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Developmental trajectories of Big Five personality traits among adolescents and young adults: Differences by sex, alcohol use, and marijuana use

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Abstract

Individual differences in adolescent personality are related to a variety of long-term health outcomes. While previous studies have demonstrated sex differences and non-linear changes in personality development, these results remain equivocal. The current study utilized longitudinal data (n = 831) from the National Consortium on Alcohol and Neurodevelopment in Adolescence (NCANDA). Participants (ages 12–21 at baseline) completed the Ten-Item Personality Inventory and self-reported past year alcohol and marijuana use at up to 7 yearly visits. Generalized Additive Mixed-Effects Models (GAMMs) and Linear Mixed-Effects (LME) models examined sex differences in the development of personality and the association between substance use and personality. Findings support linear increases in agreeableness and conscientious and decreases in openness with age and inform on timing of sex-specific non-linear development of extraversion and emotional stability. Further, results provide novel information regarding the timing of the association between substance use and personality, and replicate past reporting of differential associations between alcohol and marijuana use and extraversion, and sex-dependent effects of marijuana use on emotional stability. These findings highlight the importance of modeling sex differences in personality development using flexible non-linear modeling strategies, and accounting for sex- and age-specific effects of alcohol and marijuana use.

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Conflict of interest
The authors declare no conflicts of interest financial or otherwise.

Introduction

The study of personality has a long and rich history, and has been studied in across the lifespan, from temperament in early infants (Thomas and Chess 1977) to coping ability at the end of life (e.g. Chochinov, Kristjanson et al. 2006). How personality during adolescence, a period of dramatic physical, emotional and psychosocial development (for review, see Steinberg and Morris 2001), relates to behaviors in later life, is of particular interest. While there are likely numerous moderating and mediating factors, individual differences in adolescent personality have been shown to be important predictors of adult life outcomes, including social competence, academic and professional achievement, and physical and mental health and longevity (for review, see Shiner and Caspi 2003). From a clinical perspective, understanding individual differences in personality development is important for informing mental health treatment efforts (Bucher, Suzuki et al. 2019) and preventing substance misuse in adolescents (Edalati and Conrod 2019), as personality may be modifiable by clinical intervention (Roberts, Luo et al. 2017).

Although debated (e.g. Matthews 2020), the five-factor model (Digman 1990) is one of the most widely accepted and utilized hierarchical structures for measuring personality, as it strikes a balance between specificity and generalizability that is more difficult to achieve using lower-order constructs (e.g., extraversion may consist of lower-order constructs such as warmth, gregariousness, assertiveness, activity, excitement seeking and positive emotions) (Shiner and Caspi 2003, McCrae 2009, Soto and Tackett 2015). The five-factor model (or Big Five) consists of *extraversion*, *emotional stability* (often referred to by its antonym, neuroticism), *conscientiousness*, *agreeableness*, and *openness*. While this factor structure has been well-described in adults, the stability of, or change in, these personality constructs during childhood and adolescence is still debated (Shiner and Caspi 2003).

There are currently two prevailing theories on personality development during adolescence. First, a meta-analysis of early longitudinal research found all Big Five personality factors increased substantially during adolescence and young adulthood (Roberts, Walton et al. 2006). This pattern, referred to as the “maturity principle,” suggests that an increase in these personality traits across adolescence and early adulthood reflects adaptations to newly evolving social roles (Caspi, Roberts et al. 2005). More recently, several large-scale studies show declines in at least one, and up to all Big Five personality factors early in adolescence, with subsequent increases in late adolescence and early adulthood (Soto, John et al. 2011, Denissen, van Aken et al. 2013, Van den Akker, Deković et al. 2014, Borghuis, Denissen et al. 2017). This pattern has been referred to as the “disruption hypothesis,” and suggests that adolescence is a key period for personality development (Soto and Tackett 2015). However, there are inconsistencies between these reports in regards to *which* of the Big Five personality factors support the disruption hypothesis. For example, Borghuis, Denissen et al. (2017) found emotional stability (in girls) and extraversion (in both male and female youth) declined in early adolescence (until approx. age 16), before increasing, while agreeableness increased throughout (ages 12–22). Conversely, Van den Akker, Deković et al. (2014) found continued declines in emotional stability (in girls) and extraversion into young adulthood (ages 9–20), but found agreeableness decreased (until approx. age 14), before increasing.

How personality development varies between male and female youth also remains unclear. While the degree and practical significance of sex differences in personality are still debated, they continue to be supported by large multi-national studies (Kaiser, Del Giudice et al. 2020). Given significant sex differences in the timing of neurobiological development (e.g., pubertal timing and neuromaturation) during adolescence, it could be expected that sex differences in personality may also emerge during this developmental period (Lenroot and Giedd 2010, Negriff and Susman 2011), and understanding these effects may provide insight into the emergence of psychiatric disorders in youth (Alloy, Hamilton et al. 2016). Past findings in adolescents and young adults largely suggest that female youth report greater extraversion, openness, agreeableness, and conscientiousness, and less emotional stability, compared to male youth (Soto, John et al. 2011, Vecchione, Alessandri et al. 2012, Van den Akker, Deković et al. 2014, Borghuis, Denissen et al. 2017, Göllner, Roberts et al. 2017). However, the timing of these sex-specific effects is less clear. For example, Soto, John et al. (2011) found the biggest differences in emotional stability between male and female youth emerged between the ages of 10 to 15, and then persisted well into adulthood; however, Göllner, Roberts et al. (2017) reported no sex-differences in emotional stability in early adolescence (ages 10–14). Similarly, while several studies support the notion that sex differences in extraversion emerge during adolescence and persist in young adulthood (Soto, John et al. 2011, Van den Akker, Deković et al. 2014, Göllner, Roberts et al. 2017), others found no sex differences in extraversion in mid-to-late adolescence (Vecchione, Alessandri et al. 2012, Borghuis, Denissen et al. 2017).

