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Short Report

Adolescent marijuana users have elevated risk-taking on the balloon analog risk task

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Abstract

Objective: Adolescents who engage in regular marijuana use may have a higher propensity to take unsafe risks despite the possible negative consequences. We compared adolescents with a history of regular marijuana use to non-using teens on a behavioral measure of risk-taking. Given the involvement of the pre-frontal cortex in both risk-taking and executive functioning, we also examined whether risk-taking was associated with measures of executive functioning.

Method: Fifty-eight demographically similar community youth (ages 17–20; 29% female), including 24 marijuana users and 34 non-using controls, completed the computerized Balloon Analog Risk Task (BART; Lejuez et al., 2002) and measures of substance use and executive function. Primary BART outcome measures included total number of popped balloons and average adjusted pumps (mean pumps excluding popped balloons).

Results: Marijuana users had more popped balloons than controls ($p<0.05$) but did not differ on average adjusted pumps. Using hierarchical multiple regression controlling for age, riskier BART performance (popped balloons) was predictive of past 18-month hard drug use ($\beta=0.30$; $p<0.05$). Having a higher number of popped balloons was also predictive of past 18-month marijuana use ($p<0.05$), but age was a stronger predictor than marijuana use. Marijuana users performed worse on one test of executive functioning (psychomotor set-shifting, $p<0.05$), but this did not correlate with risk-taking.

Conclusions: Our finding of elevated risk-taking among marijuana users is consistent with previous research that substance users may have impaired risk processing. Further, our results suggest that risk-taking is not always associated with executive dysfunction, implying the involvement of distinct neural subsystems.

Keywords

Adolescent, cannabis, drug users, risk-taking, neuropsychology, cognition, executive function

Introduction

Adolescence requires some risk-taking as independence from the family is taking form, but for some teens, risk taking may lead to unhealthy or unsafe decisions. Risky behaviors such as unprotected sex, reckless driving, and substance use are associated with lasting negative outcomes (e.g. Cavazos-Rehg et al., 2011). With regard to substance use, the annual Monitoring the Future study reported that marijuana is the most commonly used illicit drug in the United States, with 7% of 12th graders reporting daily use (Johnston et al., 2013). Individuals who engage in regular substance use may have a higher propensity to take unsafe risks (such as the decision to use recreational drugs regularly) despite the possible negative consequences (e.g. Lejuez et al., 2002; Schuster et al., 2012). Without testing adolescents prior to initiation of substance use, it is difficult to determine whether elevated levels of risk-taking predated substance use. However, risk-taking performances of adolescents with and without histories of regular marijuana use can help us to understand what leads some individuals to substance-related problems.

The Balloon Analogue Risk Task (BART; Lejuez et al., 2002) offers a behavioral assessment of risk-taking. In adult samples, riskier BART performance has been associated with higher levels of alcohol use (Fernie et al., 2010; Weafer et al., 2011) as well as substance use, gambling, unsafe sex, and stealing (Lejuez et al., 2002), and it has successfully differentiated MDMA ((+/-) 3,4-methylenedioxymethamphetamine; "ecstasy") users from controls (Hopko et al., 2006). Riskier BART performance was also associated with greater alcohol, cigarette, and polydrug use in a community sample of young adults (Lejuez et al., 2002). Among adolescents, riskier BART performance was related to greater self-reported substance use and safety risk behaviors (Aklin et al., 2005; Lejuez et al., 2003, 2007). Adolescent patients with conduct disorder and co-morbid substance abuse/dependence have also shown greater risk-taking with the BART compared to healthy controls (Crowley et al., 2006).

