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The Development of Impulsivity and Sensation Seeking: Associations with Substance Use among At-Risk Adolescents

A. M. Wasserman, **C. W. Mathias**, **N. Hill-Kapturczak**, **T. E. Karns-Wright**, **D. M. Dougherty**

University of Texas Health Science Center at San Antonio

Abstract

We investigated if the dual systems model could explain the increased rates of substance use among at-risk youth. This study sampled 365 adolescents, 289 of which had a family history of substance use disorder, assessed biannually between the ages 13–16 years old. Growth curve analyses revealed that higher levels of impulsivity were related to higher levels of sensation seeking and a slower rate of decline in impulsivity was related to a faster rate of increase in sensation seeking. Only family history status and sensation seeking were directly associated with substance use (marijuana, alcohol) at age 16, though family history status was also indirectly related to substance use through higher levels of impulsivity to higher levels of sensation seeking.

Keywords

dual systems model; adolescent substance use; family history of substance use disorder; impulsivity; sensation seeking

Introduction

Children who have a parent with a substance use disorder are at increased risk for developing substance use problems themselves (Cotton, 1979; McCaul et al., 1990) compared to children without familial risk. The dual systems model of adolescent risk-taking (Casey, Getz, & Galvan, 2008; Steinberg et al., 2008) provides a theoretical framework for understanding why children with a family history of substance use disorder—or simply FH+ youth—are at increased risk. According to the dual systems model, normative impulsivity—including the inability to inhibit a prepotent response, plan ahead, maintain attention, etc.—gradually declines in a linear fashion through adolescence until early adulthood, whereas normative sensation seeking—defined as the propensity to seek out novel or rewarding stimuli and experiences—develops more rapidly, reaching its developmental peak earlier during mid-adolescence and declining thereafter. A consequence of the contrasting developmental timing between impulsivity and sensation seeking is that they are both at their peak during adolescence. In the present study, we propose that FH+ youth are more likely to engage in heavier substance use—and thus, are at greater risk for developing later substance use problems—because of aberrations in these developmental

Correspondence concerning this article should be addressed to A. Wasserman, 7526 Louis Pasteur Dr., San Antonio, TX 78229, wassermana@uthscsa.edu. .

neurobiological processes implicated in the dual systems model compared to youth without a family history of substance use disorder, or simply FH– youth.

The Dual Systems Model

The dual systems model posits that impulsivity and sensation seeking are distinct constructs that uniquely contribute to behavior. While other models theorize that sensation seeking is a component of impulsivity (e.g., UPPS), we conjecture in line with the dual systems model that they are distinguishable albeit related aspects of personality development, particularly given that factor analyses have shown the two to be weakly correlated (Whiteside & Lynam, 2001). Conceptually, behaviors that are the result of impulsiveness are by nature unplanned or reactive (e.g., excessive spending, aggressive behavior) whereas behaviors that are the result of sensation seeking are more likely to be planned (e.g., mountain climbing). Moreover, exploratory behavior due to heightened sensation seeking could be healthy and evolutionarily adaptive (Duell & Steinberg, 2019; Steinberg, 2008). In support of the adaptive role of sensation seeking, recent work has shown that optimal levels of sensation seeking during adolescence were related to positive outcomes in adulthood such as better well-being and higher achievement (Yoneda, Ames, & Leadbeater, 2019). Neurobiologically, there is also clear support for the distinction between impulsivity and sensation seeking given their associations with different brain regions (e.g., prefrontal regions for impulsivity [Horn, Dolan, Elliot, Deakin, & Woodruff, 2003] and the ventral striatum for sensation seeking [Silverman, Jedd, & Luciana, 2015]). Behaviorally, as well, prior work has also shown that impulsivity and sensation seeking are unique constructs that independently relate to risk behavior (Wasserman, Crockett, & Hoffman, 2017). Lastly, as described earlier, impulsivity and sensation seeking have divergent growth trajectories providing further support that they are unique traits as the dual systems model theorizes.

While impulsivity and sensation seeking have been shown to be independent constructs, the dual systems model also purports that the adolescent rise in sensation seeking is the impetus for the increased risk-taking behavior whereas the gradual decline in impulsivity into adulthood may serve to weaken the influence of sensation seeking. Indeed, several lines of research suggest that declines in impulsivity may operate to reduce sensation seeking and subsequent risk behavior. Shulman and colleagues (2015) first examined this possibility and found that higher levels of impulsivity were related to higher levels of sensation seeking concurrently during adolescence, supporting a stable but not a developmental relationship between the two. Furthermore, while Shulman (2015) found a stable relationship during adolescence, no such relationship existed at ages 24–25 around the time when the prefrontal cortex is thought to be fully developed (Giedd et al., 1999). Thus, the increased capacity for top-down regulation via prefrontal cortex maturation may in turn diminish the relationship between impulsivity and sensation seeking. Similarly, Kim-Spoon et al. (2016) found that reward-seeking behavior assessed with a behavioral task predicted real-world risk behavior for adolescents but not for adults. An implication of this finding is that adults are more capable of modulating their propensity for reward-seeking behavior due to the normative decline in impulsivity.

Neuroimaging research has also provided even more robust support that declines in impulsivity may operate to reduce sensation seeking and subsequent risk behavior. Recently, developmental neuroscientists have noted the importance of a normative shift from a positive functional coupling between prefrontal and limbic networks during adolescence to a negative coupling in adulthood (Fareri et al., 2015; van Duijvenoorde, Achterberg, Braams, Peters, & Crone, 2015). These recent findings suggest that the developmental shift represents an increased capacity of the prefrontal cortex to regulate the reward-sensitive subcortical regions. To further demonstrate this, Lee and Telzer (2016) found that a negative coupling between the two brain networks was associated with better self-control of impulsive behavior, which in turn was related to reduced substance use. In summary, while impulsivity and sensation seeking may represent two unique systems, they are developmentally related in that the linear declines in impulsivity serve to improve the capacity to regulate the earlier increase in sensation seeking.

