Published in final edited form as:
Psychopharmacology (Berl). 2013 March ; 226(2): 307–319. doi:10.1007/s00213-012-2908-5.

Impulsivity, Attention, Memory, and Decision-Making among Adolescent Marijuana Users

Donald M. Dougherty[1,*], **Charles W. Mathias**[1], **Michael A. Dawes**[1], **R. Michael Furr**[2], **Nora E. Charles**[1], **Anthony Liguori**[3], **Erin E. Shannon**[3], and **Ashley Acheson**[1]

[1]Department of Psychiatry, The University of Texas Health Science Center at San Antonio, San Antonio, TX

[2]Department of Psychology, Wake Forest University, Winston-Salem, NC

[3]Department of Physiology and Pharmacology, Wake Forest School of Medicine, Winston-Salem, NC

Abstract

Rationale—Marijuana is a popular drug of abuse among adolescents, and they may be uniquely vulnerable to resulting cognitive and behavioral impairments. Previous studies have found impairments among adolescent marijuana users. However, the majority of this research has examined measures individually rather than multiple domains in a single cohesive analysis. This study used a logistic regression model that combines performance on a range of tasks to identify which measures were most altered among adolescent marijuana users.

Objectives—The purpose of this research was to determine unique associations between adolescent marijuana user and performances on multiple cognitive and behavioral domains (attention, memory, decision-making, and impulsivity) in 14- to 17-year-olds while simultaneously controlling for performances across the measures to determine which measures most strongly distinguish marijuana users from non-users.

Methods—Marijuana-using adolescents (n=45) and controls (n=48) were tested. Logistic regression analyses were conducted to test for: (a) differences between marijuana users and non-users on each measure, (b) associations between marijuana use and each measure after controlling for the other measures, and (c) the degree to which (a) and (b) together elucidated differences among marijuana users and non-users.

Results—Of all the cognitive and behavioral domains tested, impaired short-term recall memory and consequence sensitivity impulsivity were associated with marijuana use after controlling for performances across all measures.

Conclusions—This study extends previous findings by identifying cognitive and behavioral impairments most strongly associated with adolescent marijuana users. These specific deficits are potential targets of intervention for this at-risk population.

Keywords

Marijuana; Cannabis; Adolescence; Impulsivity; Memory; Attention

*Corresponding author: Donald M. Dougherty, Ph.D., Professor and Director of the Division of Neurobehavioral Research, Department of Psychiatry, The University of Texas Health Science Center at San Antonio, NRLC MC 7793, 7703 Floyd Curl Drive, San Antonio, TX 78229-3900, USA, doughertyd@uthscsa.edu, Phone (210) 567-2745; Fax (210) 567-2748.

Introduction

Recent reports indicate 3.6% of adolescents report daily marijuana use by 10th grade, and use becomes more prevalent in later adolescence (Johnston et al. 2011). This is particularly concerning because adolescent marijuana use may result in lasting cognitive deficits and behavioral problems (Schneider 2008; Steinberg 2004; Steinberg et al. 2008; King et al. 2011). Studies in animals indicate the endocannabinoid system is especially sensitive to THC exposure during adolescence and can result in permanent structural brain changes with persistent cognitive and behavioral impairments (Schneider 2008; Trezza et al. 2008; Bossong and Niesink 2010; Malone et al. 2010). A better understanding of the relative cognitive and behavioral impairments present in adolescent marijuana users may provide insight into the risks this population faces for developing psychiatric conditions including psychotic and affective disorders, as well as more severe substance use disorders (Bossong and Niesink 2010; Moore, et al. 2007; Morral, et al. 2002; Rubino, et al. 2012; van Laar, et al. 2007). Below we review findings across 4 cognitive and behavioral domains (attention, memory, decision-making, and impulse control) in adolescent and adult marijuana users.

Attention

Adult users who began using marijuana before age 16 show impairments on a visual scanning attention task (Ehrenreich et al. 1999). Current and abstinent adult marijuana users performing a visual attention task also show less activity in right prefrontal, medial and dorsal parietal cortical regions and greater activity in multiple frontal, parietal and occipital brain regions relative to controls, suggesting altered regulation of attention circuitry (Chang, Yakupoz, Cloak, & Ernst, 2006). Adolescents who use marijuana regularly have deficits in sustained attention relative to non-users or occasional users (Jacobsen et al. 2004; Harvey et al. 2007), despite relatively brief histories of marijuana use, and attention deficits present in adolescent marijuana users appear to persist even after extended (3 week) abstinence periods (Hanson et al. 2010; Medina et al. 2007).

Memory

Both adolescent and adult marijuana users reportedly have impaired performance and altered brain activity across several forms of memory. Adults who are heavy marijuana users have short-term memory impairments (Wilson et al. 1994; Heishman et al. 1997; Pope and Yurgelun-Todd 1996; Mendhiratta et al. 1988), and adolescents who are heavy marijuana users have significant short-term memory impairments even after 6 weeks of abstinence (Schwartz et al. 1989). Adolescent marijuana users also have impaired recognition memory (Solowij et al. 2011), and adult and adolescent marijuana users show persistent deficits in recall memory (e.g., Miller et al. 1977, 1978; Schwartz et al. 1989; Heishman et al. 1997; Bolla et al. 2002), with adolescents reporting earlier onset of use showing greater recall memory deficits (Solowij et al. 2011). Poor recall memory performance in adult marijuana users is accompanied by decreased activity in the prefrontal cortex, increased activity in the cerebellum, and altered hippocampal lateralization (Block et al., 2002). In adolescents users, impaired recall memory has been related to increased cerebral blood flow to the left superior medial temporal gyrus (Jacobus et al. 2012). There is evidence that recall deficits can recover with extended abstinence in moderately heavy using adolescents (~4 uses per week; Hanson et al. 2010). Additionally, adolescent and adult marijuana users show altered activity in frontal cortical and parietal cortical regions while performing working memory tasks, despite a lack of behavioral differences (Schweinsburg et al., 2008; Schweinsburg et al., 2010; Jager, Block, Luitjen, & Ramsey, 2010; Kanayama, Rogowska, Pope, Gruber, & Yugelun-Todd, 2004). These results indicate that memory impairments and altered functioning in neural substrates supporting these processes may already be a prominent characteristic of adolescent marijuana users.