Some studies have examined marijuana users specifically. For example, adolescent marijuana users demonstrated impulsive decision-making (i.e. poor reflection impulsivity) with the

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Information Sampling Test (Solowij et al., 2012); however, users had a median of less than 24 h of abstinence. Using the BART, Schuster et al. (2012) found that riskier BART performance was correlated with higher levels of risky sexual behavior among young adult marijuana users; however, participants may have used marijuana the day prior to testing and were not compared to non-users. Gonzalez et al. (2012) found no differences on the BART in a sample of young adult marijuana users versus non-using controls; however, Gonzales et al. allowed for recent marijuana use (>24 h), with a median of three days since past use. Because previous studies of young marijuana users allowed for recent use, the effects of residual marijuana levels may have affected task performance. In the current study, we examined risk-taking via the BART in late adolescent marijuana users with at least two weeks of abstinence from marijuana, in comparison to non-using controls. This approach (a) considers how marijuana users function relative to their non-using peers and (b) reduces possible residual effects from recent substance use. We hypothesized that participants reporting greater substance use would demonstrate riskier BART performance.

Further, previous studies have not yet examined the relationship of risk-taking to executive functioning in adolescent marijuana users. Executive function is a complex collection of abilities (e.g. planning and decision-making, flexibility of thinking, working memory, verbal fluency, as well as impulse control and reward processing) primarily modulated by the prefrontal cortex. Several studies have found altered prefrontal cortex processing and executive dysfunction in marijuana users (e.g. Jager et al., 2010; Schweinsburg et al., 2008; Tapert et al., 2007). Completing the BART has also been linked to increased prefrontal cortex activation in healthy controls (Rao et al., 2008), and a recent meta-analysis of neuroimaging studies suggested that individuals with substance use disorders may have altered risk processing compared to healthy controls, primarily in ventromedial prefrontal cortex, orbitofrontal cortex, striatum, and other areas involved in risk and decision-making (Gowin et al., 2013). Given the involvement of the prefrontal cortex in both risk-taking and executive functioning, we examined whether elevated risk-taking, as measured by the BART, was associated with poorer executive functioning, as measured by traditional neuropsychological tests. We hypothesized that a riskier approach to the BART would be associated with poorer performance on executive function tests.

Methods and materials

Participants

Participants were part of a longitudinal study of marijuana's effects on neurocognition during adolescence and young adulthood, with assessments at intake (ages 15–18) and at 18- and 36-month follow-ups (e.g. Hanson et al., 2010; Medina et al., 2007; Schweinsburg et al., 2008). Adolescents were recruited from local high schools. Teens and their parents/guardians were screened for demographics, psychosocial functioning, and family history of *Diagnostic and Statistical Manual for Mental Disorders, 4th Ed.* (DSM-IV; American Psychiatric Association (APA), 2000) substance use and other Axis I disorders. Confidentiality was ensured within legal limits to encourage full disclosure. Prior to participation, written informed assent (adolescents) and consent (adults and parent/guardians) were obtained in accordance with the University of California, San Diego Human Research Protections Program. At study intake, exclusionary criteria included history of psychiatric disorder other than substance use disorder, serious medical problem or head trauma, premature birth, prenatal drug or alcohol exposure, and substance use during monitored abstinence. Intake classification criteria (Medina et al., 2007) for the marijuana-user group included >60 lifetime marijuana experiences; past month marijuana use; <100 lifetime uses (<10 in past three months) of drugs other than marijuana, alcohol, or nicotine; and not meeting Cahalan criteria for heavy drinking status (Cahalan et al., 1969). To produce an adequate sample size, controls were included if they had <5 lifetime experiences with marijuana (none in the past month), no previous use of any other drug except nicotine or alcohol, and did not meet criteria for heavy drinking status.

The current data were collected at the 18-month follow-up, when participants were aged 17–20 years. A total of 48 marijuana users and 52 controls completed the BART task at the 18-month follow-up; however, 24 marijuana users and 18 controls were excluded from analyses based on the following abstinence requirements: at least two weeks since last use of marijuana, other drugs, or alcohol binge (to reduce residual effects of such use and allow for removal from the body; excluded n=23 marijuana users, n=11 controls); and at least three days since last use of any alcohol or psychiatric medications (n=2 additional controls). Beyond the abstinence requirements, follow-up controls were further excluded for meeting abuse or dependence criteria for alcohol or any other substance (n=4 additional controls). One participant in the baseline marijuana group had no marijuana uses in the previous 18 months and was also excluded, and one additional control was excluded due to meeting DSM-IV criteria for current post-traumatic stress disorder.