The Dual Systems Model and Substance Use

An implication of the dual systems model is that the developmental trends in impulsivity and sensation seeking increase the propensity for risky behavior. Prior work has established that high levels of impulsivity (Pharo, Sim, Graham, Gross, & Hayne, 2011; Romer et al., 2009) and sensation seeking (Crawford, Pentz, Chou, Li, & Dwyer, 2003; Hittner & Swickert, 2006 Malmberg et al., 2010) both predict substance use. More recently, other work has more formally tested the dual systems model by demonstrating that both impulsivity and sensation seeking predict risk behavior in the real world (Kong et al., 2013; Lydon-Stanley & Geier, 2018; Nower, Derevensky & Gupta, 2004; Wasserman et al., 2017) and in a laboratory setting (Duell et al., 2016; Gullo et al., 2017). Furthermore, individual differences in stability and growth in impulsivity and sensation seeking may be risk factors for substance use as well. Logically, individual differences in both are likely to be problematic during adolescence because sensation seeking is at its developmental peak whereas impulsivity is slowly declining; thus, any deviation from their normative growth trajectory could increase the propensity for substance use. To our knowledge, only one study has examined this possibility illustrating that both stable-high levels of and a slower rate of decline in impulsivity and stable-high levels of sensation seeking during mid-adolescence predicted increasing substance use during young adulthood (Quinn & Harden, 2013). In summary, levels of impulsivity and sensation seeking as well as individual differences in stability and growth during adolescence have been shown to contribute to the etiology of substance use.

Family History Status and Impulsivity

FH+ youth are at increased risk for substance use disorders themselves, although traits responsible for this association remain a focus of empirical attention. Researchers hypothesize the existence of a “neurobehavioral disinhibition” phenotype (Tarter et al., 2003, 2004) that is a combination of genetic and environmental risk factors (Cogdon & Canli, 2005; Sher, Grekin, & Williams, 2005) resulting in a behavioral pattern of dysregulation and impulsiveness that increases the risk of future substance use problems. These risk factors are likely to affect impulsivity because, as Pechtel and Pizzagalli (2011) theorize, the prefrontal cortex is the most susceptible brain region to genetic and environmental influences due its protracted development. Genetic traits of parents with

substance use disorder (Hartman, Lessem, Hopfer, Crowley, & Stallings, 2006; Hopfer, Stallings, Hewitt, & Crowley, 2003) transmitted to their offspring and environmental conditions more likely to be experienced by FH+ youth (e.g., life stressors; Charles et al., 2015; Chassin, Curran, Hussong, & Colder, 1996; Hussong et al., 2008) may increase the expression of impulsive behavior and provide a potential link between familial risk and substance use problems (Tarter et al., 2003). Therefore, we postulate that FH+ youth are more likely to engage in heavier substance use because the "neurobehavioral disinhibition" phenotype is more common among this at-risk group, due to genetic and environmental causes foundational to the typology.

Indeed, research has largely shown that individuals with a family history of substance use disorder display pattern of impulsive behavior, assessed with both self-reports and behavioral tasks (Acheson, Richard, Mathias, & Dougherty, 2011; Sanchez-Rioge, Stephens, & Duka, 2016; Sauders et al., 2008). Developmentally, over the course of adolescence, FH+ youth have also been shown to have consistently higher levels of impulsivity compared to FH– youth (Acheson et al., 2016; Dougherty et al., 2015). Lastly, neuroimaging research has demonstrated aberrations within the prefrontal cortex among FH+ individuals (Acheson et al., 2014a; Acheson et al. 2014b; DeVito et al., 2013; Spadoni, Simmons, Yang, & Tapert, 2013), elucidating possible neurobiological underpinning for their propensity towards impulsive behavior. To summarize, research has supported the notion that the "neurobehavioral disinhibition" phenotype is a more common occurrence among FH+ youth. We aim to extend these finding by connecting the heightened impulsivity typical of FH+ youth to the dual systems model.

The Present Study: Family History Status and the Dual Systems Model

In the present study, we examined whether a family history of substance use disorder was related to variation in mean levels and growth trajectories of impulsivity and sensation seeking from ages 13–16 years old, and whether the variation in both were associated with marijuana and alcohol use. Other research has already examined the role of family history status on the development of impulsivity and sensation seeking (Acheson et al., 2016) and also shown that preadolescent levels of impulsivity and sensation seeking were related substance use (Charles, Mathias, Acheson, & Dougherty, 2016). The present study is unique from this prior work by identifying a possible longitudinal pathway by which FH+ youth are more likely to engage in substance use behaviors than FH– youth, through the lens of the dual systems model. Specifically, due to the increased frequency of the disinhibited phenotype, FH+ youth may be less able to regulate the adolescent peak in sensation seeking, providing a developmentally-relevant pathway through which FH+ youth are at risk for substance use problems. As such, we hypothesized that family history status would be directly related to higher levels of impulsivity and indirectly related to higher levels of sensation seeking. In turn, variation in both impulsivity and sensation seeking would be related to marijuana and alcohol use. In other words, FH+ youth are more likely to engage in substance use compared to FH– youth because of differences in mean levels of and change over time in impulsivity and sensation seeking.

Method

Participants

At study entry, a community sample of 386 children ages 10–12 years old, who had not initiated substance use, and their parent(s) were recruited to participate through radio, newspaper, and television advertisements. A total of 305 (79.02%) adolescents had a biological father diagnosed with substance use disorder (FH+) and 81 did not have any parents or grandparents diagnosed with substance use disorder (FH–). The majority were female (51.6%), identified as Hispanic (72.3%), and were White (88.9%). The sample is described in more detail elsewhere (see Ryan et al., 2016). The Institutional Review Board approved all study procedures, including the provision of informed consent/assent by participants. Participant data were further protected by a Certificate of Confidentiality from the Department of Health and Human Services. Exclusion criteria regardless of family history status included: the child being diagnosed with a substance use disorder or a psychiatric disorder (except disorders that are typically comorbid with the development of substance use disorder such as oppositional defiant disorder [ODD] or attention deficit hyperactivity disorder [ADHD]), having a positive urine drug screening or breathalyzer at study entry, positive pregnancy test at study entry, an IQ < 70, or any significant physical or developmental disability.

