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Age-Varying Associations Between Cigarette Smoking, Sensation Seeking, and Impulse Control Through Adolescence and Young Adulthood

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Sensation seeking (SS) and impulse control (IC) are constructs at the core of dual systems models of adolescent risk taking. Using data from the National Longitudinal Study of Adolescent to Adult Health, age-varying associations between SS and IC (predictors) and both any smoking in the previous 30 days and daily smoking (outcomes) were examined. The association between SS and both any smoking in the previous 30 days and daily smoking was strongest during adolescence. IC was consistently associated with any smoking in the previous 30 days and daily smoking, with the strongest association emerging during the mid-20s to early 30s. The results provide a nuanced perspective on when the components of dual systems models may be most related to smoking.

Adolescence is widely recognized as a time of increased engagement in risky behaviors—behaviors high in subjective desirability but that expose the individual to potential loss (Geier & Luna, 2009)—compared to other developmental groups (Arnett, 1992; Spear, 2000). In terms of cigarette smoking, smoking initiation is most likely to occur during adolescence relative to other developmental periods (Chen & Kandel, 1995; Lantz, 2003). Indeed, the majority of adults who smoke daily start smoking by the age of 18 (U.S. Department of Health and Human Services, 2012). Despite recent declines, 18% of 8th graders and 40% of 12th graders report having tried cigarettes at some time, and 6.1% and 18.7% of 8th graders and 12th graders, respectively, report being daily smokers (Johnston, O'Malley, Bachman, & Schulenberg, 2012).

Notably, an increase in risk taking during adolescence appears to be conserved across species, with adolescent rodents (spanning postnatal days 28–42; Spear, 2000) showing high levels of risk taking relative to rodents at other ages (Laviola, Macrì, Morley-Fletcher, & Adriani, 2003). Cross-species observations of risky behavior suggest that biological factors strongly contribute to adolescent risk taking. Consistent with these cross-species observations, brain-based models of adolescent risk taking highlight an adolescent-specific organization of brain circuitries as an evolutionary feature in attempts to provide insight into increases in risk taking during adolescence (Casey, Jones, & Hare, 2008b; Steinberg et al., 2008). These models emphasize an adolescent-specific configuration of frontostriatal circuitry in explaining adolescent-associated vulnerabilities to risky behaviors (e.g., Luciana & Collins, 2012; Somerville & Casey, 2010), including substance use and cigarette smoking specifically (Geier, 2013; Lydon, Wilson, Child, & Geier, 2014). Adolescents are perceived as being particularly vulnerable to smoking behaviors due to an adolescent-specific increase in activity in limbic and paralimbic brain areas involved in incentive processing (Ernst et al., 2005; Galvan et al., 2006; Van Leijenhorst et al., 2010) alongside continued immaturities in the functioning of prefrontal regions involved in cognitive control (K. Hwang,

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Velanova, & Luna, 2010; Ordaz, Foran, Velanova, & Luna, 2013). This unique configuration results in an imbalance of limbic relative to prefrontal control that renders adolescents more sensitive to rewarding stimuli (Geier, Terwilliger, Teslovich, Velanova, & Luna, 2010; Urošević, Collins, Muetzel, Lim, & Luciana, 2012) and less likely to inhibit impulses to approach rewards (Somerville, Hare, & Casey, 2011).

Between-Person Differences in Adolescent Risk Taking

Notably, while adolescence is a time of normatively increased risk taking, there is tremendous heterogeneity in engagement in risky behaviors during adolescence. In terms of smoking, cigarette use during adolescence is by no means the norm (Hooshmand, Willoughby, & Good, 2012; Johnston, O'Malley, Bachman, & Schulenberg, 2009), suggesting that a subset of adolescents may be most vulnerable to engaging in cigarette smoking during this developmental period of normatively heighted risk. Brain-based perspectives suggest a role for individual differences in the normative imbalance between limbic and prefrontal control over behavior that render some adolescents more vulnerable relative to others in engaging in risky behaviors (e.g., Casey, Getz, & Galvan, 2008a). Indeed, based on findings that age accounts for a modest proportion of the variance in processes highlighted by brain-based models (e.g., reward sensitivity; Bjork, Smith, Chen, & Hommer, 2010) due to vast individual differences within age groups (Somerville, Jones, & Casey, 2010), an extreme version of this perspective has emerged, whereby normative developmental changes in brain structure and function are unlikely to fully account for the changes in risky behaviors during adolescence (Bjork & Pardini, 2015). From this perspective, it is suggested that the majority of adolescents exhibit a modest imbalance between incentive-motivational and cognitive control functioning and that it is a subset of individuals who exhibit an imbalance between these two systems that is sufficiently extreme to meaningfully affect engagement in risky behaviors.

Perspectives highlighting the importance of individual differences in the configuration of frontostriatal circuitry during adolescence have been informed by research on between-person differences in sensation seeking and impulse control. The focus on sensation seeking and impulse control reflects the view that they are psychological manifestations of the socioemotional system and cognitive control systems, respectively, highlighted in dual process models of adolescent risk taking (Shulman et al., 2016). Sensation seeking is the tendency to seek varied, novel, and intense sensations and experiences (Zuckerman, 1994) and is associated with the functioning of the midbrain dopamine system (Norbury & Husain, 2015; Roberti, 2004). Impulse control reflects the ability to regulate behavior in order to achieve long-term goals and is associated with the functioning of the prefrontal cortex and the integrity of frontostriatal connections (Kim & Lee, 2011; Liston et al., 2006; Luna, Padmanabhan, & O'Hearn, 2010).