Decision-Making

Several studies have reported decision-making deficits in adult marijuana users, but similar measures have not been studied extensively in adolescents. Adults who are heavy marijuana users have impaired decision-making during a card-sorting task compared to infrequent users (Pope and Yurgelun-Todd 1996). They also show decision-making impairments on the Iowa Gambling Task (IGT) after both acute and extended abstinence periods (Whitlow et al. 2004; Wesley et al. 2011; Bolla et al., 2002, 2005). Adult marijuana users also have less activity following losses on the IGT in the anterior cingulate cortex, medial frontal cortex, precuneus, superior parietal lobe, occipital lobe and cerebellum (Wesley et al. 2011), indicating neural circuitry regulating decision-making may also be altered. However, it is unclear whether similar decision-making impairments are present in adolescents.

Impulse Control

Impaired impulse control during early adolescence may contribute to marijuana use (Mezzich et al. 2007; Gullo and Dawe 2008; King et al. 2011) and marijuana use during adolescence could plausibly interfere with normal development of impulse control. Commonly used behavioral measures of impulsivity appear to index a range of neuropsychological processes (de Wit and Richards 2004; Dougherty et al. 2009; Evenden 1999; Moeller et al. 2001; Winstanley et al. 2006) and frequently include three distinct processes: (1) rapid responding that occurs before complete processing and evaluation of a stimulus (i.e., response initiation, as measured by continuous performance or go/no go tasks); (2) failure to inhibit an already initiated response (i.e., response inhibition, as measured by stop signal tasks); and (3) reward-directed responding that persists despite less than optimal outcomes (i.e., consequence sensitivity, as measured by delay discounting and related delayed reward choice measures) (Dougherty et al. 2005). Adult marijuana users have altered frontal cortical activity (Eldreth et al. 2004; Tapert et al. 2007) and impaired performance (Bolla et al. 2002) during inhibition tasks. Young adult marijuana users (18–26 years old) show impaired consequence sensitivity relative to drug-naive controls on the Information Sampling Test (Clark et al. 2009). Finally, adolescent marijuana users with Conduct Disorder have increased response initiation impulsivity on a continuous performance task relative to non-user controls (Dougherty et al. 2007). Given these findings, otherwise healthy adolescent marijuana users may be expected to show deficits on all 3 impulsive processes outlined above, although this has not been empirically demonstrated.

Collectively, these results indicate adolescent marijuana users show impairments similar to those present in adult marijuana users with much longer use histories. The purpose of the present study was to test a sample of adolescent marijuana users and non-users on a battery of cognitive and behavioral measures that have been found to be altered in marijuana users. Measures are tested individually, as in previous research, as well as in a combined model. The use of a combined model including a number of cognitive and behavioral variables at one time allows for the identification of specific processes that are most strongly associated with adolescent marijuana users. The aim of this research was to reveal specific impairments that drive broader differences observed between adolescent marijuana users and non-users in order to guide future research on the etiology and treatment of marijuana use disorders.

Methods

Participant Recruitment, Screening and Enrollment Procedures

Adolescents were recruited from the Winston-Salem, NC area and classified based on their history of marijuana use. Users (n=45) reported using marijuana a minimum of 4 days per week for at least the last 6 months. Non-users (n=48) had no previous experience with marijuana. The Institutional Review Boards of Wake Forest University Health Sciences and

The University of Texas Health Science Center at San Antonio approved the study procedures, which were carried out in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Privacy was further protected by a Certificate of Confidentiality from the Department of Health and Human Services.

Recruitment: Volunteers responded to radio and television advertisements for "a research study comparing how using or not using marijuana affects mood, attention, and problem solving." Adolescents and a parent or legal guardian were first interviewed over the telephone to obtain general demographic and health characteristics (see Shannon et al. 2007). Interested respondents were invited for a comprehensive on-site interview to determine eligibility.

Screening Procedures: Data were gathered from the adolescent and/or the parent/guardian as a collateral observer for both groups. A physician assistant conducted a detailed health history and a physical examination of each adolescent to check for visual or motor impairments that might affect ability to comply with study procedures and to screen for the presence of serious medical conditions. Both the adolescent and the parent/guardian were interviewed using the Kiddie-Schedule for Affective Disorders and Schizophrenia: Present and Lifetime Version (K-SADS-PL; Kaufman et al. 1997) to assess psychiatric status. The Wechsler Abbreviated Scale of Intelligence (WASI; Psychological Corporation, 1999) was administered to the adolescent to assess intelligence. The adolescent was also interviewed using the Drug History Questionnaire (DHQ) to quantify current and lifetime substance use. For adolescents reporting marijuana use, the Modified Substance Use Disorders Module (Martin et al. 1995, 2000) of the Structured Clinical Interview for DSM-IV-TR Disorders (SCID; First et al. 2002) was administered. These data were self-reported and answers were not shared with the parent/legal guardian.

Upon arrival on both screening and experimental days, adolescents provided breath and urine samples to verify absence of recent use of alcohol, cocaine, benzodiazepines, opiates, or amphetamines (and THC in the Non-user group). Breath samples were tested using the AlcoTest® 7110 MKIII C device (Draeger Safety Inc., Durango, CO). Urine was tested using the Panel/Dip Drugs of Abuse Testing Device (Redwood Biotech, Santa Rosa, CA).

Exclusion criteria included: (1) physical conditions (e.g., dyslexia, motor impairments, or serious vision problems) that would interfere with reading forms or responding on a computer; (2) current or past DSM-IV Axis I psychiatric disorder; or (3) a Full Scale IQ < 70. Marijuana users were required to have no more than 10 lifetime uses of any illicit drug other than marijuana, and controls were required to have never used any illicit drugs. Subjects who met past or present criteria for substance use disorders other than marijuana use disorders (Users) or any past or present substance use disorder (Non-Users) were excluded. Current and lifetime alcohol and cigarette use were not exclusionary for either group.