While these are not the only studies to investigate personality development, or sex differences therein, they highlight two major inconsistencies in past studies: 1) it is unclear which if any personality traits support the “disruption hypothesis”, and 2) there are discrepancies regarding the timing, or developmental course, of sex differences in personality. One important factor that could contribute to this effect is researchers’ choice of analytic modeling strategy. For example, two previous studies used polynomial growth parameters (e.g., linear and quadratic slopes across ages) and reported that extraversion either decreased linearly from 9 to 20 years of age (Van den Akker, Deković et al. 2014), or showed quadratic growth, with early decreases and subsequent increases from ages 12 to 22 (Borghuis, Denissen et al. 2017). However, another study found that changes in personality with age could not be adequately fit with traditional growth parameters (even with higher order polynomials); when reporting mean level changes, they found extraversion decreased between ages 10 to 15 before largely leveling off into young adulthood (Soto, John et al. 2011). In the current study, we seek to address past discrepancies in the sex-specific development of personality by using data-driven non-linear modeling strategies, and comparing them to more traditional growth models, to test our hypothesis that analytic strategy plays a role in the conclusions draw from developmental studies.

Another area of research the current dataset is well-suited to investigate is the association between personality and substance use. Alcohol and marijuana are the most commonly used substances by youth (Johnston, Miech et al. 2020) and are associated with a myriad of cognitive and neural alterations (Jones, Lueras et al. 2017, Morin, Afzali et al. 2019, Chye, Christensen et al. 2020). A recent review and meta-analytic work (primarily in young adults) suggests that alcohol use is associated with low conscientiousness, agreeableness, and emotional stability, and high extraversion (Malouff, Thorsteinsson et al. 2007, Adan, Forero et al. 2017), with longitudinal work confirming that increases in conscientiousness and emotional stability with age are associated with decreases in problematic alcohol use (Littlefield, Sher et al. 2010). Similarly, in adolescents, higher extraversion and lower conscientiousness, openness and agreeableness are associated with alcohol use (Ibáñez, Camacho et al. 2015, Gallego, Mezquita et al. 2018), and high adolescent extraversion, in particular, may be a common predictor of future alcohol use (George, Connor et al. 2010, Ayer, Rettew et al. 2011, Newton-Howes, Horwood et al. 2015, Yañez, Bennasar-Veny et al. 2020).

Marijuana use is also associated with lower emotional stability, agreeableness and conscientiousness in adolescents and young adults (Lee-Winn, Mendelson et al. 2018, Dash, Slutske et al. 2019, LaSpada, Delker et al. 2020). However, when combining alcohol with other illicit substance use (including marijuana), *greater* openness has been shown to be associated with heavy substance use in young adulthood (Chassin, Flora et al. 2004). Meanwhile, when simultaneously examined in a sample of young adults concurrently using alcohol and marijuana, marijuana use was associated with greater openness, but alcohol use with lower openness (Chambliss, Blust et al. 2016). Similarly, extraversion has been shown to be differentially related to substance use, with higher extraversion associated with more alcohol use but less marijuana use (Flory, Lynam et al. 2002). Taken together, these findings highlight the importance of simultaneous modeling of both alcohol and marijuana use in the same sample.

Work looking at sex differences in the association between substance use and personality in adolescents and young adults is limited. Cross-sectional studies have found that the association between reduced emotional stability and marijuana use was greater in female adolescents than male adolescents (Lee-Winn, Mendelson et al. 2018), and that the negative association between alcohol use and emotional stability and conscientiousness in young adults is more predominant in women (Kashdan, Vetter et al. 2005, Adan, Navarro et al. 2016). However, robust longitudinal studies that allow for the assessment of substance use alongside potential non-linear developmental changes in personality are needed.

Using seven waves of longitudinal data (ages 12–21 years at baseline) from the National Consortium on Alcohol and Neurodevelopment in Adolescence (NCANDA) dataset, the current study sought to examine personality changes across adolescence and young adulthood. In addition to replicating previous literature on personality development in a robust, longitudinal, multi-site national cohort, the study had the following five goals:

First, we aimed to use generalized additive mixed effect models (GAMMs) to empirically assess non-linear change in personality across age and compare these effects to more traditional linear mixed effects (LME) models with polynomial growth trajectories (i.e., linear, quadratic, and cubic). We hypothesized added model flexibility would yield findings that better coalesce past literature, and choice of modeling strategy would partially explain past discrepant reporting.

Second, we examined sex differences in personality development. In addition to replicating previous reports of greater extraversion, openness, agreeableness, and conscientiousness, and less emotional stability, in female youth (Soto, John et al. 2011, Vecchione, Alessandri et al. 2012, Van den Akker, Deković et al. 2014, Borghuis, Denissen et al. 2017, Göllner, Roberts et al. 2017), we expected our non-linear modeling strategy would again help provide clarity in regards to the *timing* of sex differences in personality development.

Third, we examined the association between substance use and personality. While previous studies generally suggest greater alcohol and marijuana use is associated with lower agreeableness, conscientiousness and emotional stability (Malouff, Thorsteinsson et al. 2007, Ibáñez, Camacho et al. 2015, Adan, Forero et al. 2017, Gallego, Mezquita et al. 2018, Lee-Winn, Mendelson et al. 2018, Dash, Slutske et al. 2019, LaSpada, Delker et al. 2020), associations with extraversion and openness may vary based on substance (Flory, Lynam et al. 2002, Chambliss, Blust et al. 2016). Therefore, we simultaneously modeled both alcohol and marijuana use, and hypothesized they would be differentially related to reported extraversion and openness.

Fourth, we examined the sex-specific association between substance use and personality. Based on limited past literature, we hypothesized that the association between substance use and lower emotional stability and conscientiousness would be more prominent in female youth (Kashdan, Vetter et al. 2005, Adan, Navarro et al. 2016, Lee-Winn, Mendelson et al. 2018).

Finally, while previous reports highlight the importance of comprehensively assessing personality (e.g. using multiscale or multimethod approaches) (Costa Jr, McCrae et al. 2019), this is not always feasible in large multi-site studies, such as NCANDA. Thus, here, we demonstrate the ability of an abbreviated measure, the Ten-Item Personality Inventory (TIPI) (Gosling, Rentfrow et al. 2003), to obtain robust results largely consistent with prior literature.

