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Risky decision making in a laboratory driving task is associated with health risk behaviors during late adolescence but not adulthood

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Abstract

Adolescence is characterized by increasing incidence of health risk behaviors, including experimentation with drugs and alcohol. To fill the gap in our understanding of the associations between risky decision-making and health risk behaviors, we investigated associations between laboratory-based risky decision-making using the Stoplight task and self-reported health risk behaviors. Given that there has been no examination of potential age differences in the associations between risky decision-making and health risk behaviors, we also examined whether the association of risky decision-making with health risk behaviors is consistent across adolescence and adulthood using two-group structural equation modeling (SEM). The results indicated significant differences across the two age groups: adolescents (17–20 year olds) who took more risks on the Stoplight task reported greater frequency and earlier onset of substance use, whereas stoplight performance was not associated with substance use frequency or onset among adults (31–61 year olds). Our findings suggest that a laboratory-based measure of risky decision-making is significantly related to health risk behaviors among adolescents but not among adults.

Adolescence is characterized by heightened vulnerability to health risk behaviors, such as experimentation with drugs and alcohol, that are major proximal causes of addiction and substance abuse related problems (Dahl, 2004). Substance use behaviors are particularly common and disabling among youths and have profound consequences for health, economic, and social outcomes throughout the lifespan (Insel, 2014). Recent federal data indicate that substantial numbers of U.S. adolescents are currently using drugs, with 42% of high school students reporting alcohol use, 20% tobacco use, and 25% marijuana use (CDC,

2013). As such, substance use behaviors represent a particular—and potentially preventable—risk to mortality, health, and functioning. The personal and societal costs of these adolescent health risk behaviors (including over \$1 billion annually spent in the U.S. on prevention efforts) requires research that will enhance the capacity of scientists, practitioners, and policy makers to identify at-risk adolescents and improve public health outcomes (Steinberg, 2008).

Although not all risk-taking behaviors are associated with increased vulnerability to health risk behaviors (see Crone & Dahl, 2012), researchers have paid increased attention to risk taking in adolescence because of its potential negative consequences. Recent studies have provided evidence for the neurobiological bases of developmental changes in risk taking that increase during pre- and early adolescence and throughout middle adolescence. In particular, studies of reward processing show that regions of the striatum, receiving projections from midbrain dopamine neurons, are more active in adolescents relative to adults in response to and in anticipation of rewards (Ernst et al., 2005; Galvan et al., 2006; Somerville, Hare, & Casey, 2011). In addition, neural correlates of cognitive control have been posited to interact with neural mechanisms of valuation and to contribute to impulse control difficulties in adolescence (Casey, Getz, & Galvan, 2008). This cognitive control network includes regions of the prefrontal cortex that undergo maturation, including increased myelination and experience-dependent synaptogenesis and pruning, throughout adolescence and into early adulthood (Paus, 2005).

Risk taking in adolescence is hypothesized to be derived from distinct developmental trajectories of two neural systems: a frontostriatal system underlying the assessment of value and risk associated with appetitive and aversive stimuli, and a separate prefrontal system exerting control over the pursuit or avoidance of risky options (Casey et al., 2008; Steinberg, 2010). The neurobiological model of adolescent development from this viewpoint proposes an imbalance in development of these two neural systems to be at the core of risky behaviors in adolescence: That is, dramatic and rapid increases in reward sensitivity during adolescence in conjunction with impaired development in cognitive control contribute to heightened rates of risk taking (Steinberg, 2008; Wahlstrom, White, & Luciana, 2010).

Recently, a laboratory driving task called the Stoplight task (Steinberg et al., 2008) has been widely used as a measure of risky decision-making in both behavioral research and neuroscience paradigms (e.g., Chein, Albert, O'Brien, Uckert, & Steinberg, 2011; Kahn, Peake, Dishion, Stormshak, & Pfeifer, 2015). Risky driving decisions made during the Stoplight task are shown to be greater among adolescents compared to adults, especially in emotionally or motivationally laden contexts (Albert, Chein, & Steinberg, 2013) supporting its usefulness in identifying youth at risk for reckless behavior.