In line with the hypothesized role for between-person differences in both sensation seeking and impulse control in risky behaviors during adolescence, there are substantial between-person differences in both the expression of and the magnitude of change over years in both sensation seeking and impulse control during adolescence (Harden & Tucker-Drob, 2011). Furthermore, both sensation seeking and impulse control have emerged as consistent predictors of cigarette smoking, with high sensation seeking and low impulse control associated with greater likelihood of engaging in cigarette smoking (H. Hwang & Park, 2015; Malmberg et al., 2010; Martin et al., 2002; Mitchell, 1999; Reynolds et al., 2007; Zuckerman, Ball, & Black, 1990).

While research to date has highlighted the importance of between-person differences in sensation seeking and impulse control for smoking behaviors, the uniqueness of the associations between sensation seeking and impulse control to the adolescent period is unclear. Given that brain-based models of adolescent risk taking have highlighted sensation seeking and impulse control as particularly important for understanding risky behaviors during adolescence, it is surprising that little work has examined the age-varying associations between sensation seeking, impulse control, and cigarette smoking.

Associations Between Sensation Seeking and Cigarette Smoking Across Age

Age-varying associations between sensation seeking and cigarette smoking would be expected for a number of reasons. Normative increases in sensation seeking emerge during adolescence (Harden & Tucker-Drob, 2011; Romer, Duckworth, Sznitman, & Park, 2010; Steinberg et al., 2008) due to increased activation in dopamine-rich brain regions involved in incentive processing (Galvan et al., 2006; Van Leijenhorst et al., 2010). From this perspective, individuals high in sensation seeking during adolescence may be *particularly* high in sensation seeking relative to individuals at other ages given the normatively heightened sensation seeking occurring during this period. Thus, they may be more susceptible to pursuing cigarette smoking, a high sensation activity that provides many potential sensory rewards (e.g., Naqvi & Bechara, 2005).

Furthermore, in considering age-varying associations between factors at the core of brain-based models of adolescent risk taking, it has become increasingly recognized that adolescent risk taking must be understood in relation to the broader biopsychosocial context of risk taking (Defoe, Dubas, Figner, & van Aken, 2015; Willoughby, Good, Adachi, Hamza, & Tavernier, 2013). From this perspective, the experience of heightened sensation seeking occurs in the context of not quite adult-like regulatory capacities due to normative immaturities in cognitive control (Luna, 2009; Paulsen, Hallquist, Geier, & Luna, 2015; see Figure 1), decreases in parental monitoring (Dishion, Nelson, & Kavanagh, 2003; Hill, Bromell, Tyson, & Flint, 2007), and greater susceptibility to antisocial peer influence (Brown, 2004; Steinberg & Silverberg, 1986). This confluence of biopsychosocial vulnerabilities may render the role of sensation seeking in promoting smoking especially prominent during adolescence. Furthermore, the illegal status of cigarettes during the adolescent period may render between-person differences in sensation seeking particularly important during adolescence as the illegal status acts as a source of stimulation for those high in sensation seeking (Kopstein, Crum, Celentano, & Martin, 2001). In terms of young adulthood, risky behavior is relatively highly tolerated (Sussman & Arnett, 2014), cigarettes are legal and readily available, and many young adults live in social contexts associated with less social control than experienced during adolescence (Jones, Harel, & Levinson, 1992). These social–cultural dynamics will likely temper the role of between-person differences in sensation seeking and cigarette smoking in young adulthood.

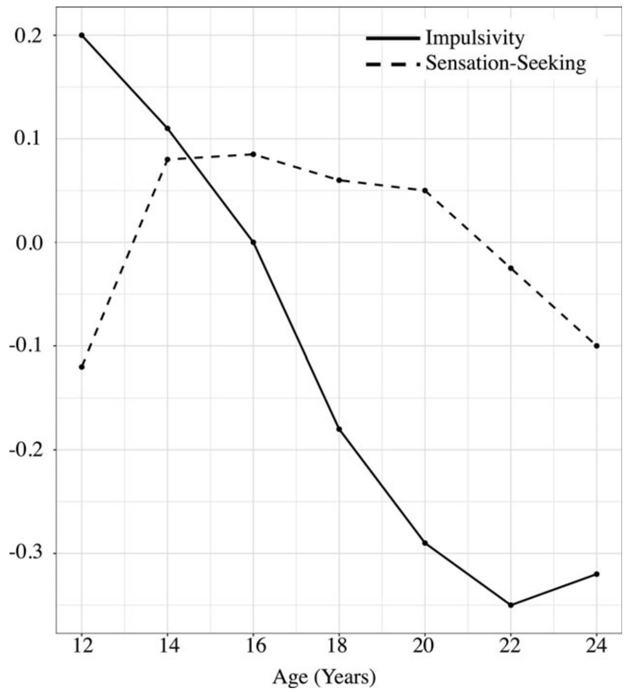

FIGURE 1 Age-related change in sensation seeking and impulsivity from ages 12 to 24 years. Figure adapted from Harden and Tucker-Drob (2011) and their analyses. Scores for impulsivity and sensation seeking are standardized. The between-person association between sensation seeking and cigarette smoking is hypothesized to be greatest at ages 14–16 years given the normatively heightened level of sensation seeking in the context of continued immaturities in impulsivity.