Experimental Procedure

On the testing day, qualified participants arrived between 8:30–9:00 a.m. and provided breath and urine samples for alcohol and other drug screening. Participants completed the Barratt Impulsiveness Scale (BIS-11; Patton et al. 1995; Stanford et al. 2009). Users also completed the 47-item Marijuana Craving Questionnaire (Heishmann et al., 2001). This questionnaire is comprised of 47 statements rated 1 to 7 (i.e., Strongly Agree to Strongly Disagree) to assess current thoughts or feelings about marijuana use (e.g., *Right now, I am making plans to use marijuana* and *I would feel less anxious if I smoked marijuana right now*). Total marijuana craving scores can range from 47 to 329.

Participants completed cognitive and behavioral performance tests measuring five domains: (1) attention; (2) memory; (3) decision making; (4) impulse control; and (5) intelligence. Intelligence was always assessed first on the screening day; the order of administration of the remaining tasks was counterbalanced within each group.

Verification of abstinence from marijuana use: Users were required to abstain from marijuana use between the screening and testing visits (at least 18 hours abstinence). Abstinence was assessed by calculating change in the urinary Δ^9-tetrahydrocannabinol (THC) to creatinine ratio; an increase greater than 50% from screening to testing was exclusionary (Huestis et al. 1995; Huestis and Cone 1998; Kouri et al. 1999). Three participants in the User group were excluded for increases of 162%, 236%, and 598%. THC and creatinine were measured by our reference laboratory (NorChem Drug Testing; Flagstaff, AZ).

Cognitive and Behavioral Domain Measures

Attention—Sustained attention was assessed using two measures: the Rapid Visual Information Processing (RVP), and IMT Correct Detections.

Rapid Visual Information Processing (RVP): The RVP, a component of the Cambridge Neuropsychological Test Automated Battery (CANTAB; CeNeS Limited, 1999), tests sustained attention involving identification of target number sequences. During the RVP, digits ranging from 2 to 9 are presented in pseudo-random order at 100 digits per minute during a 7-min session. Participants must identify target sequences of digits (e.g., 3-5-7, 2-4-6, or 4-6-8) by pressing a button. After a brief practice, 27 sequences were randomized within a 4-min testing period. The primary measure is the number of Total Correct Identifications.

Immediate Memory Task (IMT): The IMT (Dougherty and Marsh, 2002, 2003) is a modified Continuous Performance Test (Beck et al. 1956). It assesses attention and response initiation impulsivity, defined as a response to a target stimulus before complete processing of that stimulus (Dougherty and Marsh 2002, 2003). In this computerized task, a series of 5-digit numbers are presented in rapid sequence (500 ms on, 500 ms off) during a 10-min session. Participants are instructed to respond to a number that matches the previous number. Sustained attention is assessed by the total of correct detections of consecutive matching 5-digit numbers. The primary measure of sustained attention in the IMT is the total number of Correct Detections.

Memory—Two measures were used to assess verbal learning and short- and long-term aspects of memory, the Brown-Peterson Memory Test (B-P), and the Buschke Selective Rating Test (BSRT).

Brown-Peterson Memory Test (B-P): The B-P (Brown 1958; Peterson and Peterson 1959; Mertins et al. 2006) is a validated test of short-term memory and recall that involves consonant trigrams (for example, QLX, SZB). After hearing each trigram, a participant is given a random number and told to count backwards and out loud by three from that number (for example, “98, 95, 92 …”). After a delay interval of 9, 18, or 36 s, the participant is asked to recall the consonant trigram. Delay intervals are presented in randomized order. There are five trials of each delay interval for a total of 15 trials. The primary variable of the B-P Memory Test is the number of Total Correct Trigrams Recalled.

Buschke Selective Reminding Test (BSRT): The BSRT (Buschke 1973; Beatty et al. 1996) is a validated measure of verbal learning and transfer into long-term memory storage.

A list of 12 common words is read to the participant, who then attempts to recite as many of them as possible within 60 seconds (Trial 1). Next, the participant is “selectively reminded” of forgotten words by hearing words that were not recalled during Trial 1. The participant is then given another 60 seconds to recall as many of the 12 original words as possible (Trial 2). The reminding/recall cycle is continued until 12 trials are completed. The number of Total Words Recalled and Consistent Long-Term Retrieval (total number of words consistently recalled from trial to trial without further reminding) are the primary measures of learning and memory.

Decision Making—Two measures were used to assess decision making, the Iowa Gambling Task and the Intradimensional/Extradimensional Shift test.

Iowa Gambling Task (IGT): The IGT (Bechara et al. 1997) is a 15-min computerized task in which participants choose from four decks of cards that result in rewards of different magnitudes and associated losses. Each deck (labeled A, B, C, and D) contained 60 cards, and participants made 100 choices during the testing session. Two decks of cards led to short-term minimal monetary rewards, but were more advantageous eventually due to larger losses in the other two decks. The primary dependent measure of the IGT is the Total Difference Score, calculated as the number of advantageous choices minus disadvantageous choices.

Intradimensional/Extradimensional Shift (ID/ED): The ID/ED test (CeNeS Limited, 1999) is a modification of the Wisconsin Card Sorting Task (WCST; Heaton 1981). Pairs of stimuli (one correct and one incorrect) are presented in nine stages, each defined by a selection criterion. After six consecutive correct responses in each stage, the selection criterion changes. The participant infers criterion changes from feedback following each correct or incorrect choice. There are both intra- and extra-dimensional stages. For example, an intra-dimensional attribute might be color-filled shapes and an extra-dimensional attribute might be lines overlaying shapes. The primary dependent variable is the number of Total Errors (Adjusted), which includes predicted errors for individuals who fail to complete all stages (CeNeS Limited, 1999).