Following these exclusions, the resulting sample of 58 demographically matched adolescents and young adults (ages 17–20; 29% female; 60% Caucasian; see Table 1) included 24 marijuana users and 34 non-using controls. At the 18-month follow-up, marijuana users were about seven months older (p<0.05), and as expected, reported higher levels of marijuana, alcohol, and other drug use than controls. marijuana users had 200+ lifetime marijuana use episodes and <130 lifetime experiences with other drugs. In addition, 10 marijuana users met DSM-IV criteria for marijuana abuse and seven for marijuana dependence (one for past dependence), 10 met criteria for alcohol abuse, and two met criteria for other drug abuse. At the 18-month follow-up, the 34 controls had ≤15 lifetime experiences with marijuana, minimal to no previous other drug use except nicotine or alcohol (three controls had 1–2 past drug uses).

Measures

Screening interview. A structured clinical interview measured psychosocial functioning, health history, and family history of psychiatric and substance use disorders (Rice et al., 1995). Probable DSM-IV Axis I disorders were determined by the computerized Diagnostic Interview Schedule for Children Predictive Scales (Lucas et al., 2001; Shaffer et al., 2000). Adult participants living independently completed corresponding modules of the computerized Diagnostic Interview Schedule (C-DIS-IV; Robins et al., 1996).

Table 1. Demographic and substance use information for participants.

	Controls (n=34) M (SD)	Marijuana users (n=24) M (SD)
Age[a]	18.9 (0.9)	19.5 (0.9)
CBCL Externalizing T-score[a]	48.4 (6.7)	52.1 (7.7)
Age regular (weekly) marijuana use began	–	15.8 (1.8)
Lifetime marijuana use episodes[b]	2.0 (3.7)	771.9 (488.3)
Marijuana use days, past 18 months[b]	1.4 (3.5)	252.7 (196.0)
Days since last marijuana use at NP testing session[b]	623.5 (584.8)[c]	52.9 (52.7)
Lifetime alcohol use episodes[b]	46.9 (65.3)	430.3 (338.7)
Occasions drunk, past 18 months[b]	7.2 (12.9)	71.7 (93.7)
Lifetime other drug use episodes[b]	0.1 (0.4)	28.8 (32.9)
Other drug use days, past 18 months[b]	0.03 (0.2)	18.9 (26.4)

NP: neuropsychological; SD: standard deviation; CBCL: Child Behavior Checklist Youth Self-Report and Adult Self-Report (Achenbach and Rescorla, 2001).
[a]p<0.05; [b]p<0.001.
[c]Includes only controls who have used marijuana in their lifetime (n=13).

Parent interview. A parent/guardian was interviewed on child development and behavior, and youth/family medical and psychiatric history (Rice et al., 1995). Parents/guardians corroborated youth diagnostic reports with the parent version of the Diagnostic Interview Schedule for Children Predictive Scales. If participant self-report and parent collateral data were discrepant, additional information was reviewed from the file, and data were coded to reflect the presence of the symptom, to reduce participant and researcher bias.

Substance use. Participants were administered the Customary Drinking and Drug Use Record to evaluate their lifetime, past three-month, and past 18-month use of nicotine, alcohol, marijuana, stimulants (cocaine, amphetamines, MDMA/ecstasy), hallucinogens, inhalants, opiates (heroin, narcotic pain medications), dissociatives (phencyclidine, ketamine), sedatives (gamma-hydroxybutyric acid, barbiturates, benzodiazepines), and abuse of over-the-counter or prescription medications. Teens were also assessed for alcohol and drug withdrawal symptoms, related life problems, and DSM-IV abuse and dependence criteria (Brown et al., 1998; Stewart and Brown, 1995). The Timeline Follow-back (Sobell and Sobell, 1992) facilitated recall of substance use over the past 28 days through a calendar layout.