Methods

Participants

Data were analyzed from participants of the NCANDA study. Youth between 12 and 21 years of age (n = 831) were recruited at five sites across the United States: Duke University, Oregon Health & Science University (OHSU), University of Pittsburgh, SRI International, and University of California San Diego (UCSD). Adults provided informed consent, while adolescents and their parents provided informed assent and consent, respectively, and all study procedures were approved by the respective institutional review board for each site. As part of the broader study, at baseline and annual follow-up visits, participants completed a comprehensive battery including neuropsychological assessment (Sullivan, Brumback et al. 2016), self-reports of behavior, psychiatric symptoms and substance use, and a multimodal neuroimaging session (Pfefferbaum, Rohlfing et al. 2016, Pohl, Sullivan et al. 2016). Exclusionary criteria for study entry included current use of psychoactive medication, current or persistent major Axis I psychiatric disorders, significant learning or developmental disorders and serious major medical conditions (Brown, Brumback et al. 2015). While a majority of participants had limited drug and alcohol exposure at enrollment, a small proportion (n = 139) were recruited who exceeded age-specific alcohol and marijuana low-use thresholds (NIAAA 2011). Additional recruitment, demographic and procedural details have been published previous (Brown, Brumback et al. 2015). The NCANDA project employs an accelerated longitudinal design, and the current study used all available data across the first seven waves of data collection, from November 2012 to December 2020.

Measures

To measure the Big Five personality dimensions, participants were administered the Ten-Item Personality Inventory (TIPI), a brief measure shown to have convergence with longer Big Five measures as well as good test-retest reliability (Gosling, Rentfrow et al. 2003). The TIPI consists of 10 questions, with two questions for each subscale: extraversion, agreeableness, conscientiousness, emotional stability, and openness. Each question asked participants to rate on a scale of 1 (disagree strongly) to 7 (agree strongly) how much a pair of words (e.g., “extraverted, enthusiastic”) applied to them. The responses on the two questions for each subscale were averaged and served as the primary outcome measure for all analyses. Due to protocol changes during the fifth wave of data collection, the study moved from administering the TIPI during all annual visits, to only administering it if participants were completing their age 24 or 27 visit (final n’s for each wave are reported below).

Alcohol and marijuana use were measured using the Customary Drinking and Drug Use Record (CDDR) (Brown, Myers et al. 1998). At all visits, participants self-reported the number of days they drank and used marijuana during the past year. That is, participants were asked: “During the past year, (so out of 365 days), how many days did you drink alcohol?”, with an identical question asked regarding marijuana use. Due to non-normal distributions, past-year alcohol and marijuana use variables were log-transformed prior to all analyses.

Statistical analyses

Previous studies investigating the development of personality across adolescence often used linear growth models with polynomial effects (i.e., modeling age as a linear, quadratic, or cubic). However, when examining development across a broad age range, it is possible that data do not always conform to this restricted parametric growth model, and when examining group-level effects (such as sex-differences), different groups may not necessarily demonstrate similar developmental trajectories. Generalized Additive Mixed Models (GAMMs), an extension of generalized linear mixed models, do not assume the shape of developmental growth *a priori*, but instead allow for age-related non-linear smooth functions (modeled via cubic splines) that best represent the relationship between predictor variables (e.g., age) and outcomes (e.g., personality). Similar to traditional linear mixed-effects models (LMEs), GAMMs allow for appropriate modeling of the within-subject correlation of longitudinal data, as well as other important random effects (e.g., site and familial relatedness). Here, we modeled changes in personality development as a function of sex using both GAMMs and LMEs, and present findings side-by-side in order to assess the impact of modeling choice. All tested models can be found in Table S1. Analyses were conducted using R 4.1.1 (R Core Team 2020). Code necessary for reproducing all descriptive statistics and final analyses is available on the Open Science Framework (OSF) at https://osf.io/jqvm9/.

Generalized Additive Mixed-effects Models (GAMMs)—To assess the effects of age and sex on personality development, we fit GAMMs using the 'mgcv' package in R (Wood 2017) and carried out a series of model comparisons, similar to the approach taken in recent neurodevelopmental studies (e.g., van Duijvenvoorde, Westhoff et al. 2019). For each of the 5 TIPI scales, we fit three successive models that included age-related development across the whole sample (Model 1), a main effect of sex (Model 2), and differences in the age-related personality development by sex (Model 3). All models included a random intercept per participant, family, and data collection sites.

When interpreting sex effects on personality development, it is important to note when first fitting Model 3, sex was included as a 'factor', resulting in the estimation of a separate smoothed age trajectory in male and female participants. While this has the benefit of producing interpretable smoothed terms for each group, a traditional interaction term, such as that seen in linear modeling, is not produced. Therefore, to test the statistical significance of sex-specific developmental trajectories, standard hypothesis testing was used to compare the log-likelihood values from each model (Wood 2017). Then, to provide additional statistical support, Model 3 was refit with sex coded as an '*ordered* factor.' Here, a smoothed age trajectory is calculated for the 'reference' group only (i.e., female participants), and a smooth term representing the *difference* between the developmental trajectories of the reference group and the other group (i.e., male participants) was estimated. While this method provides less information regarding the shape of the age-related trajectory for each group, it produces an estimate and significance-testing for the *difference* between groups, akin to traditional linear interaction terms, and has also been used previously in developmental studies (e.g., Herting, Johnson et al. 2018).

Finally, to assess the association between substance use and personality, we modeled time-invariant (constant associations across age), linear time-varying (associations that increase or decrease across age), and quadratic time-varying (e.g., associations that may peak in adolescence) associations of past year alcohol and marijuana use. These three potential associations could occur for alcohol use, marijuana use, or both, resulting in a combination of nine different models (Models 4–12). Additionally, to capture potential sex-specific associations of alcohol use, marijuana use, our both, a total 27 additional models were necessary to exhaustively explore these relationships (Models 13–39). These predictors were added to the best fitting developmental model compared using standard hypothesis testing.