Associations Between Impulse Control and Cigarette Smoking Across Age

In contrast to the hypothesized age-varying association between sensation seeking and smoking, impulse control may be more consistently associated with daily smoking through adolescence and adulthood. During adolescence, impulse control functions to rein in behaviors such as smoking that, while in line with short-term desires, may not be in line with longer term goals (Steinberg, 2007). As such, adolescents with low impulse control may be more likely to smoke. Later, when smoking may be driven by impulses other than sensation seeking—including those associated with drug-induced transformations to incentive processing and stress response systems (Bechara, 2005; Koob & Le Moal, 1997; Robinson & Berridge, 1993; Volkow, Fowler, & Wang, 2004; see Lydon et al., 2014 for review)—impulse control will remain relevant in curbing smoking behaviors in favor of other, more long-term goals. Furthermore, persistent cigarette smoking has a detrimental impact on impulse control (see Lydon et al., 2014 for review). As a result, given the role of impulse control as both a determinant and consequence of cigarette smoking (De Wit, 2009; Perry & Carroll, 2008), smokers in adulthood may be more likely to exhibit impulse control deficits relative to smokers in adolescence due to lengthier exposure to nicotine.

The Present Study

To investigate the hypothesized age-varying associations between sensation seeking, impulse control, and smoking through adolescence into young adulthood, the present study used time-varying effect modeling (TVEM; Tan, Shiyko, Li, Li, & Dierker, 2012). TVEM is an analytic approach suited to flexibly estimate the associations between predictors (e.g., sensation seeking, impulse control) and an outcome (e.g., daily cigarette smoking) as functions of continuous age. It was hypothesized that the prevalence of daily smoking would increase through adolescence and plateau during young adulthood (Schuler, Vasilenko, & Lanza, 2015). In terms of the core components of dual systems models, it was hypothesized that sensation seeking would be greatest during adolescence and decrease through adolescence and into young adulthood and that impulse control would increase through adolescence into young adulthood. It was also hypothesized that the association between sensation seeking and daily smoking would be greatest during adolescence, while the association between impulse control and daily smoking would be more consistently associated with daily smoking through adolescence and young adulthood. Given the hypothesized role for addiction-associated processes in the association between sensation seeking and daily smoking, whereby daily smoking with increasing age becomes driven by addiction rather than sensation seeking processes, age-varying associations between sensation seeking, impulse control, and *any* smoking in the previous 30 days through adolescence into young adulthood were also examined. It was hypothesized that the reduction in the association between sensation seeking and smoking through young adulthood would be smaller for any smoking relative to daily smoking due to a reduced role of addiction processes in the promotion of nondaily smoking behaviors.

METHOD

Participants

The study used public-use data from the National Longitudinal Study of Adolescent to Adult Health (Add Health; Harris et al., 2009), a nationally representative, longitudinal study of adolescents following a cohort of adolescents in Grades 7 through 12 at Wave 1 of data collection from 1994 to 2009. The present study examined data from Wave 2 (1996), Wave 3 (2001–2002), and Wave 4 (2008–2009)—the waves at which sensation seeking, impulse control, and smoking measures were available. Participants providing complete sensation seeking, cigarette smoking, impulse control, race/ethnicity, and gender data for at least one Add Health wave were eligible for inclusion. Our sample included 5,080 individuals (53.98% female) and 13,075 measurement occasions (an average of 1.86 measurement occasions per person). Participants self-identified as White (59.67%), Black (23.84%), Asian (3.23%), Hispanic/Latino (10.41%), and other (2.76%).

To determine the extent to which missing data affected the representativeness of the data used in the present study, comparisons of available Wave 1 data were conducted between participants with complete data and participants who were not included due to missing data. Independent samples *t*-tests revealed no significant differences in total family income before taxes ($p = .10$) across groups of participants with versus without missing data. Participants with missing data were significantly more likely ($p < .01$) to be older at Wave 1 ($M_{age} = 16.20$) than those without missing data ($M_{age} = 15.99$). Chi-square tests were conducted on dichotomous data. No differences emerged in the proportion of participants across the missing and nonmissing data groups in terms of having a parent who reported being a smoker ($p = .24$), having a full-time employed parent ($p = .39$), or self-identifying as other ($p = .32$) or Black ($p = .15$) race/ethnicity. The missing data sample had a higher proportion of males relative to females (43.22% females, $p < .01$), was less likely to self-identify as White (49.51%, $p < .01$), and more likely to self-identify as Asian (5.83%, $p < .01$) than participants in the sample without missing data.

Measures

Cigarette smoking. Using reports of days smoked out of the past 30 days, a dichotomous daily smoking variable (Schuler et al., 2015) was created to indicate participants reporting smoking every day versus those who did not smoke every day in the past 30 days. A second dichotomous any smoking variable was created to indicate participants reporting smoking at any time in the previous 30 days versus those who did not smoke even once in the past 30 days.