BART. The BART is a computer-based risk-taking assessment (Lejuez et al., 2002). Participants used the space bar to pump 30 simulated balloons one at a time to achieve the highest possible score. Balloons pop at an unpredictable rate (possible range: 1–128 pumps; average=64 pumps), and a noise follows each response (popping, or coins falling for a "save" response). The points earned for a balloon are lost if it pops, but temporary points can be saved by choosing "Save Points." Participants weigh the increasing risk of popping each balloon (and losing points) against the potential gain of continuing to pump the balloon (to accrue points and gain a reward). The primary outcome measures were the mean number of pumps for balloons that did not pop (average adjusted pumps) and the total number of popped balloons during the session. High values on either variable suggest greater risk taking. The number of points earned on any balloon and the total points saved are not revealed to the participant – only whether they had earned a small, medium, big, or bonus prize (i.e. various sizes of candy) depending on the amount of points saved. They were shown the possible candy rewards prior to starting the task and received the reward immediately upon completion of the task. Participants had no practice trials to assess risk, and each participant completed the same task (i.e. the balloons and the destiny pop points of the balloons were exactly the same, and occurred in the same order, for each participant). This measure has good test-retest reliability (r =0.77; White et al., 2008).

Mood and personality. Mood and personality were measured to help characterize the sample and examine whether elevations in depressive, anxiety, or internalizing/externalizing symptoms were related to BART performance. Mood and anxiety were assessed using the Beck Depression Inventory (BDI; Beck, 1978) and the Spielberger State-Trait Anxiety Inventory (STAI; Spielberger et al., 1970). We used the Child Behavior Checklist (CBCL) Youth Self-Report and Adult Self-Report (Achenbach and Rescorla, 2001) to measure internalizing and externalizing behaviors.

Neuropsychological testing. General intellectual ability was assessed by the Vocabulary (at project intake) and Block Design subtests of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). Measures of executive function included the Digit Span task (number of digits recalled in forward and backward sequence) from the Wechsler Adult Intelligence Scale-Third Edition (WAIS-III; Wechsler, 1997); and the Trail Making, Towers, and Verbal Fluency tests from the Delis-Kaplan Executive Functioning System (D-KEFS; Delis et al., 2001).

Procedures

Participants were abstinent from marijuana, other drugs, and alcohol binge for at least two weeks prior to the assessment, verified with biweekly breathalyzer tests and urine screens (Quest Diagnostics) including at the neuropsychological testing session. The urine screen tested for major substances including amphetamines, barbiturates, benzodiazepines, cocaine metabolites, marijuana metabolites, and opiates. Exclusions for recent substance

Table 2. Balloon Analogue Risk Task (BART: Lejuez et al., 2002) and other neuropsychological test results.

	Controls (n=34) M (SD)	Marijuana users (n=24) M (SD)
BART		
Average adjusted pumps	37.2 (11.5)	39.7 (11.4)
Popped balloons[a]	9.1 (2.8)	10.8 (3.0)
General intellectual ability		
WASI Vocabulary T-Score	58.2 (8.8)	59.0 (7.0)
WASI Block Design T-Score	60.6 (5.8)	59.3 (6.0)
Measures of executive functions		
WAIS-III Digit Span Backward (raw score)	7.9 (2.3)	7.0 (1.5)
D-KEFS Trail Making: Number-Letter Switching SS[a]	11.7 (1.6)	11.1 (1.9)
D-KEFS Towers: Total Achievement SS	11.3 (2.4)	11.5 (2.6)
D-KEFS Verbal Fluency: Letter Fluency SS	13.0 (3.2)	13.3 (2.9)
Measures of attention and processing speed		
WAIS-III Digit Span Forward (raw score)	11.4 (2.4)	10.6 (1.6)
D-KEFS Trail Making: Number Sequencing SS	12.3 (1.8)	12.4 (1.8)
D-KEFS Trail Making: Letter Sequencing SS	12.6 (1.7)	12.5 (1.5)

D-KEFS: Delis-Kaplan Executive Functioning System (Delis et al., 2001); SD: standard deviation; SS: scaled score; WAIS-III: Wechsler Adult Intelligence Scale-Third Edition (Wechsler, 1997); WASI: Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999).
[a]p<0.05.

use are described above in the section on participants. All participants completed questionnaires and the neuropsychological battery. Teens and their parents/guardians received monetary compensation upon study completion.