Linear Mixed-effects (LME) Models—To compare developmental GAMM results to models with more traditional polynomial growth parameters, we fit a series of LME models. Unlike GAMMs, which allow for the assessment of sex differences in non-linear personality development with only 3 models, the LME framework requires the iterative addition of consecutive higher-order polynomial age predictors to statistically assess the benefit of added model complexity. Here, we chose to assess the effect of 3 orders of polynomial effects (i.e., linear, quadratic, and cubic), along with their potential interaction with sex, using the 'nlme' package in R (Pinheiro, Bates et al. 2009). Starting with a linear age effect, we compared three successive models to assess the pattern of age-related development across the whole sample (Model 40), a main effect of sex (Model 41), and differences in the age-related effects by sex (Model 42). This process was then repeated for quadratic (Models 42–45), cubic (Models 46–48) polynomial age effects. For each interaction model, the effect of sex was assumed to interact with all lower-order polynomial age effects. Finally, the best fitting model for each polynomial age effect was then compared, to determine the final model. Identical to GAMMs, all models included a random intercept per participant, family, and data collection sites.

Results

The demographic breakdown of the NCANDA sample has been described previously (Brown, Brumback et al. 2015). Briefly, female (51%) and male (49%) participants identified as either white non-Hispanic (64%), African American/Black (12%), Hispanic/Latino (11%), Asian (8%), multi-racial (4%), Pacific Islander (<1%), or Native American/American Indian (<1%). At baseline, 20% reported parents with education below a college degree, 27% with at least one parent attaining a college degree, and 53% with at least one parent with education greater than a college degree; annual family income ranged from below $12,000 to greater than $200,000.

The TIPI was completed during at least one visit for 829 of the 831 subjects, with a total of 3,402 case observations across the 7 waves. However, 24 cases included incomplete reporting of substance use measures, and 4 cases included inconsistencies in reported substance use (e.g., more past month reported use than past year reported use). To provide direct statistical comparison of nested models, only subjects' timepoints with complete data (no missing substance use values) were included in the final analyses. Notably, all developmental findings remain unchanged when those timepoints with missing substance use values were included. In total 3,374 case observations across 829 subjects were included in final analyses; the breakdown by wave follows: Baseline (n = 813), Year 1 (n = 758), Year 2 (n = 701), Year 3 (n = 625), Year 4 (n = 367), Year 5 (n = 49), Year 6 (n = 61).

As expected alcohol and marijuana use both increased with age (Figure S1). Overall, 68% (n = 563) of the sample reporting drinking, and 48% (n = 396) of the sample reported using marijuana during at least one wave of data collection. Of those reporting substance use, over the course of the study to-date, past year alcohol use ranged from 1 to 365 days with an average of 28.5 (SD = 42.3) days per year, and past year marijuana use ranged from 1 to 365 days with an average of 49.1 (SD = 91.6) days per year.

Fit statistics and model comparisons for GAMMs examining age- and sex-related effects on personality development, and the association between personality and past year substance use (alcohol and marijuana) can be found in Table S2. Parameter estimates of the final best-fitting GAMMs (including substance use) can be found in Table 1. All significant findings reported herein are from the final best fitting models, including the effects of past year alcohol and marijuana use. For models with sex-by-age and/or substance use-by-age interactions, models were refit with their intercepts adjusted to (i.e. age centered to) ages 13, 16, 19, 22 and 25 in order to provide added interpretation to underlying main-effects of sex and substance use. In the absence of standard parametric age coefficients in GAMMs, we report the effective degrees of freedom (EDF), which sheds light on the degree of non-linearity for a given developmental trajectory (e.g., EDF = 1 represents a linear fit). Effect sizes for all parametric coefficients are reported as standardized regression coefficients for continuous predictors (i.e., age, alcohol use, and marijuana use) and Cohen's d for categorical predictors (i.e., sex).

Agreeableness

For all participants, both GAMM (EDF = 1.000) and LME ($b = 0.037$, $p < 0.001$, $\beta = 0.097$) models suggest agreeableness increased linearly with age and male participants reported lower agreeableness compared to female participants ($b = -0.359$, $p < 0.001$, $d = -0.315$) (Figure 1). Further, there was a time-invariant effect of marijuana use, with more marijuana use associated with less agreeableness ($b = -0.040$, $p < 0.05$, $\beta = -0.050$) across all ages.

Conscientiousness

For all participants, both GAMM (EDF = 1.000) and LME ($b = 0.031$, $p < 0.01$, $\beta = 0.086$) models suggest conscientiousness increased linearly with age, and male participants reported lower conscientiousness compared to female participants ($b = -0.341$, $p < 0.001$, $d = -0.282$) (Figure 1). Further, there was a linearly-time-varying effect of alcohol, with greater alcohol use associated with less conscientiousness in early (age 13, $b = -0.102$, $p < 0.01$, $\beta = -0.131$) through late (age 19, $b = -0.044$, $p < 0.05$, $\beta = -0.057$) adolescence, but not in young adulthood (age 22). Meanwhile, there was a quadratically-time-varying effect of marijuana use, with greater marijuana use associated with less conscientiousness in early adolescence (age 13, $b = -0.189$, $p < 0.01$, $\beta = -0.217$), but not mid adolescence (age 16) though young adulthood (age 22); however, this effect returned later in adulthood (age 25, $b = -0.154$, $p < 0.001$, $\beta = -0.180$).

Openness

For all participants, both GAMM (EDF = 1.000) and LME ($b = -0.044$, $p < 0.001$, $\beta = -0.119$) models suggest openness *decreased* linearly with age, and male participants reported lower openness, compared to female participants ($b = 0.136$, $p < 0.05$, $d = 0.120$) (Figure 1). Further, there was a significant time-invariant effect of alcohol use, with more alcohol use associated with more openness ($b = 0.036$, $p < 0.05$, $\beta = 0.050$), across the entire age range.