Impulsivity—Impulsive behavior was assessed using the Immediate Memory Task, the GoStop Impulsivity Paradigm, the Two Choice Impulsivity Paradigm, and the Single Key Impulsivity Paradigm.

Immediate Memory Task (IMT): The IMT also measures impulse control. Impulsivity is defined as responses (i.e., commission errors) to near-matches of the 5-digit numbers presented. The primary dependent variable of IMT impulsivity is the total number of Commission Errors.

GoStop Impulsivity Paradigm (GoStop): The GoStop task (Dougherty et al. 2003c, 2005) assesses the ability to withhold an already initiated response in the face of changing information. In this task, 5-digit numbers are presented in rapid sequence (500 ms on, 1500 ms off), half of which are exact matches to the immediately preceding number. Matching numbers include “go” trials, numbers presented in black for the full 500 ms, and “stop” trials, numbers that change from black to red at one of four predefined delays: 50, 150, 250, or 350 ms after stimulus onset. Participants must respond to a matching number while it is still on the screen, but withhold that response if it changes from black (*go*) to red (*stop*). The primary dependent variable of the GoStop is the total number of incorrect responses to the *stop* stimuli, the Inhibition Failures. Because previous research has shown that the 150 ms stop delay best discriminates between impulsive and control groups (e.g., Dougherty et al., 2003; Dougherty et al. 2009; Marsh et al. 2002), only data for those trials are analyzed in this study.

Two Choice Impulsivity Paradigm (TCIP): The TCIP (Dougherty et al. 2003a, 2005) tests consequence sensitivity aspects of impulsivity, offering discrete choices between rewards of different magnitudes and temporal delays (Dougherty et al. 2005). Fifty choices between a circle and square are presented simultaneously on a computer monitor (left/right orientation randomized). Choosing a circle earns 5 points after a 5-second delay; choosing a square earns 15 points after a 15-second delay. Participants infer the delay/reward contingencies during a practice session of 5 circles and 5 squares presented individually. Points earned are displayed throughout the 5- to 13-minute session. The primary dependent variable of TCIP impulsivity is the number of Total Short Choices.

Single Key Impulsivity Paradigm (SKIP): The SKIP (Dougherty et al. 2003b, 2005) tests consequence sensitivity aspects of impulsivity, but uses free operant choices for rewards. In a 20-min session, the participant can respond freely by clicking a computer mouse. Each response earns points that increase linearly as the length of the delay between responses increases. The participant infers the delay/reward contingencies from point counters that display the points earned for each response, which provides immediate feedback about the delay/reward contingency, as well as the total accumulation of points earned. The primary dependent variable of SKIP impulsivity is the number of Total Responses.

General Intellectual Ability—Intelligence was measured using the Wechsler Abbreviated Scale of Intelligence (WASI; Psychological Corporation, 1999). The WASI estimates intelligence based on the sum of four subscale scores: vocabulary, block design, similarities, and matrix reasoning. IQ scores are calculated using age-based norms. Full scale IQ score was the primary measure of intelligence.

Data Analyses

Characteristics of the marijuana User and Non-user groups were compared with Chi-square (i.e., gender and ethnicity) and two-tailed independent samples *t*-tests (i.e., age, BIS-11). Before primary analyses, scores from each task were transformed to *Z*-scores to allow for effect size comparisons across measures.

We used logistic regression to test the primary hypotheses regarding which cognitive and behavioral variables were most robustly associated with marijuana use. For each variable that reflects cognitive and inhibitory control, logistic regression provides an odds ratio (OR) statistic and a Wald test. For the combined variable analysis, Nagelkerke's R^2 reflects the proportion of variance in marijuana use explained by the set of independent variables entered, and the overall accuracy of using those variables to classify participants into either group (Users or Non-users) is reported. Logistic regression was chosen because this method allowed us to examine the relative combined and unique relation of each aspect of impulsivity and information processing variable with marijuana use or non-use. Additionally, logistic regression is designed for binary outcomes (User versus Non-user) and requires less restrictive assumptions about the normality of the distribution of data than do traditional parametric t-tests, correlations, and linear regression. This is important for this research because many of our variables were not normally distributed.

We evaluated the strength of the association between marijuana use and each measure of impulsivity and information processing by conducting separate one-predictor logistic regression analyses to determine the degree to which each variable, by itself, was associated with marijuana use or non-use. Each analysis treated the group as the dependent variable and a cognitive or inhibitory control variable as a predictor variable. These analyses reveal the degree to which marijuana users differ from non-users on each cognitive and inhibitory control variable. Next, we combined all 12 variables in one multiple-predictor logistic regression model to determine which variables accounted for the differences between groups when controlling for scores on other variables. This final analysis allows us to identify the specific processes that differ most between adolescent marijuana users and non-users while simultaneously controlling for performances across all measures.

Results

Demographic Characteristics

Groups did not differ significantly in terms of age, gender, or ethnicity. There was no association between age and either self-reported trait impulsivity (BIS-11) or performance on any impulsivity or information-processing tasks ($p > .01$, Bonferroni correction for multiple comparisons). Compared to Non-users, Users showed significantly greater trait impulsivity, as measured by BIS-11 Attention, Motor, and Nonplanning subscales (Table 1).

Users reported smoking marijuana an average of 5.2 days per week (± 1.2), with an average of 2.8 (± 1.7) years of marijuana use (Table 2). The age of onset of DSM-IV clinical symptoms of problem marijuana use was 15.3 years. Among Users, 77% met DSM-IV criteria for marijuana abuse ($n = 15$) or dependence ($n = 20$). The median score on the Marijuana Craving Questionnaire was 81.44 (range 61–99). The average THC/creatinine ratio was significantly reduced among Users between the screening and experimental testing sessions ($F1,41 = 11.8$, $p = .001$; screening day $M = 1.7 \pm 1.9$; Testing Day $M = 1.2 \pm 1.4$). No participants met criteria for abuse or dependence for any other drug. Among all users, 40% had never used any illicit drugs other than marijuana, and only one tested positive for a drug besides THC (benzodiazepine). This subject reported taking alprazolam (Xanax®) 2 days before testing. Two other subjects reported other illicit drug use in the past week; however, most subjects reported their most recent other illicit drug use was at least a few months prior to testing.