Sensation seeking. Sensation seeking was measured using a single item asking participants to rate their agreement with the statement "I like to take risks" using a Likert scale ranging from 1 (*strongly agree*) to 5 (*strongly disagree*). Scores were reverse-coded such that higher scores indicated higher levels of sensation seeking. This item has previously been used as a measure of sensation seeking (Peach & Gaultney, 2013).

Impulse control. Impulse control was measured as the mean score of two items, "I go with my gut feeling and don't think much about the consequences of each alternative" and "I live life without much thought of the future." Items were rated using a 5-point Likert scale ranging from 1 (*strongly agree*) to 5 (*strongly disagree*). Higher scores indicate greater impulse control. This scale has been used previously as a measure of impulse control (Peach & Gaultney, 2013).

Analysis

Analyses were conducted using time-varying effect modeling (TVEM), a type of nonparametric spline regression that flexibly estimates how the association between a predictor and an outcome differs as a function of time without assuming that the association follows a parametric function of time (Tan et al., 2012). While standard regression models are often specified with a regression term for time that yields a single point estimate for the time effect, TVEM estimates a function that represents the regression coefficient between the predictor (e.g., sensation seeking) and outcome (e.g., daily smoking) across continuous time (e.g., age). The resulting regression coefficient function is then presented graphically, along with a corresponding 95% confidence band, to demonstrate how the association between predictor and outcome changes over time.

First, the age trends in daily smoking, any smoking in the previous 30 days, sensation seeking, and impulse control were modeled using separate, intercept-only TVEMs. This allowed an examination of how the mean values of these variables changed over age in months through adolescence into young adulthood. A multivariate TVEM was then used to model the age-varying associations between any smoking in the past 30 days, sensation seeking, and impulsivity. The following equation specified the multivariate model:

$$E\left(\text{smoking}_{ij}\right) = \frac{\exp\ (\eta_{ij})}{1+\exp\ (\eta_{ij})}$$

where

$$\begin{aligned}\eta_{ij} = {} & \beta_0(t_{ij}) + \beta_1(t_{ij})X(\text{Sensation Seeking})_{ij1} + \\ & \beta_2(t_{ij})X(\text{Impulse Control})_{ij2} + \\ & \beta_3 X(\text{Sex})_{i3} + \beta_4 X(\text{Black})_{i4} + \\ & \beta_5 X(\text{Asian})_{i5} + \beta_6 X(\text{Hispanic/Latino})_{i6} + \\ & \beta_7 X(\text{Other})_{i7}\end{aligned}$$

where the exponentiated intercept $e^{\beta_o(t_{ij})}$ represents the odds of smoking over age when all other predictors are zero (note that sex was sample mean centered and White was the reference category for race/ethnicity). Slopes β_1 and β_2 represent the age-varying associations between sensation seeking and impulse control, respectively. β_3 to β_7 represent the time-invariant effects of sex and race/ethnicity and were entered as control variables. A second model of the same form was run using daily smoking as the outcome variable.

In all analyses, the time metric was age in months (coded to the nearest month). All analyses were conducted in SAS using the TVEM SAS macro (Li et al., 2015) available for download at methodology.psu.edu. All TVEM models used the p-spline method of estimation.

RESULTS

As a coefficient for the association between a predictor and outcome is estimated at each point in continuous time with TVEM, time-varying coefficients for the predictors are presented as plots instead of tables as is convention. In the sections below, the plots are described and interpreted.

Cigarette Smoking, Sensation Seeking, and Impulse Control Across Adolescence and Early Adulthood

Figure 2 shows the results for the intercept-only model of any smoking in the previous 30 days. This figure examines how the prevalence of any smoking in the previous 30 days changes with age. The odds of reporting any smoking in the previous 30 days are presented in odds ratio on the *y*-axis. The black line indicates how the odds ratio (OR) differs across age (*x*-axis). Note that age in months was used in all models, but for interpretability age is presented in years in the figure. The dotted lines surrounding the

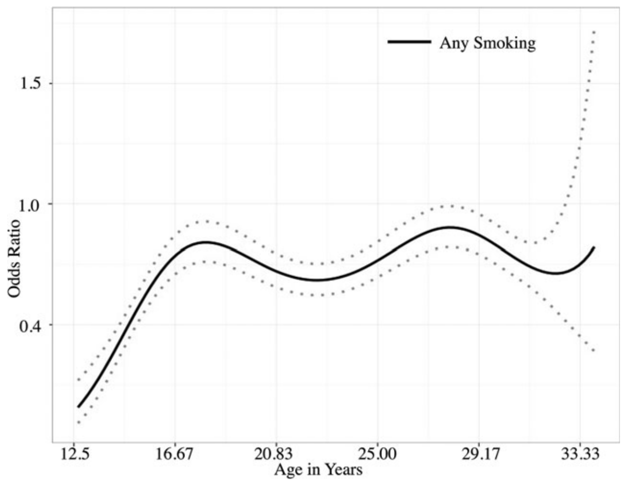

FIGURE 2 Results for the intercept-only model of any smoking in the previous 30 days. The odds of reporting any smoking in the previous 30 days is presented in odds ratio on the *y*-axis. The black line indicates how the odds ratio differs across age (*x*-axis). Note that age in months was used in all models, but for interpretability age is presented in years in the figure. The dotted lines surrounding the black line represent 95% confidence bands of the odds ratio function.