Extraversion

There were sex-specific effects in the non-linear development of reported extraversion, which was confirmed (EDF = 3.368, F = 4.98, $p < 0.01$) when estimating the differences in these trajectories using GAMMs. LME models also confirmed that sex-specific quadratic ($\chi^2_{(2)} = 20.24$, $p < 0.001$) and cubic ($\chi^2_{(4)} = 32.97$, $p < 0.001$) developmental trajectories both fit the data better than a linear effect, with the cubic model fitting the data better than a quadratic model ($\chi^2_{(2)} = 12.73$, $p = 0.002$). Here, both male and female participants showed declines in reported extraversion with age during early-adolescence; however, while extraversion continued to decline across the entire age range in male participants, it began to level off in female participants during mid- to late-adolescence (Figure 2). As a result, compared to male participants, female participants reported higher extraversion in early adolescence (age 13, $b = 0.315$, $p < 0.05$, $d = 0.199$), comparable extraversion in mid adolescence (age 16), and higher extraversion in late adolescence (age 19, $b = 0.223$, $p < 0.05$, $d = 0.141$) and early adulthood (age 22, $b = 0.607$, $p < 0.001$, $d = 0.384$).

There was also a time-invariant effect of alcohol use on reported extraversion, such that more alcohol use was associated with more extraversion ($b = 0.106$, $p < 0.001$, $\beta = 0.105$). However, here, there was a linearly-time-varying effect of marijuana use on extraversion. While there was no effect of marijuana use on extraversion in early (age 13) through late (age 19) adolescence, greater marijuana use was associated with less extraversion in young adulthood (age 25, $b = -0.081$, $p < 0.05$, $\beta = -0.073$).

Emotional Stability

There was also a sex-specific effect in the non-linear development of reported emotional stability, which was confirmed (EDF = 4.131, $F = 6.45$, $p < 0.001$) when we estimated the differences in these trajectories using GAMMs. This was again confirmed by LME models, which found sex-specific quadratic ($\chi^2_{(2)} = 20.64$, $p < 0.001$) and cubic ($\chi^2_{(4)} = 33.52$, $p < 0.001$) models fit better than a purely linear model, with a cubic model fitting the better than a quadratic model ($\chi^2_{(2)} = 12.88$, $p = 0.002$). The final GAMM suggested a linear increase (EDF = 1.00) in emotional stability with age for male participants. Meanwhile, female participants reported early declines in emotional stability followed by a slight subsequent increase (Figure 2). As such, both male and female participants reported similar levels of emotional stability in early-adolescence (age 13), but male participants reported higher emotional stability than female participants in mid adolescence (age 16, $b = 0.566$, $p < 0.001$, $d = 0.442$), through early adulthood (age 22, $b = 0.461$, $p < 0.001$, $d = 0.360$).

Finally, there was a sex-dependent, quadratically-time-varying effect of marijuana use on self-reported emotional stability. For female participants, more marijuana use was associated with less emotional stability in early adolescence (age 13, $b = -0.491$, $p < 0.001$, $\beta = -0.561$), though young adulthood (age 22, $b = -0.078$, $p < 0.05$, $\beta = -0.084$). For male participants, marijuana use is not associated with emotional stability in early adolescence (age 13) through late adolescence (age 19), but was associated with less emotional stability in young adulthood (age 22, $b = -0.094$, $p < 0.01$, $\beta = -0.099$).

Discussion

The current study sought to flexibly model developmental trajectories of personality in adolescence and young adulthood as a function of sex and explore the association between substance use (alcohol and marijuana) and personality across age. We report three general conclusions: 1) there were linear increases in agreeableness and conscientious and decreases in openness, across this age range, the slope of which did not differ developmentally by sex, and significant sex-specific non-linear developmental differences in extraversion and emotional stability; 2) male participants reported lower agreeableness, conscientiousness, and openness across the entire age range, less extraversion at all ages except during mid-adolescence (age 16), and more emotional stability in all but early adolescence (age 13); 3) alcohol use was associated with greater extraversion and openness across the entire age range, and less conscientiousness in adolescence (ages 13–19), while marijuana use was associated with less agreeableness throughout the entire age range, less conscientiousness in early adolescence (age 13) and young adulthood (age 25), less extraversion in young adulthood (age 25), and less emotional stability throughout the entire developmental age range in female youth, and in young adulthood (ages 22–25) in male youth.

Developmentally, our findings provide partial support for the maturity principle (Caspi, Roberts et al. 2005, Roberts, Walton et al. 2006), as we found both conscientiousness and agreeableness to increase linearly from ages 12 to 25. This is consistent with at least one report that found agreeableness and conscientiousness increased consistently across adolescence and young adulthood (ages 12–22), with non-linear effects occurring primarily in other traits (Borghuis, Denissen et al. 2017). Meanwhile, another study found the lowest levels of agreeableness and conscientiousness occurred around ages 12–13 (the earliest age assessed in the current study) (Soto, John et al. 2011). Our data provide strong replication of these results, in a large multi-site cohort, and suggest that any "disruptions" seen in agreeableness and conscientiousness may take place during childhood, prior to their continued maturation in adolescence and young adulthood.

Contrary to this effect, we note decreases in openness across the entire age range. While openness has been shown to decline in late childhood and early adolescence (ages 10–15) (Soto, John et al. 2011, Göllner, Roberts et al. 2017), there is no evidence, to our knowledge, of *self-reported* decreases in openness in late adolescence and young adulthood, though *parent-reported* adolescent personality findings suggest decreases in openness in this age range (e.g., Van den Akker, Deković et al. 2014). Interestingly, out of all five personality traits, when assessed in adolescence, openness has been shown to have the lowest internal consistency, and replicability across multiple samples and cultures (De Fruyt, De Bolle et al. 2009). Thus, it's possible that our 10-item question of personality could be less sensitive to true mean-level changes in openness in this population.

Our findings also provide partial support for the disruption hypothesis (Soto and Tackett 2015), as we found extraversion in both male and female youth, and emotional stability in female youth, decreased in early adolescence (until at least age 16). However, unlike previous reports (Borghuis, Denissen et al. 2017), we found extraversion never increased during late adolescence and young adulthood. Instead, male participants continued to show linear declines in extraversion, while female participants showed a leveling off of extraversion. This is where we believe our flexible analytic strategy helps clarify past results. For example, Borghuis, Denissen et al. (2017) tested only linear and quadratic growth parameters, and found U-shaped trajectories for extraversion. Similarly, when quadratic growth parameters were fit to our data (Figure 2), we replicated this previously observed effect in female participants; however, more flexible modeling (as well as a cubic growth trajectory) suggest, this quadratic growth does not best fit the data. Instead our results converge with past reports that show continued linear declines in extraversion in late adolescence in male youth (Van den Akker, Deković et al. 2014), and stable levels of extraversion in late adolescence for female youth (Soto, John et al. 2011, Vecchione, Alessandri et al. 2012). As described in a recent review, findings on mean-level change in extraversion continue to be inconsistent (Slobodskaya 2021); however, our findings seem to link together several previous reports, and suggest that flexible modeling (or higher-order growth parameters) are necessary to capture sex-specific effects in the development of reported extraversion.