Participants in both groups who had ever used alcohol (Users: n = 38; Non-users: n =20) or cigarettes (Users: n = 44; Non-users: n = 12) had a similar age of onset for alcohol (Users: $M = 13.69 \pm 2.00$, Non-users: $M = 13.95 \pm 2.84$) and cigarettes (Users: $M = 12.93$, SD 2.29, Non-users: $M = 12.27 \pm 3.93$). Most of the sample did not report regular cigarette use.

Group Differentiation – Individual Analyses of Behavioral Measures

Users showed poor performance on measures of attention and memory compared to Non-Users, as well as higher rates of decision-making errors and greater impulsivity (Table 3). Although there was a difference in IQ between Users and Non-users, it did not reach statistical significance, $t(91) = 1.86$, *ns*. The left column of Table 4 depicts the results of the individual analyses, which tested associations between each cognitive and behavioral measure and being a User or Non-user. Several measures were significantly related to group membership: IMT Correct Detections (Wald = 6.09, $p = .011$), Brown-Peterson Total Recall (Wald = 13.45, $p = .000$), BSRT Total Recall (Wald = 5.57, $p = .014$), ID/ED Total Adjusted Errors (Wald = 5.67, $p = .008$) and TCIP Proportion Short Responses (Wald = 9.73, $p = .001$).

Group Differentiation – Combined Analyses of Behavioral Measures

The model containing all 12 behavioral variables accounted for a significant amount of the variance between groups (Nagelkerke's $R^2 = .44$, $\chi^2(12) = 37.48$, p = .000), with an overall classification accuracy of 80% (81% of Non-users and 78% of Users). This multiple-predictor analysis describes the relative association of each predictor with being a User or Non-user when other predictors are held constant (Table 4, right). Lower memory scores for Brown-Peterson Total Recall (Wald = 5.19, $p = .012$) and higher impulsivity scores for TCIP Short Response (Wald = 7.51, $p = .012$) were associated with being in the User group. In addition, there was a trend for more inhibition failures among Users on the GoStop 150 ms stop delay (Wald = 3.03, $p = .060$) compared with Non-users. Thus, short-term memory deficits and impulsivity were significantly and uniquely related to marijuana user group membership.

Effects of Cigarette & Alcohol Use

Although marijuana use was the primary drug used by our participants, a significant number reported cigarette and/or alcohol use in the previous year. In order to remove possible confounding effects of using these substances on our results, the combined variables analyses were repeated including the self-reported number of cigarettes smoked in the previous year, similar to previously reported methods with marijuana-using adolescents and adults (e.g., Chen, Kandel, & Davies, 1997), as well as the number of alcoholic drinks consumed in the previous year. This model accounted for a significant amount of the variance between groups (Nagelkerke's $R^2 = .55$, $\chi^2(14) = 49.39$, p = .000), with an overall classification accuracy of 86% (90% of Non-users and 82% of Users). Results indicate the same two variables remained significantly related to marijuana use: TCIP total short responses (Wald = 3.94, $p = .047$) and B-P total correct trigrams recalled (Wald = 4.89, $p = .027$). As in the original analyses, no other cognitive and behavioral variables were significantly associated with group membership (all *p*s > .05).

Discussion

In this study, being an adolescent marijuana user was associated with impaired performance on measures of sustained attention, short-term memory, decision making, impulse control (both response inhibition and consequence sensitivity types), and intelligence. When these same processes were analyzed while holding other cognitive and behavioral performance variables constant, unique impairments on the short-term memory and consequence sensitivity impulsivity measures were revealed among the marijuana-using adolescents. Additionally, similar patterns of scores were observed when controlling for cigarette smoking and alcohol use. Finally, we correctly classified 80% of participants as Users or Non-users based on scores on the 12 behavioral tasks.

Implications of attention findings

Consistent with previous studies, impaired sustained attention was associated with adolescent marijuana use (Jacobsen et al, 2004; Harvey et al., 2007). The IMT appeared to be more sensitive than the RVP (possibly due to stimulus complexity and/or number of trials), however, performances on attention measures were not associated with marijuana use after controlling for other predictors. This suggests that impairments on measures other than sustained attention were more robustly associated with being an adolescent marijuana user.

Implications of memory findings

Our observation that impairments in short-term recall memory are strongly associated with being an adolescent marijuana user is consistent with previous reports in adolescent and adult marijuana users (e.g., Miller et al. 1977, 1978; Schwartz et al. 1989; Hanson et al. 2010; Heishman et al. 1997). Adult marijuana users have substantially impaired short-term and recall memory (Mendhiratta et al. 1988; Wilson et al. 1994; Pope and Yurgelun-Todd 1996; Heishman et al. 1997; Bolla et al. 2002), as did marijuana-dependent adolescents even after 6 weeks of continuous monitored abstinence (Schwartz et al. 1989). Memory deficits in adolescents, who have used marijuana for relatively fewer years, appear similar to those in adults with decades of marijuana use (Solowij et al. 2002, 2011). In contrast, deficits in verbal learning and transfer into long-term memory storage were not robustly associated with marijuana use, indicating deficits in these processes may not be a defining characteristic of adolescent marijuana users. Collectively, these findings support the suggestion that adolescent marijuana users may have altered prefrontal development and connectivity with parahippocampal regions, which may underlie impairments in short-term memory (Jager et al. 2010).

