of the association between pubertal timing and psychopathology in adolescence: Are there sex differences in risk? *Psychological Bulletin*, *143*(9), 903–938. https://doi.org/10.1037/bul0000106

Van den Akker, A. L., Deković, M., Asscher, J., & Prinzie, P. (2014). Mean-level personality development across childhood and adolescence: A temporary defiance of the maturity principle and bidirectional associations with parenting. *Journal of Personality and Social Psychology*, *107*(4), 736–750. https://doi.org/10.1037/a0037248

Van den Akker, A. L., Deković, M., & Prinzie, P. (2010). Transitioning to adolescence: How changes in child personality and overreactive parenting predict adolescent adjustment problems. *Development and Psychopathology*, *22*(1), 151–163. https://doi.org/10.1017/S0954579409990320

Vijayakumar, N., Op de Macks, Z., Shirtcliff, E. A., & Pfeifer, J. H. (2018). Puberty and the human brain: Insights into adolescent development. *Neuroscience and Biobehavioral Reviews*, *92*, 417–436. https://doi.org/10.1016/j.neubiorev.2018.06.004

Whittle, S., Simmons, J. G., Byrne, M. L., Strikwerda-Brown, C., Kerestes, R., Seal, M. L., Olsson, C. A., Dudgeon, P., Mundy, L. K., Patton, G. C., & Allen, N. B. (2015). Associations between early adrenarche, affective brain function and mental health in children. *Social Cognitive and Affective Neuroscience*, *10*(9), 1282–1290. https://doi.org/10.1093/scan/nsv014

Widiger, T. A., & Oltmanns, J. R. (2017). Neuroticism is a fundamental domain of personality with enormous public health implications. *World Psychiatry*, *16*(2), 144–145. https://doi.org/10.1002/wps.20411

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