For emotional stability, our findings continue to fit well with past literature. Like others (Soto, John et al. 2011, Vecchione, Alessandri et al. 2012, Borghuis, Denissen et al. 2017), we find steady increases in emotional stability in male participants across the entire developmental age range, while female participants demonstrate a dip in emotional stability during mid-adolescence, followed by a slight rise, before largely leveling off in late adolescence and early adulthood. Again, we note an important difference here between our GAMM findings and quadratically- and cubically-fit linear models. Our LME model results suggest that in male participants, emotional stability rises slightly during early- and mid-adolescence before declining in late-adolescence and early adulthood (Figure 2). While this effect in male youth has been demonstrated previously (Van den Akker, Deković et al. 2014), we found that after controlling for substance use, and using more flexible non-linear modeling strategies, a linear fit was better in male youth. Therefore, like with extraversion, our findings replicate several previous results, and suggest that disparate findings may be due to different modeling strategies.

In general, the sex differences noted in our sample are highly convergent with past literature. That is, female youth typically report greater extraversion, openness, agreeableness, and conscientiousness, and less emotional stability, and these effects for openness, agreeableness and conscientiousness are persistent throughout adolescence and young adulthood (Soto, John et al. 2011, Vecchione, Alessandri et al. 2012, Van den Akker, Deković et al. 2014, Borghuis, Denissen et al. 2017, Göllner, Roberts et al. 2017), while past findings regarding the developmental timing of sex differences in extraversion and emotional stability have been less clear. Our findings provide added support for the existing notion that the largest differences in emotional stability and extraversion between male and female youth emerge by mid-to-late adolescence and persist into young adulthood (Soto, John et al. 2011, Van den Akker, Deković et al. 2014, Göllner, Roberts et al. 2017). These findings, particularly in regards to emotional stability, may have relevance for sex differences in rates of internalizing mental health disorders, with women showing much higher rates of depression than men, beginning during adolescence (Hankin, Abramson et al. 1998).

Regarding the association between substance use and personality, our results fit with past literature. Like others (Malouff, Thorsteinsson et al. 2007, Adan, Forero et al. 2017), we see that alcohol use is associated with lower conscientiousness and higher extraversion, though our findings suggest the association between alcohol use and conscientiousness may be limited to adolescence, dissipating in young adulthood. Further, we replicate past reports of greater marijuana use being associated with less agreeableness, conscientiousness and emotional stability (Lee-Winn, Mendelson et al. 2018, Dash, Slutske et al. 2019, LaSpada, Delker et al. 2020); however, our results suggest these associations between marijuana use and conscientiousness are limited to early adolescence and later in young adulthood.

Importantly, we replicate previous reports of alcohol and marijuana use being differentially related to extraversion (with more extraversion associated with more alcohol use and less marijuana use), particularly in young adulthood (Flory, Lynam et al. 2002), highlighting the importance of examining their effects concurrently. Additionally, while past reports found the association between marijuana use and emotional stability was stronger in female youth than male youth (Adan, Navarro et al. 2016, Lee-Winn, Mendelson et al. 2018), we found that greater marijuana use was associated with lower emotional stability throughout adolescence and young adulthood for female youth, but only in young adulthood for male youth. Lastly, in contradiction to past literature, we found alcohol use was associated with *higher* openness. However, as noted in regards to the developmental increase in openness we found, it is possible that the 10-item measure of personality may not have reliably captured this trait. Thus, these results should be interpreted with caution.

In young adults, lower emotional stability has been associated with using marijuana as a coping mechanism, an effect mediated by anxiety sensitivity (Chowdhury, Kevorkian et al. 2016); however, young adults with lower conscientiousness are also more likely to experience negative consequences related to their marijuana use (Allen and Holder 2014). This suggests that adolescents and young adults with lower conscientiousness and emotional stability may be more prone to using marijuana as a method for managing stress and anxiety, but may also be more likely to experience negative consequences of their drug use, and that female youth may be more susceptible to these effects. Meanwhile, previous studies demonstrated that extraversion is associated with positive alcohol expectancies (Anderson, Schweinsburg et al. 2005) and that alcohol expectancies mediate the relationship between extraversion and alcohol use (particularly weekend alcohol use) (Ibáñez, Camacho et al. 2015), suggesting that those reporting higher extraversion may be more inclined to drink alcohol for its prosocial effects.

Finally, strengths and weaknesses regarding our modeling techniques should be noted. First, our GAMMs produced subtle but important differences compared to LME models in the development of extraversion in females and emotional stability in males. While our LME results, using lower-order polynomial effects, may align with *singular* past studies, our GAMM results help bring convergence to *several* past studies, some of which had more narrow age ranges. However, GAMMs do not provide parametric coefficients for growth parameters, even in the case of linear growth, making it difficult to assess of effect sizes for both change across age and age-dependent sex-specific effects. Here, simultaneously fitting traditional polynomial effects (using LME), where appropriate, may be of added benefit. Future studies should consider using GAMMs as an exploratory analytic first step in identifying subtle changes in personality over time, before following up with traditional linear models.