Implications of decision making findings

Lane and colleagues (2007) reported that heavy marijuana users showed impaired performance on the Wisconsin Card Sorting Task relative to control participants with limited marijuana use. A similar task and sample was used in our study. Although we found that performance on the Intradimensional/Extradimensional Shift task (ID/ED) discriminated between marijuana Users and Non-users, neither decision-making task predicted group membership in the combined variable analysis. These results suggest that impaired decision-making is not a primary deficit of adolescent marijuana users. However, both measures of decision-making used in the present study also include significant learning components, so these findings may be related to a limited influence of adolescent marijuana use on learning abilities.

Implications of impulsivity findings

Increased impulsivity among marijuana users in our study is also consistent with previous findings. Adult marijuana users have altered brain activity or performance on inhibition tasks (Bolla et al. 2002; Eldreth et al. 2004; Tapert et al. 2007). Our study suggests that response consequence sensitivity and to a lesser extent response inhibition impulsivity (but not response initiation impulsivity) are robustly associated with being an adolescent marijuana user. Previous research in adolescent marijuana users also showed poorer performance on the Information Sampling Test (Clark et al. 2009), consistent with greater consequence sensitivity impulsivity, and impaired response inhibition (Tapert et al., 2007). In addition, adolescents with more impulsive performance on the TCIP lapse to marijuana use earlier in treatment trials (Dawes et al., in preparation), suggesting that the consequence sensitivity aspect of impulsivity may be important in response to treatment. Increased consequence impulsivity and response inhibition impulsivity occurs in individuals at risk for developing drug and alcohol use disorders (Acheson et al. 2011a; Acheson et al. 2011b; Nigg et al. 2006; Rubio et al. 2008; Saunders et al. 2008), suggesting that these traits may precede marijuana use and could have contributed to initiating drug use.

Implications of groups' substance use experience

A limitation of this study is participants' exposure to substances other than marijuana in our user group. However, these participants had relatively little experience with substances other than marijuana and identified marijuana as their drug of choice. Controlling for cigarette and alcohol use within the last year produced very similar results to our original analyses, suggesting our results pertain to the specific associations between marijuana use and the cognitive and impulse control variables. It is not possible to distinguish from this data whether these differences could be observed before exposure to marijuana or whether they are a consequence of marijuana use. Given the relatively short duration of use, it seems plausible that these deficits existed prior to marijuana use. To address this, we are currently conducting longitudinal studies using similar measures in children at risk for substance use disorders and will be testing these individuals across adolescence.

Overall study implications and future directions

Our study extends previous findings by demonstrating that impaired short-term recall memory and increased consequence sensitivity impulsivity are most strongly associated with adolescent marijuana users among the battery of measures we tested. This provides a foundation for future studies to target specific processes and corresponding neurobiological substrates altered in adolescent marijuana users. These impairments may relate to these individuals' increased risk for future psychiatric conditions, including psychotic and affective disorders as well as more severe substance use disorders (Bossong and Niesink 2010; Moore et al. 2007; Morral et al. 2002; Rubino et al. 2012; van Laar et al. 2007). Prospective studies are needed to determine to what extent these impairments may be a cause or consequence marijuana use, and we are currently conducting this research. Finally, treatment strategies that better account for these impairments may result in improved compliance and minimize relapses.

Acknowledgments

We gratefully acknowledge the assistance of Christy Duncan, P.A. in collection of data from which this manuscript was prepared.

Funding for this study was provided by NIDA grant R21-DA020993 from the National Institute on Drug Abuse. Additionally, Dr. Dougherty acknowledges support from the William and Marguerite Wurzbach Distinguished Professorship and The University of Texas Regent's Scholar Award.

References

Acheson A, Richard DM, Mathias CW, Dougherty DM. Adults with a family history of alcohol related problems are more impulsive on measures of response initiation and response inhibition. Drug Alcohol Depend. 2011a; 117:198–203.10.1016/j.drugalcdep.2011.02.001 [PubMed: 21376480]

Acheson A, Vincent AS, Sorocco KH, Lovallo WR. Greater Discounting of Delayed Rewards in Young Adults with Family Histories of Alcohol and Drug Use Disorders: Studies from the Oklahoma Family Health Patterns Project. Alcohol Clin Exp Res. 2011b10.1111/j.1530-0277.2011.01507.x

Albert D, Steinberg L. Age differences in strategic planning as indexed by the tower of London. Child Dev. 2011; 82:1501–17.10.1111/j.1467-8624.2011.01613.x [PubMed: 21679178]

Beatty WW, Krull KR, Wilbanks SL, Blanco CR, Hames KA, Paul RH. Further validation of constructs from the selective reminding test. J Clin Exp Neuropsychol. 1996; 18:52–5.10.1080/01688639608408261 [PubMed: 8926296]

Bechara A, Damasio H, Tranel D, Damasio AR. Deciding advantageously before knowing the advantageous strategy. Science. 1997; 275:1293–1295.10.1126/science.275.5304.1293 [PubMed: 9036851]

Bohm B, Smedler AC, Forssberg H. Impulse control, working memory and other executive functions in preterm children when starting school. Acta Paediatr. 2004; 93:1363–71.10.1111/j.1651-2227.2004.tb02938.x [PubMed: 15499959]

Bolla KI, Brown K, Eldreth D, Tate K, Cadet JL. Dose-related neurocognitive effects of marijuana use. Neurology. 2002; 26:480–492.10.1212/01.WNL.0000031422.66442.49

Bolla KI, Eldreth D, Matochik JA, Cadet JL. Neural substrates of faulty decision-making in abstinent marijuana users. NeuroImage. 2005; 59:1337–1343.10.1016/j.neuroimage.2005.02.012

Bossong MG, Niesink RJ. Adolescent brain maturation, the endogenous cannabinoid system and the neurobiology of cannabis-induced schizophrenia. Prog Neurobiol. 2010; 92:370–385.10.1016/j.pneurobio.2010.06.010 [PubMed: 20624444]

Brown J. Some tests of the decay of immediate memory. Quarterly J Exp Psychol. 1958; 10:12–21.10.1080/17470215808416249

Buschke H. Selective reminding for analysis of memory and learning. J Verbal Learn Verbal Behav. 1973; 12:543–550.10.1016/S0022-5371(73)80034-9

Casey B, Jones RM, Somerville LH. Braking and Accelerating of the Adolescent Brain. J Res Adolesc. 2011; 21:21–33.10.1111/j. 1532-7795.2010.007.x [PubMed: 21475613]

CeNes Limited. CANTAB for Windows Test Administration Guide. Cambridge, England: 1999.