Statistical analysis

We used Fisher's Exact Tests to compare categorical variables between groups and analysis of variance (ANOVA) to examine group differences on continuous variables. Some alcohol and drug use variables did not meet requirements for parametric analysis; therefore we used the Mann-Whitney procedure to compare these characteristics between groups. Because marijuana users were slightly older than controls, age was controlled in analyses of test performance using univariate analysis of covariance (ANCOVA). Effect sizes are presented as partial eta-squared (η_p^2, range: 0–1), and interpretations of statistical significance were made if p<0.05. We used Pearson correlations to examine associations between risk-taking, demographic, and neuropsychological variables. As an exploratory analysis, we performed hierarchical multiple regressions to examine whether BART performance predicted past 18-month substance use, as described below. Distributions of substance use variables were examined and appropriately $\log_{10}$ transformed to meet the assumptions of parametric analysis.

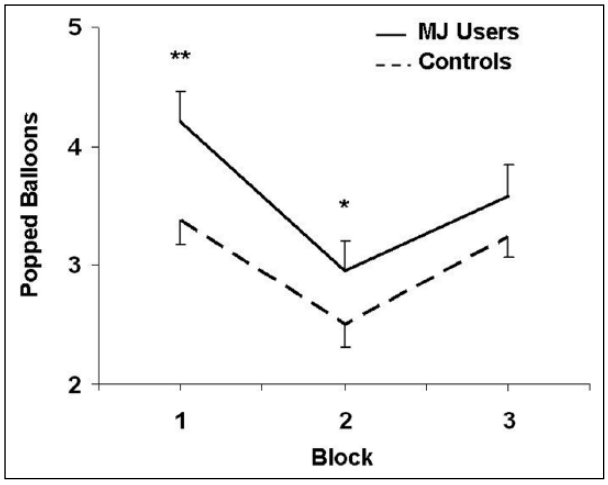

Figure 1. Adolescent marijuana (MJ) users (n=24) had more popped balloons on the Balloon Analog Risk Task (BART) relative to non-using controls (n=34) (overall: p<0.05), particularly on blocks 1 and 2. Each block included 10 trials. Error bars depict standard errors. *p≤0.05; **p<0.01.

Results

BART

Marijuana users had more popped balloons (F(1,55)=6.49, p=0.014, η_p^2=0.11) than controls, over and above the effects of age (see Table 2). This was particularly notable on the first (F(1,55)=8.99, p=0.004, η_p^2=0.14) and second set of 10 balloons (F(1,55)=4.03, p=0.05, η_p^2=0.07); the group difference on the third set did not reach our criteria for significance (F(1,55)=1.70, p=0.20, η_p^2=0.03) (see Figure 1). Groups did not differ on average adjusted pumps (F(1,55)=1.50, p=0.23, η_p^2=0.03), therefore we did not further explore this variable.

Neuropsychological testing

Marijuana users performed worse than controls on D-KEFS Trail Making Number Letter Switching (i.e. visuomotor set-shifting; F(1,55)=4.19, p=0.046, η_p^2=0.07), above and beyond effects of age (see Table 2). Groups did not differ on other measures of executive function (D-KEFS Towers or Verbal Fluency, WAIS-III Digit Span Backward), attention/processing speed (WAIS-III

Digit Span forward, D-KEFS Trail Making: Number Sequencing and Letter Sequencing), or intelligence (WASI Vocabulary or Block Design; high average range overall).

Self-report mood and behavior

Marijuana users scored higher than non-using controls on CBCL externalizing behaviors ($F(1,55)=4.66$, $p=0.035$, $\eta_p^2=0.08$) (see Table 1), after accounting for age. Groups did not differ on the BDI, STAI, or CBCL Internalizing scales.