Participants eligible for the study completed a baseline assessment and follow-up assessments every six months that included self-reported questionnaires, interviews, and behavioral tasks. Measures pertinent to the current study are described in more detail below. A more comprehensive description of the measures for the main study are described elsewhere (Ryan et al., 2016). The baseline assessment took approximately six hours to complete whereas follow-up assessments took approximately four hours. Both the child and parent were compensated $120 at baseline and $120 and $75 at follow-up assessments, respectively. Additionally, participants were provided with lunch and breaks during visits.

To be included in the current analytic sample, participants had to have data for the exogenous predictor variable (i.e., family history status) and data for one outcome variables (i.e., impulsivity, sensation seeking, substance use) for at least one time-point (between the ages of 13 to 16 years old). The analytic sample included $n = 365$ from the original sample: 289 (79.2%) were classified as FH+ and 76 (20.8%) were FH–. The remainder of the original sample included $n = 21$. The reason for the 21 participants being excluded from the current analysis is because they did not complete any follow-up assessments the between ages of 13 to 16 years old. Analyses revealed no significant differences in the proportion of FH+ youth, impulsivity at baseline, or sensation seeking at baseline between the analytic and non-analytic samples.

Measures

Family History Status—At study entry, parents of the adolescent completed the Family History Assessment Module (Janca et al., 1992; Rice et al., 1995) which asks about family history of substance abuse and psychiatric problems. Participants were classified as FH+ if the adolescent's biological father had a current or past diagnosed substance use disorder or

FH– if the adolescent had no parents or grandparents with substance use disorder. This resulted in a dichotomous variable with 0 = “No family history of substance use disorder (FH–)” and 1 = “Family history of substance use disorder (FH+).”

Impulsivity (Ages 13–16)—The Barratt Impulsiveness Scale (BIS; Patton et al., 1995) is a 30-item adolescent-reported measure intended to measure the frequency of impulsive behavior (e.g., “I act on spur of the moment”). Possible responses ranged from 1 = *rarely/never* to 4 = *almost always/always*. For the analyses, summary scores were used at each time-point with higher scores reflecting higher levels of impulsivity. Prior work has shown that the BIS has acceptable reliability and validity (Stanford et al., 2009). Cronbach’s alpha coefficient for reliability ranged from .80 to .84.

Sensation Seeking (Ages 13–16)—The Sensation Seeking Scale for Children (SSS-C; Russo et al., 1993) is a 26-item adolescent-reported measure of sensation seeking. Reliability and validity for this measure have been previously established (Russo et al., 1993). Adolescents were presented with two opposing statements (e.g., “I don’t do anything I might get in trouble for” and “I like to do new and exciting things, even if I think I might get in trouble for doing them”) and are instructed to select the response they most agree with, resulting in a dichotomous response option. For the analyses, summed scores were used at each time-point with higher scores reflecting higher levels of sensation seeking. Kuder-Richardson (KR-20) reliability estimates ranged from .85 to .87.

Substance Use (Age 16)—Adolescents completed a drug history questionnaire (DHQ; Sobell, Kwan, & Sobell, 1995) that measures the frequency of substance use including marijuana and alcohol. Additionally, adolescents completed a timeline follow-back (TLFB) interview (Sobell & Sobell, 1992) in which they reported the amount of substance use in the past six months using a calendar. For the TLFB, adolescents were reminded of key dates (e.g., holidays) to aid recall whenever possible. For the present study, substance use at age 16 was the primary outcome. Importantly, prior research has demonstrated that age 16 is a critical stage for when substance use has significant implications for adolescent functioning and escalation of substance use (Ehrenreich et al., 1999; Filbey, McQueeny, DeWitt, & Mishra, 2015; Sagar et al., 2015). The frequency of marijuana use was coded using a combination of the DHQ and TLFB and resulted in the following distribution: 0 = “No use” (n = 174, 76.3%); 1 = “< 1 use a month” (n = 28, 12.3%); 2 = “≤ 1 use in a week” (n = 11, 4.8%); and 3 = “At least several uses per week” (n = 15, 6.6%). Similarly, alcohol use was created with a combination of the DHQ and TLFB. However, the frequency of alcohol use had limited variability: 0 = “No use” (n = 179, 79.6%); 1 = “< 1 use a month” (n = 41, 18.2%); 2 = “≤ 1 use in a week” (n = 5, 2.2%). Thus, a dichotomous outcome for alcohol use was created resulting in the following distribution: 0 = “No use” (n = 179, 79.6 %) and 1 = “< 1 use a month or more” (n = 46; 20.4%). The correlation between the marijuana and alcohol use outcomes was r = .59, p < .01. To ensure the results were not due to differences in how the outcomes were measured (i.e., frequency of use versus dichotomization) or the results were skewed by the group of heavy users, additional analyses were conducted with marijuana use dichotomized analogously to alcohol use.

Analytic Method

Descriptive Analyses—First, descriptive analyses were conducted. The observed means for impulsivity and sensation seeking were plotted separately for FH+ and FH– youth to demonstrate their respective trajectories. Moreover, a series of independent sample t-tests were conducted for both impulsivity and sensation seeking at each time-point to test for mean differences between the two groups. Bivariate correlations were also conducted and reported in the supplemental material.