Chambers RA, Taylor JR, Potenza MN. Developmental neurocircuitry of motivation in adolescence: A critical period of addiction vulnerability. Am J Psychiatry. 2003; 160:1041–1052.10.1176/appi.ajp. 160.6.1041 [PubMed: 12777258]

Chen K, Kandel DB, Davies M. Relationships between frequency and quantity of marijuana use and last year proxy dependence among adolescents and adults in the United States. Drug Alcohol Depend. 1997; 46:53–67.10.1016/S0376-8716(97)00047-1 [PubMed: 9246553]

Clark L, Roiser JP, Robbins TW, Sahakian BJ. Disrupted 'reflection' impulsivity in cannabis users but not current or former ecstasy users. J Psychopharmacol. 2009; 23:14–22.10.1177/0269881108089587 [PubMed: 18515464]

Dougherty DM, Marsh DM, Mathias CW. Immediate and Delayed Memory Tasks: A computerized measure of memory, attention, and impulsivity. Behav Res Methods Instrum Comp. 2002; 34:391–398.10.3758/BF03195467

Dougherty, DM.; Marsh, DM. Neurobehavioral Research Laboratory and Clinic. University of Texas Health Science Center at Houston; Houston, TX: 2003. Immediate and Delayed Memory Task (Version 1.0) [Manual].

Dougherty, DM.; Marsh, DM.; Mathias, CW. Neurobehavioral Research Laboratory and Clinic. University of Texas Health Science Center; Houston, Houston, TX: 2003a. Two Choice Impulsivity Paradigm (Version 1.0) [Manual].

Dougherty DM, Mathias CW, Liguori A, Marsh DM, Dawes MA, Moeller FG. Behavioral impulsivity in adolescents with Conduct Disorder who use Marijuana. Addict Disord Their Treat. 2007; 6:43–50.

Dougherty, DM.; Marsh, DM.; Mathias, CW.; Papageorgiou, TD. Neurobehavioral Research Laboratory and Clinic. University of Texas Health Science Center at Houston; Houston, TX: 2003b. Single Key Impulsivity Paradigm (Version 1.0) [Manual].

Dougherty, DM.; Mathias, CW.; Marsh, DM. Neurobehavioral Research Laboratory and Clinic. University of Texas Health Science Center; Houston, Houston, TX: 2003c. GoStop Impulsivity Paradigm (Version 1.0) [Manual].

Dougherty DM, Mathias CW, Marsh DM, Jagar AA. Laboratory behavioral measures of impulsivity. Behav Res Methods. 2005; 37:82–90.10.3758/BF03206401 [PubMed: 16097347]

Ehrenreich H, Rinn T, Kunert HJ, Moeller MR, Poser W, Schilling L, Gigerenzer G, Hoehe MR. Specific attentional dysfunction in adults following early start of cannabis use. Psychopharmacology. 1999; 142:295–301.10.1007/s002130050892 [PubMed: 10208322]

Eldreth DA, Matochik JA, Cadet JL, Bolla KI. Abnormal brain activity in prefrontal brain regions in abstinent marijuana users. Neuroimage. 2004; 23:914–920.10.1016/j.neuroimage.2004.07.032 [PubMed: 15528091]

Ellgren M, Artmann A, Tkalych O, Gupta A, Hansen HS, Hansen SH, Devi LA, Hurd YL. Dynamic changes of the endogenous cannabinoid and opioid mesocorticolimbic systems during adolescence: THC effects. Eur Neuropsychopharmacol. 2008; 18:826–34.10.1016/j.euroneuro. 2008.06.009 [PubMed: 18674887]

Ernst M, Fudge JL. A developmental neurobiological model of motivated behavior: anatomy, connectivity and ontogeny of the triadic nodes. Neurosci Biobehav Rev. 2009; 33:367–82.10.1016/j.neurobiorev.2008.10.009 [PubMed: 19028521]

First, MB.; Spitzer, RL.; Gibbon, M.; Williams, JBW. Biometrics Research. New York State Psychiatric Institute; New York: 2002. Structured Clinical Interview for DSM-IV-TR Axis I Disorders, Research Version, Non-patient Edition (SCID-I/NP).

Fontes MA, Bolla KI, Cunha PJ, Almeida PP, Jungerman F, Laranjeira RR, Bressan RA, Lacerda AL. Cannabis use before age 15 and subsequent executive functioning. Br J Psychiatry. 2011; 198:442–7.10.1192/bjp.bp.110.077479 [PubMed: 21628706]

Gullo MJ, Dawe S. Impulsivity and adolescent substance use: Rashly dismissed as 'all-bad?'. Neurosci Biobehav Rev. 2008; 32:1507–1518.10.1016/j.neurobiorev.2008.06.003 [PubMed: 18588911]

Hanson KL, Winward JL, Schweinsburg AD, Medina KL, Brown SA, Tapert SF. Longitudinal study of cognition among adolescent marijuana users over three weeks of abstinence. Addict Behav. 2010; 35:970–6.10.1016/j.addbeh.2010.06.012 [PubMed: 20621421]

Harvey MA, Sellman JD, Porter RJ, Frampton CM. The relationship between non-acute adolescent cannabis use and cognition. Drug Alcohol Rev. 2007; 26:309–319.10.1080/09595230701247772. [PubMed: 17454021]

Heaton, RK. Wisconsin Card Sorting Test: Computer Version-2. Psychological Assessment Resources; Odessa, FL: 1993.