The current study attempts to address two important gaps in our understanding of adolescent risk taking. First, although there are studies evaluating the predictive validity of laboratory based measures of risk taking propensity primarily using young adult samples (e.g., the Balloon Analogue Risk Task or BART; Lejuez et al., 2002), no study has examined the association between performance on the Stoplight task and self-reports of risk-taking behaviors outside of the laboratory. Second, there has been no examination of potential age

differences in the associations between risky decision-making and health risk behaviors. Thus, it is unclear whether the anticipated association of laboratory-based measures of risky decision-making with health risk behaviors is consistent across adolescence and adulthood. Prior research has shown that Stoplight task performance is associated with sensation seeking (Steinberg et al., 2008) and neural activity in the valuation system (Chein et al., 2011). Given such evidence for neurobiological processes underlying risky decision-making as well as findings showing heightened brain activation toward reward among adolescents compared to children and adults (e.g., Galvan et al., 2006), it may be that the phenotypic correlations between risky decision-making (Stoplight) and health risk behaviors are notably elevated during adolescence.

Thus, our primary goal was to examine whether level of risky decision-making in the Stoplight task is statistically correlated with level of health risk behaviors. In addition, we examined whether the associations between risky decision-making and health risk behaviors differ between adolescence and adulthood. Our sample included adolescents of 17–20 years who were old enough to have a driver's license, making the adolescent and the adult samples comparable with respect to the implications and meaning of risk-taking in a driving simulation game. However, the adolescents' ages represented the period in which regions of the prefrontal cortex involving cognitive control ability are still undergoing maturation and regions of the striatum are hyper-responsive to rewards (Steinberg, 2008).

Method

Participants

The adolescent sample included 24 adolescents (18 males and 6 females) ages 17 to 20 years ($M = 18.56$, $SD = 1.08$), who self-identified as White and lived in Southwestern Virginia. The mean education level of the adolescents' parents fell between associate and bachelor's degree. The adult sample included 24 adults, ages 31 to 61 years ($M = 41.96$, $SD = 9.23$) from the same geographical regions. There were 16 females and 8 males with an ethnic composition of 79% White and 21% Other. Half (50%) of adults were married or living with a partner as though married. The average years of completed education was 13.73 years ($SD = 1.93$) and the mean family income was between \$25,000 and \$34,999 per year.

Procedure

Adolescent participants were recruited from a community sample of adolescents who participated in an existing study (see Kim-Spoon, Farley, Holmes, Longo, & McCullough, 2014). This community sample's ethnic and socioeconomic demographics closely matched those of southwest Virginia in the most recent U.S. Census at the time of data collection (United States Census Bureau, 2012). As part of data collection for the existing study, adolescents ($N = 167$) reported health risk behaviors. Based on these data, we followed the oversampling extreme observations strategy (e.g., McClelland & Judd, 1993) to maximize individual differences in health risk behaviors in a small sample. Thus, from this larger cohort, we recruited adolescents whose health risk behaviors were relatively high ($n = 12$; self-reported using at least one drug, i.e., cigarette, alcohol, or marijuana, "a few times a week" to "everyday") and demographically matched adolescents whose health risk

behaviors levels were relatively low ($n = 12$; self-described having used a drug five or less times in lifetime). In terms of demographic characteristics, adolescents with high versus low health risk behaviors were matched on age ($M = 18.76$ years for adolescents with high health risk behaviors and $M = 18.27$ years for adolescents with low health risk behaviors), gender (4 females and 8 males for both), ethnicity (100% White for both), and parents' highest education degree ($M = 5$ for both with 5 indicating "associate degree"). During the study, adolescents' risky decision-making and health risk behaviors were assessed using neuroimaging, behavioral tasks, and questionnaires. Data in the current investigation utilized behavioral performance data on the Stoplight task and self-reported questionnaire data on health risk behaviors. Written consent and assent were obtained and participants were compensated for their participation (an average of \$85 for about 2.5 to 3 hours for study completion provided at the end of the session). The procedures of the study were approved by the university's internal review board.