Several additional limitations should also be noted. First, while our goal was to evaluate the development of personality in association between past-year substance use, it is difficult to determine from our models whether substance use is *predictive* of changes in personality. In fact, it is most likely that personality and substance use have bidirectional effects over the course of development. With this question in mind, a different set of modeling techniques (e.g., structural equation modeling) would be necessary to test such effects. Given the broad range of timing of substance use initiation (with a subsample of participants drinking before study entry) and our desire to focus on the non-linear shape of personality development, such analyses fall beyond the scope of the current report, and may be better answered by more robust single cohort longitudinal studies (e.g., the Adolescent Brain Cognitive Development study). Further, our measure of substance use (past year alcohol and marijuana use days) is rather course, and does not capture the vast array of patterns and quantity (e.g. binge drinking) of use often occurring during this developmental period. However, as is the case in most studies to date, marijuana use has proven to be difficult to properly quantify (e.g., amount of THC in a single puff). As such, we have chosen to prioritize selection of use variables that could be equated across the two substances, so that our findings may be compared in a meaningful way. Future studies with more nuanced substance use measurement (particularly for marijuana use) are warranted. It is also the case that, for this study, we are using sex at birth as the variable of interest, in the absence of other potentially meaningful and related variables of individual difference, such as gender identity or other psychosocial or cultural factors that may influence personality. Therefore, interpretation of sex-specific findings is limited. Finally, as noted before, personality effects may be most generalizable when measured in a multimethod, multiscale, and even multinational capacity (Costa Jr, McCrae et al. 2019). While our findings replicate many previous results and highlight the ability of even brief measures of gaining insight into personality, their generalizability may be questioned. Future studies with similar methodological techniques, but different samples, or measures, could provide further confirmation of our results.

In conclusion, we used a large, multi-site longitudinal dataset to replicate and extend several past findings on personality development in adolescence. We confirm findings of steady linear increases in agreeableness and conscientiousness across adolescence and young adulthood, and provide additional clarity regarding discrepant reporting on the development of extraversion and emotional stability. We also replicate the preponderance of literature that finds female youth report higher agreeableness, openness, conscientiousness and extraversion and lower emotional stability, compared to male youth, and provide added clarity on the developmental timing of such effects. Finally, we provide novel information regarding the timing of the association between substance use and personality, and we replicate past reporting of differential associations between alcohol and marijuana use on extraversion and sex-dependent effects of marijuana use on emotional stability. Taken together, these findings highlight the importance of modeling sex differences in personality development, using flexible non-linear modeling strategies, and accounting for sex- and age-specific effects of alcohol and marijuana use.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Data Availability

The data in this manuscript are based on the following data release from the National Consortium on Alcohol and Neurodevelopment in Adolescence (NCANDA): Pohl KM, Sullivan EV, Podhajsky S, Baker FC, Brown SA, Clark DB, Colrain IM, DeBellis M, Goldston D, Nagel BJ, Nooner KB, Tapert SF, Pfefferbaum A: The 'NCANDA_PUBLIC_6Y_REDCAP_V03' Data Release of the National Consortium on Alcohol and NeuroDevelopment in Adolescence (NCANDA), Sage Bionetworks Synapse. https://dx.doi.org/10.7303/syn26522873

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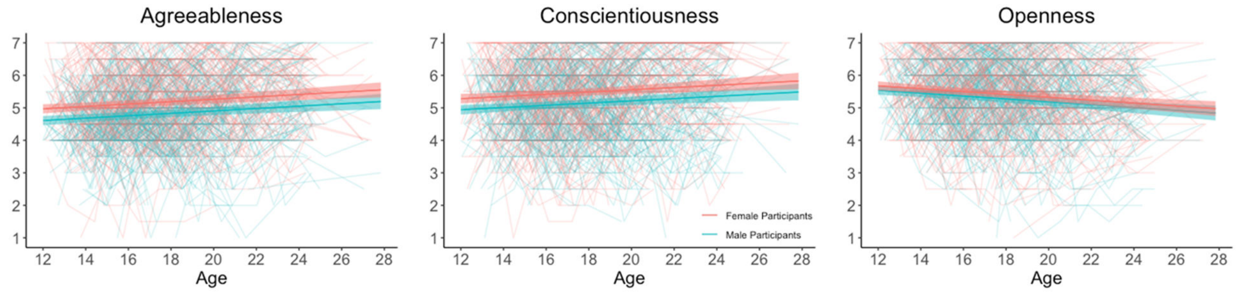

Figure 1. Linear age effects in self-reported agreeableness, conscientiousness and openness.
Smoothed age-related developmental trajectories and 95% confidence intervals for male (blue) and female (red) participants based off the final best-fitting generalized additive mixed-effects model. There was a significant linear increase in agreeableness and conscientiousness and decrease in openness with age in both male and female participants. Male participants had lower overall agreeableness, conscientiousness and openness compared to female participants.