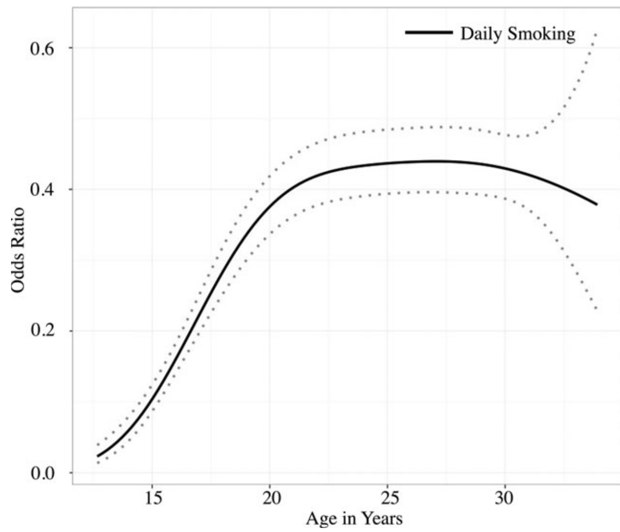

FIGURE 3 Results for the intercept-only model of daily smoking in the previous 30 days. The odds of reporting any smoking in the previous 30 days is presented in odds ratio on the *y*-axis. The black line indicates how the odds ratio differs across age (*x*-axis). Note that age in months was used in all models, but for interpretability age is presented in years in the figure. The dotted lines surrounding the black line represent 95% confidence bands of the odds ratio function.

black line represent 95% confidence intervals (CI) of the odds ratio function. From this figure, it can be observed that the odds of any smoking in the past 30 days increases dramatically from age 12.5 (OR = 0.16, 95% CI = [0.09, 0.27]) to age 18 (OR = 0.84, 95% CI = [0.76,0.93]), decreases through the early- to mid-20s reaching its lowest point at age 22.54 years (OR = 0.68, 95% CI = [0.62,0.75]), rises again until peaking at age 27.91 (OR = 0.90, 95% CI = [0.82, 0.99]), before decreasing once more, reaching a low point at age 32.41 years (OR = 0.71, CI = [0.55,0.92]).

Figure 3 depicts the results for the intercept-only model of daily smoking and is interpreted in the same way as Figure 2. As can be seen, the odds of daily smoking increase dramatically through adolescence. The lowest odds are at age 12.67 (OR = 0.03, CI = [0.02, 0.05]), rise into the 20s, reaching their highest value at age 23.40 years (OR = 0.53, 95% CI = [0.43, 0.64]).

Figure 4 shows the results for the intercept-only models of sensation seeking and impulse control. The models were run separately, but both sensation seeking and impulse control are presented together to allow for comparison. As both sensation seeking and impulse control were continuous variables, the *y*-axis shows the mean score of the variables rather than odds ratios. Sensation seeking (indicated by the continuous black line) was greatest during adolescence, highest at age 13.74 (score = 4.16, 95% CI = [4.04, 4.28]) and decreased through adolescence into early adulthood, with the lowest value emerging at age 30.91 (score = 3.52, 95% CI = [3.44, 3.60]). Impulse control (indicated by the dashed black line) was lowest at age

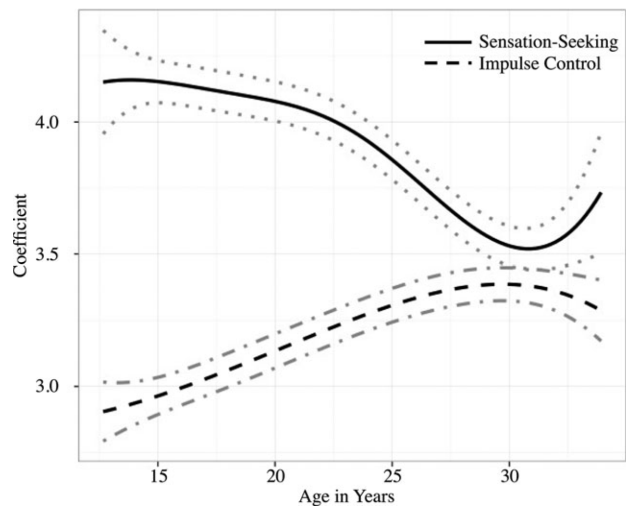

FIGURE 4 Results for the intercept-only models of sensation seeking and impulse control. The models were run separately, but both sensation seeking and impulse control are presented together for comparison. The *y*-axis shows the mean score of the variables. Sensation seeking is indicated by the continuous black line. Impulse control is indicated by the dashed black line. Gray lines represent 95% confidence bands.

12.67 years (score = 2.90, 95% CI = [2.79, 3.02]), increased into young adulthood, and reached its highest value at age 28.34 (score = 3.38, 95% CI = [3.32, 3.44]).

Age-Varying Associations Between Any Smoking, Sensation Seeking, and Impulse Control

Figure 5 presents the results for the multivariate TVEM examining the association between sensation seeking, impulse control, and any smoking in the previous 30 days. The figure shows the association between sensation seeking (continuous black line) and impulse control (dashed black line) in odds ratios (*y*-axis) across age in years (*x*-axis). The gray lines surrounding the black lines are 95% confidence bands. The black lines show the strength and direction of the association between sensation seeking, impulse control, and any smoking in the previous 30 days. When the confidence bands of the black lines contain the straight, dashed black line at an odds ratio of 1, then the association between that predictor and outcome is not significant at that particular age.