Adult participants were drawn from an on-going research project that involves early adolescents (13–14 year olds) and their primary caregivers. These participants were recruited by various advertisement methods including flyers and e-mail distributions. Adults performed behavioral tasks and completed questionnaires. Written consent was obtained and participants were compensated for their participation (an average of \$110 for about 5 hours for study completion provided at the end of the session). The procedures of the study were approved by the university's internal review board. From the larger sample ($N = 131$), we followed the same procedure used for the adolescent sample and selected those whose health risk behaviors were relatively high ($n = 12$; self-reported using at least one drug, i.e., cigarette, alcohol, or marijuana, "a few times a week" to "everyday") and demographically matched adults whose levels of health risk behaviors were relatively low ($n = 12$; self-described having used a drug five or less times in lifetime). In terms of demographic characteristics, adults with high versus low health risk behaviors were matched as close as possible on age ($M = 39.16$ years for adults with high health risk behaviors and $M = 44.75$ years for adults with low health risk behaviors), gender (8 females and 4 males for both), ethnicity (9 Whites and 3 non-Whites for adults with high health risk behaviors and 10 Whites and 2 non-Whites for adults with low health risk behaviors), and years of completed education with ($M = 13$ years for adults with high health risk behaviors and $M = 14$ years for adults with low health risk behaviors).

Measures

Health Risk Behaviors—For both adolescent and adult samples, the same substance use questionnaire was used, derived from questions of the Youth Risk Behavior Survey (CDC, 2012; Wills, Yaeger, & Sandy, 2003). We used a web-based computerized questionnaire for substance use because this format is known to be more effective for increased self disclosure and uninhibited responses to highly sensitive topics (such as underage alcohol use) that might otherwise not be disclosed using traditional survey methodologies or in-person interviews (Rhodes, Bowie, & Hergenrather, 2003). Participants completed three items assessing typical frequency (e.g., "Which is the most true for you about smoking cigarettes?" 1 = *never*, 2 = *tried once-twice*, 3 = *used three-five times*, 4 = *usually use a few times a month*, 5 = *usually use a few times a week*, and 6 = *usually use every day*) and three

items assessing age of initiation (e.g., “How old were you when you smoked a whole cigarette for the first time?” 1 = 8 years old or younger, 2 = 9–10 years old, 3 = 11–12 years old, 4 = 13–14 years old, 5 = 15–16 years old, and 6 = 17 years old or older, and 7 = never) of cigarette, alcohol, and marijuana use. Standardized scores of substance use frequency and onset were averaged across cigarette, alcohol, and marijuana use to obtain a composite severity score (Cronbach’s alpha = .79 for the adolescent sample and .81 for the adult sample) and a composite onset score (Cronbach’s alpha = .75 for the adolescent sample and .67 for the adult sample).

Risky decision-making—The Stoplight task (Chein et al., 2011) was used as a behavioral measure of risky decision-making. It is a computerized first-person driving task in which participants control the progression of a vehicle along a straight track. The goal is to advance through a series of intersections to reach a finish line as quickly as possible and receive a monetary reward. At each intersection, as the vehicle approaches a changing traffic signal cycling from green to yellow to red, participants must make a decision about whether to brake and lose time by waiting for the light to return to green or run through the light and chance a crash. Successfully crossing an intersection without braking saves time, whereas braking and waiting for the signal to turn green again results in a time delay. However, if participants do not brake and a crash ensues, the loss of time is even greater than if they were to brake and wait for the light. Adolescent participants completed one round involving 20 intersections which were treated as separate trials. Adult participants completed one round involving 32 intersections. We conducted analyses using the scores based on all 32 intersections as well as using the scores based on only the first 20 intersections (the scores based on 32 intersections and the scores based on the first 20 intersections were correlated at .89, $p < .001$). The results were highly similar. To make the task more consistent between the two samples, we used the scores based on the first 20 intersections. The degree of risky decision-making was indicated by the number of intersections the participant went through without braking divided by the total number of intersections traversed.