Growth Curve Models—All growth curve models were estimated in Mplus 8.1 (Muthén & Muthén, 1998–2017) with full-information maximum likelihood (FIML) estimation to handle missing data. Marijuana use was treated as categorical due to its ordinal response distribution and alcohol as binary due to its dichotomous response distribution; therefore, a logit link function was used for both outcomes. For the time-varying outcomes of impulsivity and sensation seeking, the metric of time used for the analyses was age which ranged from 13–16 years old measured at six-month intervals for a total of seven time-points. Intercept factors were estimated by fixing each loading for the time-varying outcomes to 1. Instead of a traditional slope factor, a latent basis growth factor (Bollen & Curran, 2006) was estimated by fixing the loading at age 13 to 0, fixing the age 16 time-point to 1, and freely estimating the loadings for the intermediate time-points. The latent basis factor was used to account for both linear and non-linear (e.g., quadratic) change in a single factor. Thus, the intercept factors can be interpreted as individual differences conditional at age 13 and slope factors can be interpreted as individual differences in the rate of change from 13–16 years old. To ascertain the amount of variance explained for the time-varying outcomes of impulsivity and sensation seeking, pseudo-R^2 (Hoffman, 2015) were computed which signify the proportion of between-person variance explained by the predictors for each growth factor.

First, an unconditional growth curve model was estimated and then a series of conditional growth curve models were estimated to test the study hypotheses. Model fit was assessed with the confirmatory fit index (CFI) and root mean error of approximation (RMSEA) with cutoffs of CFA > .90 and RMSEA <.10 as indicators of acceptable fit (Barrett, 2007) and cutoffs of CFI > .95 and RMSEA <.05 as indicators of excellent fit (Hu & Bentler, 1999).

Unconditional Growth Model: Prior to testing the main hypotheses, an unconditional growth model was estimated for both the seven time-points for impulsivity and sensation seeking between the ages 13–16. In other words, a growth model was estimated for both impulsivity and sensation seeking simultaneously without any predictors to determine the developmental trajectories for both and to describe the average pattern of and variation in change over time.

Conditional Growth Model: Next, conditional growth models were estimated for each substance use outcome separately to address the study hypotheses for a total of two models. A comprehensive model tested the direct effect of FH status on substance use at age 16 and indirect relationships through impulsivity and sensation seeking. The results for marijuana use are discussed in more detail because there was more variability in marijuana use than

alcohol use. Lastly, in order to ensure the robustness of the results, all conditional growth models were rerun but excluded individuals who reported using alcohol or marijuana at age 13 (n = 12) to demonstrate that the effects were not influenced by recent substance use. If there are any differences in the significance of the results between the models that included the full and the reduced analytic sample, they are discussed in detail. Otherwise, it will be simply noted that there was no difference between the two models. Preliminary conditional growth models that tested the relationship between impulsivity or sensation seeking separately and substance use were also conducted, the results of which are reported in the supplemental material.

Indirect Effects: Indirect effects were tested with bias-corrected bootstrapped standard errors to account for the tendency of the distribution of standard errors for indirect effects to be non-normal (MacKinnon, Lockwood, & Williams, 2004). Results for the indirect effects are reported as 95% confidence intervals and are considered significant if the upper and lower bounds of the confidence interval do not contain zero (Preacher & Hayes, 2008).

Results

Descriptive Statistics

See Figure 1 for a plot of the observed means for both impulsivity and sensation seeking at each time-point separately for FH+ and FH– youth. Impulsivity tended to decline whereas sensation seeking tended to increase between ages 13 to 15.5 and decline from age 15.5 to 16, consistent with the dual systems model. A series of t-tests revealed that FH+ youth had higher levels of impulsivity compared to FH– youth; however, there was no group difference at any time-point for sensation seeking. Bivariate correlations are reported as a table in the supplemental material.

Unconditional Growth Model

The unconditional growth model for impulsivity and sensation seeking had excellent overall fit, $\chi^2(92) = 187.21$, $p < .01$; CFI = .97; RMSEA [90% CI] = .05 [.04, .06]. For impulsivity, there was a significant decrease over time that was mostly linear, although there was no significant change from age 13 to 13.5 years old. For sensation seeking, there was a significant increase over time that is best described as nonlinear, such that sensation seeking increased from age 13 to 15.5 years and then decreased from age 15.5 to 16 years. For both impulsivity and sensation seeking, there was significant variability in both the initial levels and rates of change. Based on the intraclass correlation estimated from a random intercept-only model, 60.71% and 52.13% of the impulsivity and sensation-seeking variance, respectively, was between-persons and the remainder within-person.

Conditional Growth Models

Comprehensive Model and Marijuana Use—A comprehensive model was estimated in which the direct effect of FH status on marijuana use and indirect effects through initial levels of and growth in impulsivity and sensation seeking were tested. Thus, there were three possible pathways through which FH status could indirectly relate to marijuana use: through

the impulsivity growth factors, through the sensation-seeking growth factors, and/or through the impulsivity growth factors to the sensation-seeking growth factors.

See Figure 2 and Table 1a for model results. The comprehensive model for marijuana use had excellent overall fit, $\chi^2(113) = 173.96$, $p < .01$; CFI = .96; RMSEA [90% CI] = .04 [.03, .05]. FH status was directly related to higher initial levels of impulsivity at age 13. FH status was not related to the rate of change in impulsivity, initial levels of sensation seeking, or the rate of change in sensation seeking. With regards to the time-varying outcomes, higher initial levels of impulsivity were related to higher initial levels of sensation seeking at age 13 and a slower rate of decrease in impulsivity was related to a faster rate of increase in sensation seeking (i.e., positive association). Thus, there was both a stable and developmental relationship between impulsivity and sensation seeking. With respect to the indirect effects, FH status was indirectly related to marijuana use through higher initial levels of impulsivity at age 13 to higher initial levels of sensation seeking at age 13, $\beta = 0.18$ [0.07, 0.41]. In support of the primary hypothesis, the higher levels of impulsivity among FH + youth compared to FH– youth were associated with elevated levels of sensation seeking, which in turn was related to more frequent marijuana use. There was no difference in the significance of the results between the model that included the full analytic sample and the model that excluded individuals who reported engaging in substance use at age 13. Similarly, there was no difference in the results if marijuana use was dichotomized.