Correlations

BART risk-taking and neuropsychological performance. The number of popped balloons was positively correlated with D-KEFS Trail Making Letter Sequencing (i.e. psychomotor processing speed) scaled score (i.e. more popped balloons = better sequencing; $r=0.30$, $p=0.02$). The number of popped balloons did not correlate with measures of intelligence or executive function. To examine the effects of age and group, we computed partial correlations controlling for age and group membership, and the correlation of popped balloons with Letter Sequencing remained significant. BART performance was not associated with self-reported depression, anxiety, or internalizing/externalizing behavior, demographic variables, or age.

Regressions

We used a series of exploratory hierarchical multiple regressions to examine whether BART performance predicted past 18-month substance use in the whole sample. We entered age in Block 1, and the number of popped balloons in Block 2. The $\log_{10}$ transformed dependent variables were (a) past 18-month marijuana use episodes, (b) other drug use episodes, or (c) number of times drunk. Controlling for age, the equation using BART popped balloons to predict past 18-month marijuana use was significant: Block 2, $F(2, 55)=4.86$, $p=0.016$; $R^2_{\Delta}=5.3\%$. Specifically, higher age was positively associated with marijuana use ($\beta=0.32$, $p=0.015$); having popped more balloons was associated with more marijuana use in the past 18 months but did not reach our criteria for statistical significance ($\beta=0.23$, $p=0.072$). BART performance also predicted other drug use episodes over the past 18 months above and beyond age, with the number of popped balloons emerging as the strongest predictor: Block 2, $F(2, 55)=3.70$, $p=0.031$; $R^2_{\Delta}=9.1\%$ (popped balloons: $\beta=0.30$, $p=0.021$; age: $\beta=0.194$, $p=0.133$). Having more popped balloons was not predictive of the number of times drunk in the past 18 months. If all three substance use variables were entered simultaneously to predict the number of popped balloons, the finding was not significant. The above regression models were no longer significant when examining marijuana users alone.

Discussion

This study examined risk taking via the BART in late adolescents with or without a history of marijuana use. As hypothesized, participants reporting greater substance use evidenced riskier BART performance. Specifically, marijuana users with at least two weeks of abstinence from marijuana, other drugs, or alcohol binge (verified by biological measurement) popped more balloons than non-using controls throughout the task, especially in the first 20 (out of 30) balloons. Although speculative, it appears that the marijuana users started the task with a higher level of risk taking. After receiving feedback about their performance (in the form of popped balloons), they attempted to modify their approach to avoid popping balloons. The controls may have taken a similar approach, as illustrated in Figure 1; however, the marijuana users remained slightly more "risky" in their approach throughout the test.

Notably, the groups did not significantly differ in average adjusted pumps, which is the most commonly used variable for this task. Importantly, Pleskac et al. (2008) have suggested that the average adjusted pumps score may be biased and an underestimate of risky responses because it excludes the trials in which the balloon popped, as explained further below. For this reason, the number of popped balloons may be a more sensitive measure of risk-taking. Importantly, the groups were matched on self-reported levels of depressive, anxiety, and internalizing symptoms; marijuana users scored higher on externalizing behavior, as expected. BART performance was not associated with these self-reported mood and personality characteristics or demographic variables including age. This suggests that group differences in risk taking may be due to marijuana or other substance use, rather than other personal characteristics.

Previous studies have found mixed results. Consistent with the current study, some found that alcohol and other substance use was related to riskier BART performance (Fernie et al., 2010; Hopko et al., 2006; Weafer et al., 2011); however, others did not find group differences between non-using controls and at-risk/addicted individuals or recently abstinent marijuana users using the BART average adjusted pumps variable (Gonzalez et al., 2012; Meda et al., 2009). Further, BART performance did not relate to cannabis use disorder symptoms in Gonzalez et al., 2012. Our study is consistent with Meda et al. (2009) and Gonzalez et al. (2012) with regard to finding no group difference on average adjusted pumps; however, the previous studies did not examine group differences in the number of popped balloons.