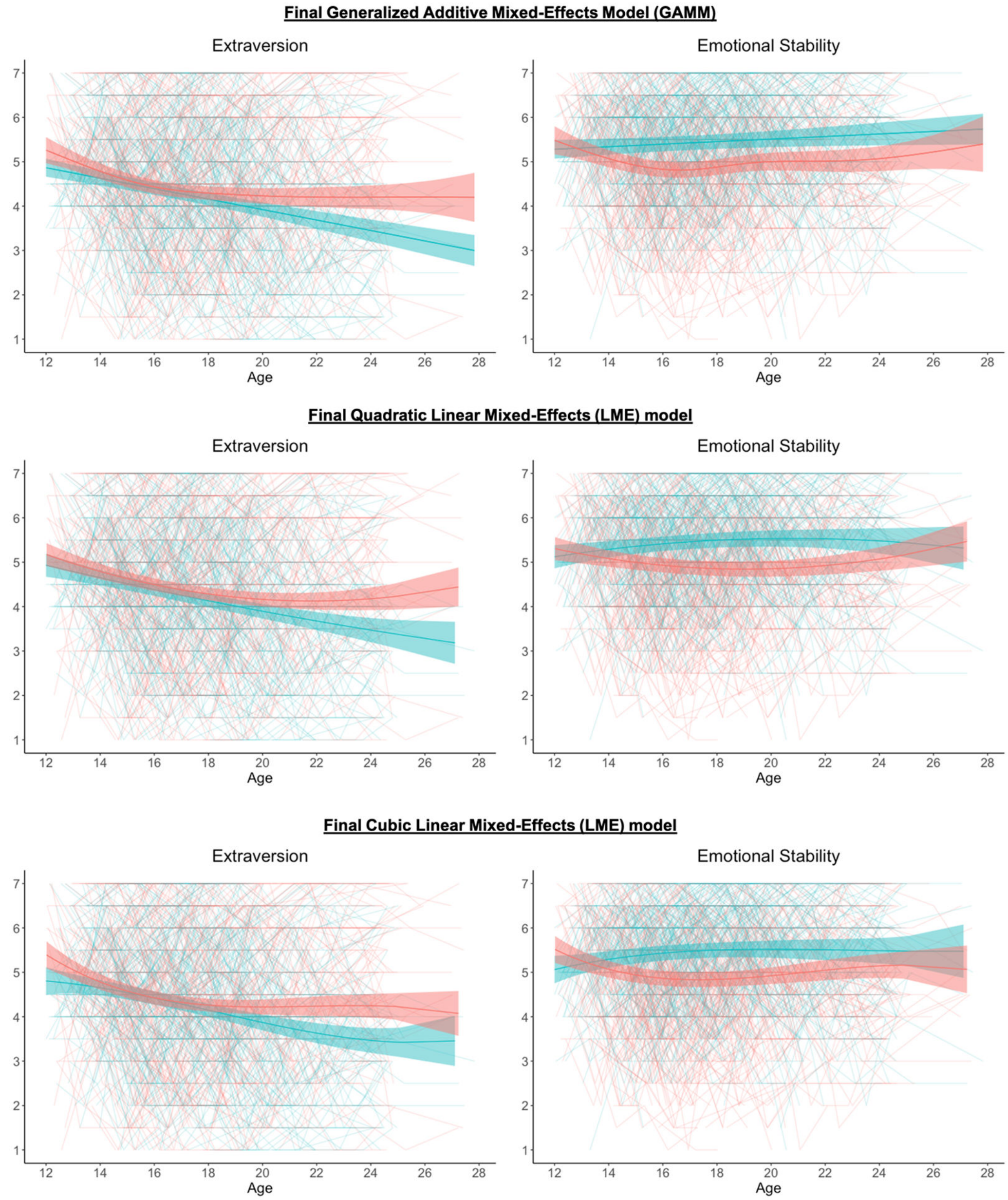

Figure 2. Non-linear age effects in self-reported extraversion and emotional stability.

Smoothed age-related developmental trajectories and 95% confidence intervals for male (blue) and female (red) participants based off the final best-fitting generalized additive mixed-effects model (top), and the final linear mixed-effects models with quadratic (middle) and cubic (bottom) age-trajectories.

Table 1.

Final best-fitting generalized additive mixed-effects models (GAMM).

Extraversion ~ s(age, by = sex) + alc + mj + mj : age (Model 6)								
	Parametric coefficients				Smooth terms			
	Estimate	Std Error	t-value	p-value		edf	F-stat	p-value
Intercept	4.3921	0.0704	62.36	<.0001	s(age):Female	3.76	11.96	<.0001
Sex(Male)	−0.2379	0.0933	−2.55	0.0108	s(age):Male	1.00	60.36	<.0001
Alcohol	0.1063	0.0213	4.98	<.0001				
Marijuana	0.2186	0.1141	1.92	0.0554				
Marijuana:Age	−0.0120	0.0058	−2.08	0.0375				
Agreeableness ~ s(age) + sex + alc + mj (Model 4)								
	Parametric coefficients				Smooth terms			
	Estimate	Std Error	t-value	p-value		edf	F-stat	p-value
Intercept	5.1906	0.0590	87.97	<.0001	s(age)	1.00	15.95	<.0001
Sex(Male)	−0.3588	0.0633	−5.67	<.0001				
Alcohol	0.0055	0.0176	0.31	0.7563				
Marijuana	−0.0405	0.0163	−2.48	0.0132				
Conscientiousness ~ s(age) + sex + alc + alc : age + mj + mj : age + mj : age^2 (Model 11)								
	Parametric coefficients				Smooth terms			
	Estimate	Std Error	t-value	p value		edf	F-stat	p-value
Intercept	5.4885	0.0570	96.33	<.0001	s(age)	1.00	10.60	0.0011
Sex(Male)	−0.3408	0.0693	−4.92	<.0001				
Alcohol	−0.2272	0.1010	−2.25	0.0245				
Alcohol:Age	0.0096	0.0049	1.97	0.0487				
Marijuana	−1.7438	0.5231	−3.33	0.0009				
Marijuana:Age	0.1803	0.0520	3.47	0.0005				
Marijuana:Age^2	−0.0047	0.0013	−3.64	0.0003				
Emotional Stability ~ s(age, by = sex) + sex + alc + mj + mj : sex + mj : age : sex + mj : age^2 : sex (Model 28)								
	Parametric coefficients				Smooth terms			
	Estimate	Std Error	t-value	p-value		edf	F-stat	p-value
Intercept	4.9598	0.0829	59.83	<.0001	s(age):Female	4.56	6.24	<.0001
Sex(Male)	0.4941	0.0753	6.56	<.0001	s(age):Male	1.00	4.04	0.0445
Alcohol	−0.0327	0.0201	−1.63	0.1040				
Marijuana(Female)	−3.2727	0.8994	−3.64	0.0003				
Marijuana(Male)	−1.9520	0.8228	−2.37	0.0177				
Marijuana:Age(Female)	0.3133	0.0880	3.56	0.0004				
Marijuana:Age(Male)	0.2184	0.0826	2.64	0.0083				
Marijuana:Age^2(Female)	−0.0076	0.0021	−3.59	0.0003				
Marijuana:Age^2(Male)	−0.0061	0.0021	−2.95	0.0032				
Openness ~ s(age) + sex + alc +mj (Model 4)								
	Parametric coefficients				Smooth terms			

	Estimate	Std Error	t-value	p-value		edf	F-stat	p-value
Intercept	5.4103	0.0577	93.79	<.0001	s(age)	1.00	24.20	<.0001
Sex(Male)	−0.1361	0.0651	−2.09	0.0367				
Alcohol	0.0360	0.0170	2.12	0.0339				
Marijuana	0.0187	0.0158	1.18	0.2374				