Data analysis

We used two-group structural equation models (SEM), based on maximum likelihood estimation, to test whether the association between Stoplight and health risk behaviors differs between adolescents and adults. We chose SEM because of its advantages including its confirmatory approach to hypothesis testing based on theoretical specification, and its use of model fit to appreciate the extent to which the hypothesized theoretical model is consistent with the empirical data. In particular, for our analyses, SEM had a superior advantage because the difference in correlations could be tested by the difference in model fits, using the change in the Comparative Fit Index (CFI) that is not affected by sample size. The sample size required for SEM depends on model complexity, the estimation method used, and the distribution characteristics of observed variables (Kline, 2011). Our model corresponded to a simple bivariate correlation, and there was no study variable that deviated from assumptions of normality (skewness greater than 3 and kurtosis 10; Kline, 2011). One missing datum was found in the Stoplight performance in the adolescent sample due to a failure to save data. We used full information maximum likelihood (FIML) methods because

they allow data from all individuals regardless of their pattern of missing data and are more appropriate than other commonly used methods such as mean substitution (Arbuckle, 1996).

To test the statistical significance of the difference between adolescent vs. adult samples with respect to the association between stoplight and health risk behaviors, we compared two nested models. We first fit a Configural Invariance model in which all parameters were freely estimated across the two groups. In a subsequent model, the Equal Covariance model, we imposed an equality constraint to test numeric invariance with respect to the covariance between Stoplight and health risk behaviors. If the strength of the association between Stoplight and health risk behaviors significantly differs between the samples, model fit should become significantly worse by imposing an equality constraint. In evaluating the overall goodness of fit, we report the chi-square goodness-of-fit statistic (χ^2), degrees of freedom (df), and corresponding p value; the CFI, and the Root Mean Square Error of Approximation (RMSEA). CFI values greater than .95 and RMSEA values of .08 or lower are indicative of good-fitting models (Hu & Bentler, 1999). For testing the adequacy of equality constraints, we report the conventional chi-square difference test results, but we focus on change in CFI (ΔCFI) because the CFI is independent of sample size, whereas the chi-square difference test tends to be sensitive to sample size. We tested if a value of ΔCFI (i.e., CFI of the Configural Invariance model minus CFI of the Equal Covariance model) was greater than the .01 recommended by Cheung & Rensvold (2002) as a meaningful difference in model fit. In reporting parameter estimates, we report 95% bias-corrected bootstrap confidence intervals, using simulation to avoid the assumptions of asymptotic normality and symmetric distribution, recommended when sample sizes are small to moderate, as is the case in the present study (Carpenter & Bithell, 2000).

Results

Descriptive statistics for all study variables for the adolescent and the adult samples appear in Table 1. The two samples did not differ with respect to the mean levels of substance use frequency ($t = -.21, p = .23$) and onset ($t = 1.76, p = .09$), but adolescents showed a greater number of risky decisions in the Stoplight task than adults ($t = 3.90, p < .001$). Multivariate general linear modeling (GLM) analyses revealed no significant gender effects on risky decision-making on Stoplight performance, substance use frequency, and onset scores among adolescents [$F(3, 19) = .56, p = .65$] or adults [$F(3, 20) = .82, p = .50$].

As shown in Table 2, the association between risky decision-making on the Stoplight task and substance use frequency significantly differed between the adolescent and the adult samples with $\Delta CFI = .17; b = .08, SE = .03, p = .03, b^* = .43, 95\% CI [0.01; 0.14]$ for adolescents and $b = .01, SE = .04, p = .83, b^* = .04, 95\% CI [-0.06; 0.07]$ for adults. Specifically, riskier decision-making was associated with greater frequency of using substances among adolescents with a medium-to-large effect size (explaining 18% of the variance) but not among adults (explaining < 1% of the variance). Similarly, the association between risky decision-making on the Stoplight task and substance use onset significantly differed between the adolescent and the adult samples with $\Delta CFI = .90; b = -.05, SE = .03, p = .05, b^* = -.41, 95\% CI [-0.11; -0.01]$ for adolescents and $b = .02, SE = .03, p = .45, b^* = .14, 95\% CI [-0.03; 0.06]$ for adults. For adolescents, riskier decision-making was

significantly associated with an earlier onset of substance use (explaining 17% of the variance). For adults, however, the levels of risky decision-making were not significantly associated with substance use onset (explaining 2% of the variance).