We also found that having a riskier BART performance (i.e. more popped balloons) significantly predicted a higher number of other drug use episodes in the past 18 months, above and beyond the effects of age. The equation using popped balloons to predict past 18-month marijuana use was also significant, but higher age was a stronger predictor than popped balloons. Having a riskier BART performance did not predict recent alcohol use. In other words, it appears that BART performance was associated with other drug use but not alcohol or marijuana use when also considering age. However, that result did not remain significant when controls were removed from the analysis. The BART may therefore have had relatively low sensitivity for measuring additional risk among regular marijuana users in this sample. Future studies could explore whether BART performance is a useful predictor of additional risk above and beyond alcohol and marijuana use.

In addition to elevated BART risk-taking, abstinent marijuana users performed worse than controls on one aspect of executive functioning measured, consistent with previous studies reporting deficient executive skills or abnormal brain activation among marijuana users in this and other samples (e.g.

Hanson et al., 2010; Medina et al., 2007; Pope and Yurgelun-Todd, 1996; Schweinsburg et al., 2008). Specifically, marijuana users exhibited poorer visuomotor set-shifting relative to non-using controls. This suggests that young, abstinent marijuana users may have a mild weakness in cognitive flexibility in the context of changing task demands. Nevertheless, it is not clear if the average group difference on this task is clinically meaningful, and marijuana users did not differ from controls on other aspects of executive skills including working memory, verbal fluency, and planning. Although not correlated with putative measures of executive function, riskier BART performance was associated with faster psychomotor sequencing speed. It is possible that a faster rate of responding may produce more popped balloons, or as speculation, risky behavior without adequate forethought may result in losses. This may concur with Solowij et al. (2012) who reported that marijuana using adolescents demonstrated "reflection impulsivity," having faster response times even when uncertain and making more errors. Vigil-Colet (2007) also found that BART performance was most strongly related to "functional impulsivity," a style in which decisions are made quickly and impulsively under certain beneficial circumstances. On the other hand, Meda et al. (2009) used principal components analysis to show that risk-taking (as measured by BART average adjusted pumps) may be distinct from other measures of the multidimensional construct of impulsivity (e.g. behavioral activation, self-reported impulsivity, reward or punishment sensitivity). Therefore the relationship between a faster processing speed, impulsivity, and risk-taking is not entirely clear and warrants additional study.

Overall, the BART appears to measure distinct aspects of risk-taking that have been associated with real-world behavior (e.g. substance use), suggesting it is a useful tool for assessing risk-taking in adolescents and young adults. Since the BART (popped balloons) was not correlated with established tests of executive functioning, this suggests that it is measuring a behavior distinct from executive function, or at least distinct from the present tests of executive functions. Given the constellation of elevated risk-taking and inferior executive functioning, marijuana using teens may be at greater risk than non-users for antisocial and safety risk behaviors, thus increasing the possibility of negative personal, social, legal, or occupational consequences (e.g. Aklin et al., 2005; Lejuez et al., 2003).

Limitations and future directions

One limitation of the present study was that, given the intercorrelations between various substances of abuse, it was not possible to determine whether elevated risk-taking is a direct consequence of marijuana or any other substance use. Further, elevated risk-taking may predate substance use. However, one might speculate that substance use exacerbates a premorbid tendency toward risk-taking, placing the user at greater risk for harmful consequences (e.g. Ersche et al., 2013). Because we studied a community sample of marijuana users (and not those seeking clinical treatment), the differences between the non-using controls and marijuana users may be attenuated relative to clinical samples of marijuana users. We also acknowledge that, given the number of comparisons made, the risk of type-I error is increased. Given the sample size, we were not able to examine the presence of gender differences, and this is an area for future research.

In addition, we used a food reward (various sizes of candy) because the participants started the study when they were less than 18 years old, and we had to adjust reimbursement for study participation to protect this initially underage sample from possible coercion. Although Gonzalez et al. (2012), as well as the originators of the BART task (i.e. Lejuez et al., 2002) used monetary rewards for BART performance (5 cents per pump), the current sample had a higher average number of pumps (by about five pumps in the non-users and 7–9 pumps in the marijuana users), suggesting that a food reward was a sufficient motivator in this sample.