Overall, after including both the impulsivity and sensation-seeking growth factors in the same model, only sensation seeking—both higher initial levels and a faster rate of increase—was directly related to more frequent marijuana use. Referring to the growth factors, initial levels of and rate of change in impulsivity were related to initial levels of and change in sensation seeking, respectively. Lastly, FH status also was related to more frequent marijuana use indirectly through higher initial levels of impulsivity to higher levels of sensation seeking.

Based on pseudo-R^2 computations, for the impulsivity growth factors (which were only modeled to be related to FH status), the comprehensive model explained 4.08% and 0% of the intercept and slope variance, respectively. For the sensation-seeking growth factors (which were modeled to be related to FH status and the impulsivity growth factors), the comprehensive model explained 13.96% and 8.89% of the intercept and slope variance, respectively.

Comprehensive Model and Alcohol Use—See Figure 2 and Table 1b for model results for the comprehensive model with alcohol use as the outcome. The comprehensive model for alcohol use had excellent overall fit, $\chi^2(113) = 169.98$, $p < .01$; CFI = .96; RMSEA [90% CI] = .04 [.03, .05]. Counter to the marijuana model, family history status and the sensation-seeking slope factor were not related to alcohol use. Rather, only higher initial levels of sensation seeking were related to an increased likelihood of alcohol use. FH status was indirectly related to alcohol use through higher initial levels of impulsivity to higher initial levels of sensation seeking, $\beta = 0.19$ [0.07, 0.43] similar to the marijuana model. There was no difference in the significance of the results between the model that

included the full analytic sample and the model that excluded individuals who reported engaging in substance use at age 13.

Discussion

The overall goal of the present study was to identify pathways through which children who have a parent with a substance use disorder (FH+) are more likely to use marijuana or alcohol compared to children without this risk factor (FH–). The main findings from the comprehensive model are as follows: 1) family history status was directly related to higher levels of impulsivity; 2) higher levels of impulsivity were related to higher levels of sensation seeking and a slower rate of decrease in impulsivity was related to a faster rate of increase in sensation seeking; 3) higher levels of and a faster rate of increase in sensation seeking were directly related to marijuana use whereas only higher levels of sensation seeking were related to alcohol use; 4) family history status was indirectly related to substance use through higher levels of impulsivity to higher levels of sensation seeking.

Overall, we consider the most important findings to be the ways in which the present study refines the dual systems model (i.e., indirect effect of family history status on substance use through impulsivity to sensation seeking). Another novel finding is the developmental relationship between impulsivity and sensation seeking because it challenges the notion of developmental independence between the two constructs. Lastly, we will discuss how our study extends the literature on adolescent substance use. Thus, the results will be discussed in the following order: refining the dual systems model, the nature of the developmental relationship between impulsivity and sensation seeking, and applying the dual systems model to adolescent substance use.

Refining the Dual Systems Model

The present study refines the dual systems model by extending the theory to an at-risk population and furthers our understanding of the role of family history status on substance use behaviors. Adolescence is a developmental stage associated with heightened sensation seeking but youth may not be able to manage this sudden change because of the more gradual declines in impulsivity, increasing the propensity for risk-taking behavior. Due to the increased frequency of the neurobehavioral disinhibition phenotype resulting in trait-like impulsiveness, we found that youth with a family history of substance use disorder were less able to regulate the adolescent increase in sensation seeking, which in turn were associated with heavier substance use. Thus, the dual systems model provides a useful framework for elucidating pathways through which children with a family history of substance use disorder are at increased risk for later substance use problems.

The Developmental Relationship between Impulsivity and Sensation Seeking

Although prior work (e.g., Shulman et al., 2015) has only found a stable relationship between impulsivity and sensation seeking, we found evidence for both a stable and developmental relationship between the two. Specifically, individuals who decreased in impulsivity at a slower rate than average tended to increase in sensation seeking at a faster rate than average. There are substantive reasons for the diverging results between the present

study and Shulman et al. (2015). Firstly, the present study oversampled high-risk adolescents whereas Shulman's study included a sample from a national study of typically developing adolescents. Perhaps the interdependence in growth between impulsivity and sensation seeking only exists for high-risk youth who may have atypical development. Secondly, Shulman's measure of impulsivity and sensation seeking both included only three items each. The use of few items to represent a construct raises the possibility of unreliable measurement (Cortina, 1993), which in turn may affect the substantive results. Indeed, their measures of impulsivity and sensation seeking both have reliability coefficients below recommended values, $\alpha = .51$ and $\alpha = .69$, respectively. The present study used well-established measures for both impulsivity and sensation seeking (i.e., BIS and SSS-C, respectively), both of which have undergone psychometric evaluation to ensure reliable measurement. Thirdly, the growth parameters for impulsivity and sensation seeking from Shulman's study ranged from 12–13 to 24–25 years old whereas the growth parameters from the present study ranged from 13–16 years old. Perhaps Shulman did not find a developmental relationship between impulsivity and sensation seeking because the growth parameters extended beyond adolescence into young adulthood. It is possible that the developmental interrelationship exists only during adolescence when both are undergoing substantial growth, similar to Shulman's finding that a mean-level relationship between impulsivity and sensation seeking was only significant during adolescence but not young adulthood. Overall, our findings of a developmental relationship between impulsivity and sensation seeking extends the dual systems model in a novel way by demonstrating that the two constructs are developmentally interdependent when it has been previously theorized their growth trajectories are unrelated.