Discussion

Until now, no empirical study has demonstrated whether risky decision-making in the laboratory, as indexed by performance on the Stoplight task, is related to health risk behaviors among adolescents and adults. In the current study, we investigated whether behavioral performance during the Stoplight task would meaningfully reflect individual differences in self-reported health risk behaviors among adolescents and adults. Our findings from adolescents provide evidence that a laboratory-based measure of risky decision-making is significantly related to health risk behaviors. There have been several studies examining the association between computerized measures of risk-taking propensity, such as the BART, and self-reported health risk behaviors. However, prior studies used predominantly undergraduate students and young adults (e.g., Lejuez et al., 2003; Pleskac, Wallsten, Wang, & Lejuez, 2008) with the exception of one study using 26 high school students (age 13 to 17 years; Lejuez, Aklin, Zvolensky, & Pedulla, 2003). For example, in the original study of the BART, Lejuez and colleagues (2002) studied 86 young adults between 18 and 25 years who were recruited based on an increased likelihood of being risk-takers and reported medium effect size correlations between BART and health risk behaviors (not adjusted for any demographic covariates) including cigarette ($r = .36, p < .01$) and alcohol ($r = .28, p < .01$) use frequencies. We found a stronger level of association between Stoplight performance and health risk behaviors suggesting that adolescents (age 17 to 20 years) who exhibit riskier decision-making on the Stoplight task are likely to report higher frequencies of substance use (cigarette, alcohol, and marijuana combined).

Furthermore, we found that adolescents who make greater numbers of risky decisions on the Stoplight task reported earlier age of onset for using cigarettes, alcohol, and marijuana. Given prior findings indicating significant associations between earlier initiation and greater substance misuse problems (Hawkins et al., 1997), these results indicate that adolescents' propensity for making risky decisions may be predictive of early initiation of substance use, which may result in long-term trajectories of substance use problems and addiction.

In the current literature, studies using laboratory-based risky decision-making have focused on adolescents and young adults (primarily undergraduate students), and we have no clear understanding regarding whether laboratory risk taking is significantly related to health risk behaviors among non-clinical mature adults. We found that, unlike adolescents, Stoplight task performance was not related to self-reported substance use behaviors among adults. One reason that risky decision-making is related to health risk behaviors among adolescents but not among adults may be that substance use behaviors are technically illegal for underage adolescents, thus risky for this population, but not necessarily so for mature adults. For adults (especially who are old enough to have teenage children), using substances may be motivated by different reasons rather than reflecting the individual's risky decision-making, especially when using a particular substance does not involve breaking the law. Methodologically, it is also possible that the age group differences may be due to differences

between adolescents and adults with regard to the memory abilities and strategies enlisted to answer health risk behavior questions (Laursen, Denissen, & Bjorklund, 2012). That is, there may be more errors in adults' reports of substance use initiation because the event was farther away in time than the initiation date for adolescents. Adolescents and adults may also use different memory strategies to recount frequency events (e.g., enumerating vs. estimating), which may reflect differences in accuracy.

In addition, the weak correlations between risky decision-making and substance use onset may be driven by adults who initiated substance use past adolescence. Thus, substance use behaviors may be influenced by the individual's propensity for risky decision-making at the initiation and progression of substance use during adolescence. However, it may be that the continuation of substance use in adulthood is less reflective of risky decision-making than other factors such as stressors. For example, following up the national sample of adults (aged 35 years) from the Monitoring the Future Study, Merline and colleagues (2004) found that adult substance use was a function of stressful life experiences (recent unemployment predicted high substance use), adulthood roles (being married was related to low substance use), and previous use (substance use at age 18 predicted substance use at age 35).

A unique contribution of the current study is the comparison between adolescents and adults regarding the association between laboratory decision-making performance and health risk behaviors. Our data indicate that individual differences shown in risky decision-making among adolescents seem to be reflected in real-world health risk behaviors. Our results further suggest stronger associations between Stoplight performance and health risk behaviors in adolescents compared to adults. Specifically, individual differences in risky decision-making explained 18% of the variance in substance use for adolescents, whereas they explained less than 1% for adults. Prior neuroimaging work indicates increased hemodynamic activity in reward-related regions, including ventral striatum and orbitofrontal cortex, among adolescents making risky decisions to "Go" in the Stoplight task relative to adults (Chein et al., 2011). The stronger association of Stoplight performance and health risk behaviors in adolescents relative to adults may similarly implicate increased neural valuation activity preceding health risk behaviors among adolescents relative to adults.