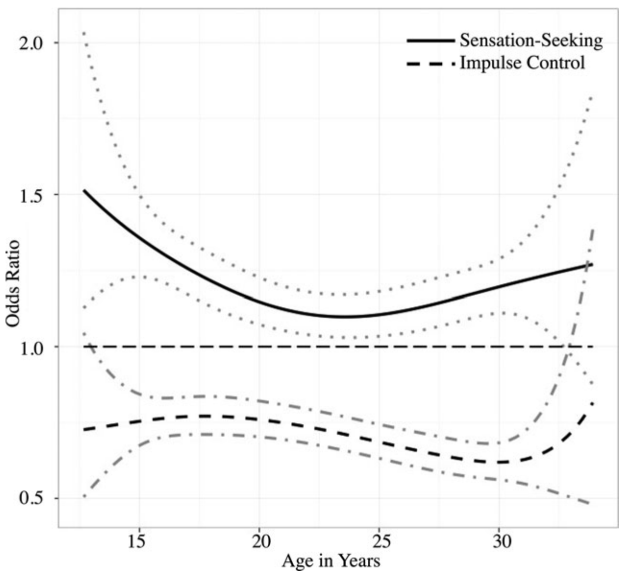

FIGURE 5 Results for the multivariate TVEM examining the association between sensation seeking, impulse control, and any smoking in the previous 30 days. The figure shows the association between any smoking and sensation seeking (continuous black line) and any smoking and impulse control (dashed black line) in odds ratios (*y*-axis) across age in years (*x*-axis). The gray lines surrounding the black lines are 95% confidence bands. The black lines show the strength and direction of the association between sensation seeking, impulse control, and any smoking in the previous 30 days. When the confidence bands cross at an odds ratio of 1, indicated by a straight, dashed black line, then the association between that predictor and outcome is not significant at that particular age.

For sensation seeking, the association with any smoking in the previous days is significant at most ages except for the late 30s. The association becomes nonsignificant at age 32.84 (OR = 1.25, 95% CI = [0.99, 1.58]), where the confidence bands cross the odds ratio of 1 (due at least partially to low data coverage at this age—hence the width of the confidence bands). As the sensation seeking line is above the odds ratio of 1 line, this indicates that with greater levels of sensation seeking come greater odds of reporting smoking in the previous 30 days. While the association is significant across many ages, the association is strongest during adolescence. The highest odds ratio is at age 12.67 (OR = 1.51, 95% CI = [1.13, 2.03]). The confidence intervals at this age are, however, quite wide. Taking the CIs into account, a more conservative estimation of the peak of the association between sensation seeking would still be during adolescence. CI widths comparable with later ages emerge at approximately age 15.67 (OR = 1.31, 95% CI = [1.21, 1.41]). This is consistent with the hypothesis that the association between sensation seeking and smoking would be greatest at the ages during which there is a developmental mismatch in the functioning of sensation seeking and impulse control systems (see Figure 1) against the backdrop of numerous biopsychosocial vulnerabilities.

For impulse control, the association with any smoking in the previous 30 days is also significant at most ages. It is not significant before age 12.88 years (OR = 0.72, 95% CI = [0.52, 1.01]) or after age 33.06 (OR = 0.72, 95% CI = [0.50, 1.03]). As the impulse control line is below the odds ratio of 1 line, this indicates that with greater impulse control, the lower the odds of reporting any smoking in the previous 30 days. While the association is significant across many ages, the association is strongest in the late 20s and early 30s, reaching the strongest association at age 30.05 (OR = 0.62, 95% CI = [0.56, 0.68]).

Age-Varying Associations Between Daily Smoking, Sensation Seeking, and Impulse Control

Figure 6 presents the results for the multivariate TVEM examining the association between sensation seeking, impulse control, and daily smoking in the previous 30 days. It is interpreted in the same manner as Figure 5. As hypothesized, the association between daily smoking and sensation seeking is greatest during adolescence. The association is highest at age 12.67 (OR = 1.66, 95% CI = [1.03,

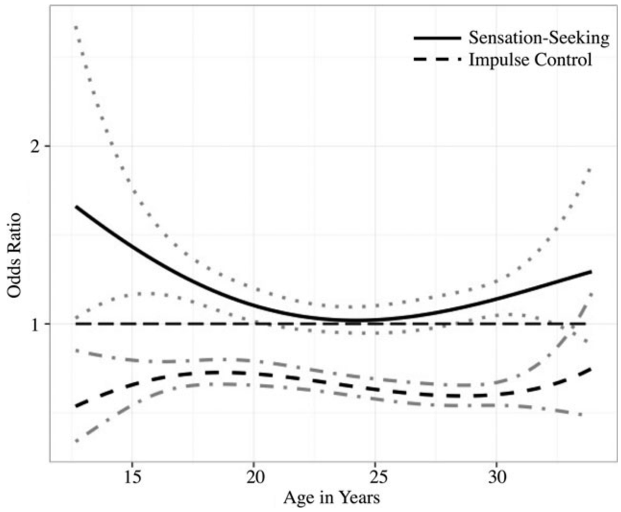

FIGURE 6 Results for the multivariate TVEM examining the association between sensation seeking, impulse control, and daily smoking in the previous 30 days. The figure shows the association between daily smoking and sensation seeking (continuous black line) and daily smoking and impulse control (dashed black line) in odds ratios (*y*-axis) across age in years (*x*-axis). The gray lines surrounding the black lines are 95% confidence bands. The black lines show the strength and direction of the association between sensation seeking, impulse control, and daily smoking in the previous 30 days. When the confidence bands cross at an odds ratio of 1, indicated by a straight, dashed black line, then the association between that predictor and outcome is not significant at that particular age.