Applying the Dual Systems Model to Adolescent Substance Use

Since its conception, the dual systems model has been a useful theoretical model for understanding adolescent substance use. Prior work with the dual systems model (Duell et al., 2016; Wasserman et al., 2017) has largely focused on the possibility that the relationship between sensation seeking and risk behavior is exacerbated by heightened impulsiveness (i.e., moderated relationship). We sought to connect Shulman's (2015) finding of a stable relationship between impulsivity and sensation seeking and Quinn and Harden's (2013) finding that stable levels of sensation seeking predicted substance use by testing the possibility of an indirect effect (i.e., statistical mediation). Indeed, we found that higher levels of impulsivity were related to heavier substance use indirectly through higher levels of sensation seeking. This finding also implies that impulsivity and sensation seeking are distinct but related constructs and share unique indirect and direct relationships, respectively, with substance use. In sum, while the dual systems model traditionally focused on a *synergistic* relationship between impulsivity and sensation seeking as they relate to substance use, our study refines the theory by providing support for a *mechanistic* relationship.

Although the dual systems model hypothesizes that impulsivity and sensation seeking are important constructs as they pertain to substance use, it remains unclear whether sensation seeking, impulsivity, or both, are the primary contributors to health risk behaviors during adolescence. Research has previously examined the effects of impulsivity and sensation

seeking and found that both predict substance use (Gullo et al., 2017; Lydon-Stanley & Geier, 2018; Pharo, et al., 2009; Romer et al., 2009). Longitudinal research has also shown that both initial levels of and rate of change in impulsivity and sensation seeking were related to substance use (Martinez-Loredo, Fernandex-Hermidao, Torre-Luque, & Fernandez-Artamendi, 2018; Pedersen, Molina, Belendiuk, & Donovan, 2012; Quinn et al., Crawford et al., 2003). Our results demonstrated that both stable-high levels of sensation seeking and a faster rate of increase in sensation seeking—after controlling for impulsivity —were uniquely related to more frequent marijuana use whereas only stable-high levels of sensation seeking were related to alcohol use. Conversely, after controlling for the sensation-seeking growth factors, neither initial levels of nor rate of change in impulsivity were directly related to substance use. Notably, however, we did find support that impulsivity has an indirect role on adolescent substance use through sensation seeking. Thus, our results suggest that the rise in sensation seeking during adolescence may play a more central role in adolescent substance use. These findings are also consistent with the dual systems model, which hypothesizes that substance use is primarily the result of an inability to regulate the escalation of sensation seeking during adolescence.

Our study also found diverging results for marijuana and alcohol use. Specifically, family history status and a faster rate of increase in sensation seeking were related to marijuana use in the comprehensive model but neither were related to alcohol use. Notably, the dissimilarity in findings was not due to differences in the classification of the outcomes (i.e., frequency of use for marijuana versus dichotomization of alcohol use) because the same pattern of results emerged when marijuana use was dichotomized analogously to alcohol use. Perhaps the difference is that marijuana use among the study cohort is more indicative of substance use problems than alcohol use. That is, even though the rate of use versus non-use did not vary substantially between marijuana and alcohol, there was a group of adolescents who were heavy marijuana users. Thus, family history status and growth in sensation seeking may not have been associated with alcohol use in the present study because it was intermittent and not reflective of problematic use whereas marijuana use might be more indicative of substance use problems, particularly among the subset of frequent users. The results from the present study mirror national trends that demonstrate reductions in problematic alcohol use such as binge drinking but increased rates in daily marijuana use among adolescents (Miech et al., 2020).

Implications

One implication of the present study is that the dual systems model may need to be refined to incorporate the development of at-risk youth, as mentioned earlier in the discussion. For example, the dual systems model postulates that impulsivity and sensation seeking are distinct constructs; however, the findings that growth in impulsivity was related to growth in sensation seeking challenges the notions that they are developmentally independent from each other. Perhaps, as mentioned earlier, a developmental relationship exists only among at-risk populations (e.g., youth with a family history of substance use disorder). Moreover, based on the results of the present study, the dual systems model provides a possible pathway through which youth with a family history of substance use disorder are more likely to engage in substance use behavior. Thus, the neurobiological processes posited by the dual

systems model may be altered among at–risk youth which has implications for substance use during adolescence and risk for more serious psychiatric problems in adulthood (e.g., substance use disorder).

The findings from the present study also have clinical implications for the prevention of substance during adolescence, especially among at-risk youth. We should note that the contrasting developmental trajectories between impulsivity and sensation seeking during adolescence is a normative process. Thus, it may be more important to change the context in which these neurobiological changes are occurring rather than attempting to directly reduce impulsivity or sensation seeking per se. One possibility is that a high-quality parent–adolescent relationship can function as an "external regulator" for their child's behavior. Indeed, neuroimaging research has shown that the capacity to regulate tendencies towards impulsive behavior can be improved by maternal presence (Telzer, Ichien, & Qu, 2015) or a high-quality relationship (Qu, Fuligni, Galvan, & Telzer, 2015). Extending these findings to the present study, perhaps interventions designed to improve the parent–adolescent relationship (for a review see Kuntsche & Kuntsche, 2016) can attenuate their child's impulsiveness and improve the ability to regulate the adolescent increase in sensation seeking, subsequently reducing substance use. In sum, the parent–adolescent relationship is an important context that can modulate the neurobiological changes that occur during adolescence and reduce risk-taking behavior, which may be especially crucial among at-risk youth.

Limitations

When discussing the findings, there are important limitations to consider. First, the base rates for both marijuana and alcohol use were low (23.7% and 20.4%, respectively). While there was enough variation to predict frequency of marijuana use, there was not enough variation to examine frequency of alcohol use. Additionally, the present study relied on self-reported measures of impulsivity, sensation seeking, and substance use obtained from the adolescent participant. Therefore, any relationship could potentially be inflated due to a shared-method effect. The substance use measures were also retrospective reports of behavior in the past six months; thus, they may be biased by recall despite efforts to reduce the possibility by reminding participants of key dates (e.g., holidays). Consequently, these reports may better reflect the pattern of substance use rather than actual substance use.