Findings from the current study should be interpreted in the context of study limitations. First, our adolescent sample (age 17–20) had an advantage of making the adolescent and the adult samples comparable in the sense that both samples included participants who were old enough to have a driver's license. Yet, we do not know about possible effects of previous driving experiences such that a driving simulation game may be more likely to invoke risky decision-making among adolescents who are still novices compared to mature adults. Second, the majority of the adult sample were females, whereas the majority of the adolescent sample were males. Due to our small sample size, we were not able to analyze data separately by gender to test possible moderation effects of gender. Although we do not have theoretically or empirically based reasons to expect that the association between risky decision-making during the Stoplight task and health risk behaviors significantly differ between males and females, caution should be exercised for generalizing the findings. Finally and most importantly, our samples consisted of small numbers of adolescents and adults who were selected to represent a large range of variances. Such sample sizes not only

limited power to test moderators but also undermined confidence in the generalizability of the results. Although the current results provide preliminary evidence that is consistent with directions and effect sizes expected based on the literature, we recommend future researchers replicate the findings with larger and more demographically diverse samples.

In conclusion, our results suggest that the associations between risky decision-making and health risk behaviors are stronger in adolescents compared to adults. The findings also provide evidence that the Stoplight task is a useful laboratory risky decision-making task associated with health risk behaviors in adolescents. Thus, it may be a promising tool for studying behavioral and neurobiological processes that underlie adolescent health risk behaviors. Future investigations of developmental changes in the neurobiological substrates of risky decision-making may offer keys for better understanding the age-related differences in the associations between risky decision-making and health risk behaviors.

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Table 1
Descriptive Statistics of Stoplight Performance, Substance Use, and Risky Sexual Behaviors among Adolescents and Adults

Variables	Adolescents			Adults		
	Mean/%	SD/N	Range	Mean/%	SD/N	Range
1. Stoplight	0.48	0.15	0.25 – 0.65	0.30	0.16	0.05 – 0.65
2. Substance Use Frequency	2.71	1.27	1.00 – 5.67	3.17	1.34	1.33 – 5.67
“1” to < “2”	29%	N = 7		25%	N = 6	
“2” to < “3”	21%	N = 5		17%	N = 4	
“3” to < “4”	33%	N = 8		8%	N = 2	
“4” to < “5”	13%	N = 3		42%	N = 10	
“5” to “6”	4%	N = 1		8%	N = 2	
3. Substance Use Onset	5.78	0.89	4.00 – 7.00	5.32	0.91	3.33 – 6.67
“1” to < “2”	0%	N = 0		0%	N = 0	
“2” to < “3”	0%	N = 0		0%	N = 0	
“3” to < “4”	0%	N = 0		13%	N = 3	
“4” to < “5”	12%	N = 3		8%	N = 2	
“5” to < “6”	42%	N = 10		54%	N = 13	
“6” to < “7”	25%	N = 6		25%	N = 6	
“7”	21%	N = 5		0%	N = 0	

Note. For substance use frequency, “1” = never, “2” = tried once-twice, “3” = used three-five times, “4” = usually use a few times a month, “5” = usually use a few times a week, and “6” = usually use every day. For substance use onset, “1” = 8 years old or younger, “2” = 9–10 years old, “3” = 11–12 years old, “4” = 13–14 years old, “5” = 15–16 years old, and “6” = 17 years old or older, and “7” = never.

Table 2
Two-Group SEM Analyses for Stoplight and Health Risk Behaviors Comparing Adolescents and Adults

Model Label	χ^2	df	p(exact)	CFI	CFI	RMSEA	[90% C.I.]	p(close)
<i>1. Stoplight and Substance Use Frequency</i>								
1-a. Configural Invariance	0	0	0	1.00		.00		.00
1-b. Equal Covariance	1.51	1	.22	.83	.17	.15	[.00; .59]	.23
<i>2. Stoplight and Substance Use Onset</i>								
2-a. Configural Invariance	0	0	0	1.00		.00		.00
2-b. Equal Covariance	3.54	1	.06	.10	.90	.33	[.00; .72]	.07

Note. p(exact) = probability of an exact fit to the data; CFI = comparative-fit index; RMSEA = root mean square error of approximation; C.I. = confidence interval; p(close) = probability of a close fit to the data.