This study used a version of the BART that required manual pumps for each balloon (i.e. tap spacebar desired number of times) and did not provide feedback after each trial (e.g. explosion point for previous balloon, amount earned). According to Pleskac et al., (2008) this manual BART may be biased due to psychomotor demands (tapping/processing speed). They further explained that the average adjusted pumps score is biased because it excludes responses that ended in an explosion (popped balloon); therefore, it is an underestimate of the number of pumps the participant would have completed if the balloon had not popped. Given that we are examining the risky behavior that would lead to increased pumps and popped balloons, the average adjusted pumps may not be the optimal estimate of risky behavior. This may partially explain why marijuana users and non-using controls did not differ on this score. A newer automatic BART avoids biases by informing participants of the optimal number of pumps (i.e. 64 out of a possible 128), allowing them to numerically input pumps (i.e. typing in the desired number (e.g. 85), rather than tapping the spacebar 85 times), and providing trial-by-trial feedback (e.g. "explosion point for last balloon = 122," amount earned, and balloon number; for further explanation see Pleskac et al., 2008). Future studies should consider the automated BART to maximize behavioral variability. Additionally, we excluded recent users (less than two weeks of abstinence) to reduce residual effects of substance use; however, it is possible that cannabis users who did not complete the abstinence protocol may have produced a different pattern of results. Thus, risk-taking behavior may be examined over the first few weeks of abstinence to determine how behavior changes when substance use is stopped. We were not able to examine the precise role of various substances on BART performance; therefore, the role of alcohol and other drug use in risk-taking should be further explored. Future studies may also examine physiological measures of marijuana levels prior to and throughout the abstinence period. Given that self-reported externalizing behavior was not correlated with BART performance, we did not pursue this variable further; however, future studies may consider the role of externalizing behavior on risk-taking and BART performance.

Implications

Marijuana and other substance use during adolescence and young adulthood is concerning because this is a critical time of continuing brain development (Gogtay et al., 2004; Gogtay and Thompson, 2010). The primary structure involved in executive functions and impulse control (i.e., the prefrontal cortex) is one of the last cortical structures to mature (Gogtay et al., 2004). A review by Gowin et al. (2013) suggests that individuals with substance use disorders show alterations in the prefrontal cortex and

in adjacent areas involved in executive functions and risk/reward processing (e.g. the ventromedial prefrontal cortex, orbital frontal cortex, dorsolateral prefrontal cortex, striatum, amygdala, anterior cingulate cortex, insular cortex), and these alterations have been associated with greater risk-taking on behavioral measures and elevated levels of substance use. Our finding of elevated risk-taking among marijuana users is in agreement with their hypothesis that substance users have impaired risk processing that may result from underactivation of areas responsible for evaluating risks and/or an overactivation of reward processing centers (Gowin et al., 2013). Marijuana users' poorer executive function (set-switching, or cognitive flexibility), while not correlated with the current measure of risk-taking, may reflect a weakness in flexibility of thinking that could also lead to deficiencies in effectively integrating and organizing information.

In their review of prefrontal cortex function and addiction, George and Koob (2010) described the prefrontal cortex as highly modulated with a variety of subsystems, and a dysfunction of any of these subsystems could explain the individual differences in self-regulation and vulnerabilities to substance use and/or addiction. Consistent with Romer et al. (2011), our findings also suggest that risk-taking is not always associated with executive dysfunction, and that there may not always be a linear relationship between the various executive cognitive functions (e.g. as tested by traditional neuropsychological measures) and more emotionally driven risk or reward processing. In light of the current and previous findings, clinicians should consider that dysfunction within one or more prefrontal executive subsystems may be responsible for behavior leading to or resulting from problematic substance use, and that risk-taking may not necessarily imply deficient executive functioning. While some risk-taking in adolescence is important as youth evolve into independent adults, continued research on the neurobehavioral mechanisms for maladaptive risk-taking can help us to understand why some youth progress to regular substance use or develop substance use disorders.

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Conflict of interest

The authors declare that there is no conflict of interest.

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