Lastly, the relationship between levels of impulsivity and sensation seeking was contemporaneous (i.e., conditional at age 13). Thus, we cannot ascertain a temporal relationship between the two constructs which impedes causal inference of the results. This demonstrates a limitation to parallel process growth curve modeling in that the intercept factors for the constructs are conditional at the same time-point. Although we acknowledge that we cannot establish a temporal relationship between the intercept factors for impulsivity and sensation seeking, we chose to address the study hypotheses with growth curve modeling because the technique properly disaggregates individual differences in stability and rate of change for time-varying constructs (Berry & Willoughby, 2017).

Conclusions

The novel findings from the current study contribute to the literature by applying the dual systems model to an at-risk population. Certain risk factors may modify the dual systems model such as family history status. Specifically, FH+ youth had higher levels of impulsivity, which in turn was related to higher levels of sensation seeking. Thus, FH+ youth may engage in heavier substance use because they are less capable of regulating the adolescent rise in sensation seeking. The present study also extends the literature by illustrating that the development between impulsivity and sensation seeking may be interdependent when they have been traditionally been conceptualized as independent constructs, given their unique developmental trajectories.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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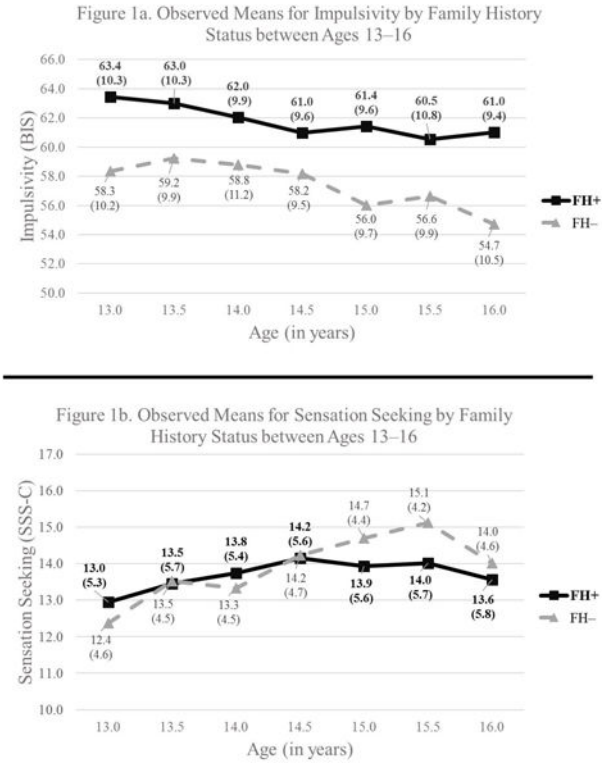

Figure 1.

Observed means and standard deviations in parentheses for impulsivity (Panel A) and sensation seeking (Panel B) between the ages of 13–16 years old. Solid, black lines and bolded numbers indicate the plot and means for family history positive youth (FH+). Gray, dashed lines and non-bolded numbers indicate the plot and means for family history negative youth (FH–).

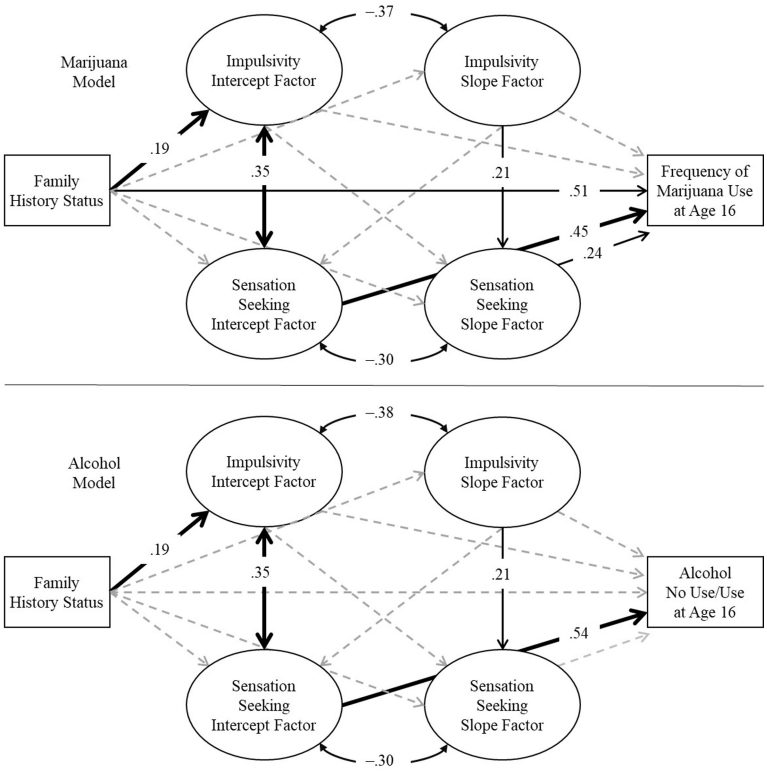

Figure 2.

Conditional growth model for impulsivity and sensation seeking assessed between the ages of 13–16 years old predicting substance use at age 16. Standardized estimates shown. Thinner, solid lines indicate significant relationships at $p < .05$, dashed lines indicate non-significant relationships. Straight, double-arrowed lines indicate a contemporaneous relationship and curved, double-arrowed lines indicate covariances. Heavier, thicker solid lines indicate a significant indirect effect. For family history status, 0 = negative, 1 = positive.

Table 1a.