2.67]). However, the CIs associated with this estimate are wide. A more conservative estimate of the highest point of the association taking the width of the CIs into account would be at approximately age 16 (OR = 1.34, 95% CI = [1.17, 1.54]), still during adolescence. The association becomes nonsignificant during early adulthood, starting at age 20.39 (OR = 1.09, 95% CI = [1.00, 1.18]) at the points where the confidence band contains the dashed line at an odds ratio of 1 before becoming significant once more at age 28.77 (OR = 1.10, 95% CI = [1.01, 1.19]), although the association is smaller than the association during adolescence, peaking at age 31.98 (OR = 1.22, 95% CI = [1.02, 1.45]).

In contrast, the association between daily smoking and impulse control remains significant through adolescence and into early adulthood. The association is nonsignificant at age 33.27 years and above (OR = 0.71, 95% CI = [0.49, 1.01]). The strength of the association is at its greatest at age 12.67 (OR = 0.54, 95% CI = [0.34, 0.85]), although taking account the wide CIs at this age, the strongest association may be more conservatively placed at age 28.55 (OR = 0.59, 95% CI = [0.54, 0.65]).

DISCUSSION

The present study examined the age-varying associations between sensation seeking, impulse control, and daily smoking in adolescence and young adulthood. As hypothesized, we observed evidence for age-varying associations between sensation seeking and cigarette smoking through adolescence and young adulthood. Consistent with our hypotheses, estimates of the association between sensation seeking and smoking behaviors were largest during adolescence relative to young adulthood. The age-varying association between sensation seeking and smoking behaviors was especially marked for daily smoking such that the association between sensation seeking and daily smoking was not significant between the ages of approximately 20 and 29 years. Also consistent with our hypotheses, there was less evidence for age-varying associations between impulse control and smoking behaviors. Impulse control was significantly associated with smoking throughout most of adolescence and young adulthood. There was evidence, however, that impulse control may be particularly important during young adulthood relative to adolescence as it was during this period that the highest estimates of the association emerged.

Age-Varying Associations Between Sensation Seeking and Cigarette Smoking

Consistent with the propositions of developmental cognitive neuroscience models (Casey et al., 2008a; Ernst, Pine, & Hardin, 2006; Luciana & Collins, 2012; Steinberg, 2010) as well as previous research (Romer et al., 2010; Steinberg et al., 2008), sensation seeking was at its peak in adolescence and declined through adolescence into young adulthood. Novel findings of the present study are the age-varying associations observed between sensation seeking and smoking. The stronger association during adolescence may reflect the experience of heightened sensation seeking in the context of still-maturing cognitive control capacities due to normative brain maturation (Giedd, 2008; Gogtay et al., 2004) as put forward by brain-based models of adolescent risk taking (e.g., Luciana & Collins, 2012; Somerville & Casey, 2010). From this perspective, individuals high in sensation seeking during adolescence may be *particularly* high in sensation seeking relative to individuals at other ages given the normatively heightened sensation seeking occurring during this period and, thus, more susceptible to pursuing cigarette smoking.

The age-varying associations between sensation seeking and smoking also urge us to consider other psychosocial vulnerabilities that may render the association between sensation seeking and smoking particularly strong during adolescence relative to other developmental periods. Beyond the processes highlighted by dual systems models, the illegal status of cigarettes during the adolescent period acts as a source of stimulation for those high in sensation seeking (Kopstein et al., 2001). In terms of young adulthood, risky behavior is relatively tolerated (Sussman & Arnett, 2014), cigarettes are readily available, and the social contexts of young adults are with less social control than experienced during adolescence (Jones et al., 1992). These social–cultural dynamics likely minimized the role of between-person differences in sensation seeking. In terms of daily smoking specifically, the smaller association in young adulthood relative to adolescence is likely reflective of the role of addiction processes (e.g., drug-induced transformations to incentive processing system; Volkow et al., 2004; Robinson & Berridge, 1993) in driving smoking behaviors. The comparison between any smoking in the previous 30 days and daily smoking highlights this potential role of addiction processes with sensation seeking remaining significantly associated with any smoking but not daily smoking through most of young adulthood.

Age-Varying Associations Between Impulse Control and Cigarette Smoking

Consistent with brain-based models and previous research was the finding that impulse control increased through adolescence into young adulthood (Casey et al., 2008a; Harden & Tucker-Drob, 2011; Steinberg et al., 2008). The association between impulse control and daily smoking was significant throughout adolescence and young adulthood. This is consistent with our hypothesis and theories positing of a role for impulse control through the initiation, escalation, and maintenance phases of drug use (see Perry & Carroll, 2008 for review). Adolescents with low impulse control may be more likely to smoke as they lack the ability to regulate behaviors that, while providing short-term rewards, may not be advantageous in the long term (Steinberg, 2007). Young adults with low impulse control may also be more likely to be smokers due to a lower ability to regulate behaviors associated with short-term rewards, but the association between impulse control and daily smoking at this developmental period may also reflect the detrimental impacts of cigarette smoking on impulse control abilities (see Lydon et al., 2014 for review).

Implications

The present findings contribute information to life-span approaches to the prevention of cigarette smoking that emphasize the need to tailor prevention programming to be developmentally appropriate given that the risk factors leading to cigarette smoking change over the life span (Stone, Becker, Huber, & Catalano, 2012). Given the age-varying associations observed in the present study, personality-based prevention programs (e.g., Conrod, Castellanos, & Mackie, 2008; Conrod, Castellanos-Ryan, & Strang, 2010) targeting sensation seeking to curb cigarette smoking may be most beneficial if undertaken during adolescence (see Sargeant, Tanski, Stoolmiller, & Hanewinkel, 2010 for the predictive validity of sensation seeking as a predictor of adolescent cigarette smoking), while programs targeting impulse control may be beneficial through adolescence and into young adulthood. Looking beyond processes at the level of the individual and involving school (Sun, Skara, Sun, Dent, & Sussman, 2006), family (Lochman & van den Steenhoven, 2002), and wider community (e.g., Biglan, Avry, Smolkowski, Duncan, & Black, 2000) contexts will also likely be necessary given the psychosocial factors beyond the brain that may be driving the observed age-varying associations between sensation seeking and cigarette smoking. Programs within such contexts will rely less on attempting to curb developmentally normative, adolescent tendencies to approach novel and potentially rewarding stimuli such as cigarettes, and more on reducing the number of smoking opportunities encountered by adolescents (Lydon, Galvan, & Geier, 2015).

While sensation seeking is a vulnerability for smoking during adolescence, high sensation seeking during this period may be leveraged to enhance the value associated with smoking abstinence through the provision of incentives in order to encourage the allocation of resources to achieve smoking abstinence. This approach is taken by contingency management approaches to smoking intervention that have shown promise in adolescent samples (e.g., Krishnan-Sarin et al., 2006; Reynolds, Dallery, Shroff, Patak, & Leraas, 2008). Given that adolescents, who as a group demonstrate normatively heightened levels of sensation seeking, show increased enhancement of executive functions with the allocation of monetary incentives relative to adults (Geier et al., 2010), this approach will likely be a fruitful area for smoking intervention in adolescents high in sensation seeking.

Limitations and Outlook

The current findings must be interpreted in light of the study's strengths and limitations. The sample used, while coming from a nationally representative data set, was not entirely representative due to missing data on key variables. Further, the sample did not include participants from early adolescence when sensation seeking has been demonstrated to increase from levels during childhood due to the maturation of subcortical structures (e.g., Collado, Felton, MacPherson, & Lejuez, 2014). A combination of less data at younger ages and the low prevalence of smoking behaviors at these ages led to wider confidence intervals around estimates of the associations between sensation seeking, impulse control, and smoking at these points relative to at other ages. This led us to be conservative in our descriptions of when the associations between sensation seeking and smoking, for example, could be interpreted as being at their peak. Larger samples of younger adolescents will be required to capture more precise estimates at these younger ages.

The data were self-reported and may be subject to recall or social desirability biases. Also, the measures used to assess sensation seeking and impulse control could be improved. The use of a one-item measure for sensation seeking is a limitation for several reasons. Multi-item measures have psychometric advantages, including greater reliability and validity. According to classical test theory, items are measured with random error. As such, scales made of multiple items are less prone to random measurement errors. In terms of validity, multiple items capture a larger number of the distinct construct facets, leading to higher construct validity. While the sensation seeking item has been used in previous studies based on modest correlations in expected directions with items related to sensation seeking (Peach & Gaultney, 2013), alternative scales exist that have more favorable psychometric properties (e.g., Arnett, 1994; Stephenson, Hoyle, Palmgreen, & Slater, 2003; Zuckerman, Eysenck, & Eysenck, 1978). The impulse control scale was made up of multiple items and, thus, is less susceptible to the limitations of single-item measures. However, in terms of validity, the use of this scale in the present and previous research (Peach & Gaultney, 2013) was based on its similarity to items from scales with favorable psychometric properties (Patton, Stanford, & Barratt, 1995). Use of these alternative scales in future research is recommended where possible.

The presence of cohort effects are possible, although, given the small age range of the individuals enrolled at Wave 1 of Add Health (approximately 6 years), any cohort effects should be minimal. Finally, it is important to note that the analyses in the present study provide information on associations rather than causal effects or directional relationships between smoking, sensation seeking, and impulse control.

Conclusions

Overall, our results highlight age-varying associations between sensation seeking, impulse control, and smoking. The association between sensation seeking and cigarette smoking, daily smoking in particular, was strongest during adolescence—a time when sensation seeking was at its peak while impulse control exhibited immaturities. In contrast, impulse control was consistently associated with smoking, with the strongest association emerging during the mid-20s to early 30s. The results provide a nuanced perspective on when during development between-person differences in the components of dual systems models may be most related to smoking.

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