Conditional Growth Model Results for Impulsivity and Sensation Seeking Predicting Marijuana Use

Effects for Intercept Factor	Impulsivity				Sensation Seeking			
	EST	SE	STD	*p*<	EST	SE	STD	*p*<
Intercept Factor								
Intercept Factor Mean	1.97	0.04	—	.01	1.63	1.96	—	.41
Intercept Factor Variance	0.09	0.01	0.97	.01	20.71	1.79	0.86	.01
Effects of Time-Invariant Predictors								
FH Status	0.14	0.04	0.19	.01	0.00	0.64	0.00	1.00
Relations Between Outcomes								
IMP Intercept	—	—	—	—	5.48	1.02	0.35	.01
IMP Slope	—	—	—	—	−0.90	1.59	−0.05	.57
Random Effect Covariances								
Within-Variable Covariance with Slope	−0.03	0.01	−0.37	.01	−5.40	1.48	−0.30	.01

Effects for Slope Factor	Impulsivity				Sensation Seeking			
	EST	SE	STD	*p*<	EST	SE	STD	*p*<
Slope Factor								
Slope Factor Mean	−0.13	0.03	—	.01	4.03	2.36	—	.09
Slope Factor Variance	0.07	0.01	1.00	.01	15.87	3.01	0.94	.01
Age 13.0 Loading	0.00	—	—	—	0.00	—	—	—
Age 13.5 Loading	0.06	0.06	0.05	.34	0.19	0.07	0.15	.01
Age 14.0 Loading	0.31	0.07	0.24	.01	0.35	0.09	0.28	.01
Age 14.5 Loading	0.52	0.06	0.40	.01	0.53	0.11	0.42	.01
Age 15.0 Loading	0.63	0.05	0.49	.01	0.67	0.13	0.52	.01
Age 15.5 Loading	0.93	0.07	0.67	.01	1.00	0.06	0.72	.01
Age 16.0 Loading	1.00	—	—	—	1.00	—	—	—
Effects of Time-Invariant Predictors								
FH Status	0.05	0.04	0.07	.26	−1.12	0.69	−0.11	.11
Relations Between Outcomes								

Effects for Slope Factor	Impulsivity				Sensation Seeking			
	EST	**SE**	**STD**	***p*<**	**EST**	**SE**	**STD**	***p*<**
IMP Intercept	—	—	—	—	−0.69	1.15	−0.05	.55
IMP Slope	—	—	—	—	3.27	1.46	0.21	.03
Effects for Marijuana Use at Age 16	EST	SE	STD	*p*<				
FH Status	3.19	1.04	0.51	.01				
IMP Intercept	0.69	0.77	0.08	.37				
IMP Slope	0.57	0.87	0.06	.51				
SS Intercept	0.23	0.05	0.45	.01				
SS Slope	0.15	0.06	0.24	.02				

Note: EST = unstandardized estimate; SE = standard error; STD = standardized estimate; FH = family history (0 = negative, 1 = positive); IMP = impulsivity; SS = sensation seeking.

Table 1b.

Conditional Growth Model Results for Impulsivity and Sensation Seeking Predicting Alcohol Use

Effects for Intercept Factor	Impulsivity				Sensation Seeking			
	EST	SE	STD	*p*<	EST	SE	STD	*p*<
Intercept Factor								
Intercept Factor Mean	1.97	0.04	—	.01	1.64	1.96	—	.40
Intercept Factor Variance	0.09	0.01	0.97	.01	20.71	1.79	0.86	.01
Effects of Time-Invariant Predictors								
FH Status	0.14	0.04	0.19	.01	−0.01	0.64	−0.01	.99
Relations Between Outcomes								
IMP Intercept	—	—	—	—	5.48	1.02	0.35	.00
IMP Slope	—	—	—	—	−0.90	1.59	−0.05	.57
Random Effect Covariances								
Within-Variable Covariance with Slope	−0.03	0.01	−0.38	.01	−5.38	1.48	−0.30	.01

Effects for Slope Factor	Impulsivity				Sensation Seeking			
	EST	SE	STD	*p*<	EST	SE	STD	*p*<
Slope Factor								
Slope Factor Mean	−0.13	0.03	—	.01	4.04	2.36	—	.09
Slope Factor Variance	0.07	0.01	1.00	.01	15.87	3.01	0.94	
Age 13.0 Loading	0.00	—	—	—	0.00	—	—	—
Age 13.5 Loading	0.06	0.06	0.05	.31	0.19	0.07	0.15	.01
Age 14.0 Loading	0.32	0.07	0.24	.01	0.35	0.09	0.28	.01
Age 14.5 Loading	0.52	0.06	0.40	.01	0.53	0.11	0.42	.01
Age 15.0 Loading	0.64	0.05	0.49	.01	0.67	0.13	0.52	.01
Age 15.5 Loading	0.93	0.07	0.67	.01	1.00	0.06	0.72	.01
Age 16.0 Loading	1.00	—	—	—	1.00	—	—	—
Effects of Time-Invariant Predictors								
FH Status	0.05	0.04	0.07	.26	−1.11	0.69	−0.11	.11
Relations Between Outcomes								

Effects for Slope Factor	Impulsivity				Sensation Seeking			
	EST	SE	STD	*p*<	EST	SE	STD	*p*<
IMP Intercept	—	—	—	—	−0.70	1.15	−0.05	.55
IMP Slope	—	—	—	—	3.29	1.45	0.21	.02
Effects for Alcohol Use at Age 16	EST	SE	STD	*p*<				
FH Status	1.02	0.56	0.19	.07				
IMP Intercept	0.18	0.76	0.03	.82				
IMP Slope	1.41	0.96	0.16	.14				
SS Intercept	0.24	0.05	0.54	.01				
SS Slope	0.12	0.07	0.23	.08				

Note: EST = unstandardized estimate; SE = standard error; STD = standardized estimate; FH = family history (0 = negative, 1 = positive); IMP = impulsivity; SS = sensation seeking.