Heishman SJ, Arasteh K, Stitzer ML. Comparative effects of alcohol and marijuana on mood, memory, and performance. Pharmacol Biochem Behav. 1997; 58:93–101.10.1016/S0091-3057(96)00456-X [PubMed: 9264076]

Jacobsen LK, Mencl WE, Westerveld M, Pugh KR. Impact of cannabis use on brain function in adolescents. Ann N Y Acad Sci. 2004; 1021:384–390.10.1196/annals.1308.053 [PubMed: 15251914]

Jacobus J, Goldenberg D, Wierenga CE, Tolentino NJ, Liu TT, Tapert SF. Altered cerebral blood flow and neurocognitive correlates in adolescent cannabis users. Psychopharmacology (Berl). 2012; 222:675–84.10.1007/s00213-012-2674-4 [PubMed: 22395430]

Jager G, Block RI, Luijten M, Ramsey NF. Cannabis use and memory brain function in adolescent boys: A cross-sectional multicenter functional magnetic resonance study. J Am Acad Child Adolesc Psychiatry. 2010; 49:561–572.10.1016/j.jaac.2010.02.001 [PubMed: 20494266]

Jager G, Ramsey NF. Long-term consequences of adolescent cannabis exposure on the development of cognition, brain structure and function: an overview of animal and human research. Curr Drug Abuse Rev. 2008; 1:114–123.10.2174/1874473710801020114 [PubMed: 19630711]

Johnston, LD.; O'Malley, PM.; Bachman, JG.; Schulenberg, JE. Monitoring the Future national survey results on drug use, 1975–2007: Volume I, Secondary school students (NIH Publication No. 08-6418A). National Institute on Drug Abuse; Bethesda, MD: 2008.

Johnston, LD.; O'Malley, PM.; Bachman, JG.; Schulenberg, JE. Monitoring the Future national results on adolescent drug use: Overview of key findings, 2010. Ann Arbor: Institute for Social Research, The University of Michigan; 2011. Available via: http://www.monitoringthefuture.org/pubs/monographs/mtf-overview2010.pdf

Kaufman J, Birmaher B, Brent D, Rao U, Flynn C, Moreci P, Williamson D, Ryan N. Schedule for affective disorders and schizophrenia for school-age children- present and lifetime version (K-SADS-PL): Initial reliability and validity data. J Am Acad Child Adolesc Psychiatry. 1997; 36:980–988. doi: 10.109700004583-199707000-00021. [PubMed: 9204677]

King KM, Fleming CB, Monahan KC, Catalano RF. Changes in self-control problems and attention problems during middle school predict alcohol, tobacco, and marijuana use during high school. Psychol Addict Behav. 2011; 25:69–79.10.1037/a0021958 [PubMed: 21219040]

Malone DT, Hill MN, Rubino T. Adolescent cannabis use and psychosis: epidemiology and neurodevelopmental models. Br J Pharmacol. 2010; 160:511–522.10.1111/j.1476-5381.2010.00721.x [PubMed: 20590561]

Martin CS, Kaczynski NA, Maisto SA, Buckstein OG, Moss HB. Patterns of DSM-IV alcohol abuse and dependence symptoms in adolescent drinkers. J Stud Alcohol. 1995; 56:672–680. [PubMed: 8558899]

Martin CS, Pollock NK, Buckstein OG, Lynch KG. Inter-rater reliability of the SCID alcohol and substance use disorders section among adolescents. Drug Alcohol Depend. 2000; 59:173–176.10.1016/S0376-8716(99)00119-2 [PubMed: 10891630]

Medina KL, Hanson KL, Schweinsburg AD, Cohen-Zion M, Nagel BJ, Tapert SF. Neuropsychological functioning in adolescent marijuana users: subtle deficits detectable after a month of abstinence. J Int Neuropsychol Soc. 2007; 13:807–20.10.1017/S1355617707071032 [PubMed: 17697412]

Mertens VB, Gagnon M, Coulombe D, Messier C. Exploratory factor analysis of neuropsychological tests and their relationship to the Brown-Peterson task. Arch Clin Neuropsychol. 2006; 21:733–9.10.1016/j.acn.2006.08.005 [PubMed: 17071363]

Mezzich AC, Tarter RE, Feske U, Kirisci L, McNamee RL, Day BS. Assessment of risk for substance use disorder consequent to consumption of illegal drugs: Psychometric validation of the neurobehavior disinhibition trait. Psychol Addict Behav. 2007; 21:508–515.10.1037/0893-164X.21.4.508 [PubMed: 18072833]

Miller, LL. Marijuana: Acute effects on human memory. In: Agurell, S.; Dewey, WL.; Willette, RE., editors. The Cannabinoids: Chemical, Pharmacologica, and Therapeutic Aspects. Academic Press; Orlando, FL: 1984. p. 21-46.

Miller LL, Cornett TL, Brightwell DR, McFarland DJ, Drew WG, Wikler A. Marijuana: effects on storage and retrieval of prose material. Psychopharmacology (Berl). 1977; 51:311–316.10.1007/BF00431642 [PubMed: 403549]

Miller LL, Cornett T, McFarland D. Marijuana: An analysis of storage and retrieval deficits in memory with the technique of restricted reminding. Pharmacol Biochem Behav. 1978; 8:327–332.10.1016/0091-3057(78)90065-5 [PubMed: 674244]

Moeller FG, Barratt ES, Dougherty DM, Schmitz JM, Swann AC. Psychiatric aspects of impulsivity. Am J Psychiatry. 2001; 158:1783–1793.10.1176/appi.ajp.158.11.1783 [PubMed: 11691682]

Moore TH, Zammit S, Lingford-Hughes A, Barnes TR, Jones PB, Burke M, Lewis G. Cannabis use and risk of psychotic or affective mental health outcomes: a systematic review. Lancet. 2007; 370:319–28.10.1016/S0140-6736(07)61162-3 [PubMed: 17662880]

Morral AR, McCaffrey DF, Paddock SM. Reassessing the marijuana gateway effect. Addiction. 2002; 97:1493–504.10.1046/j.1360-0443.2002.00280.x [PubMed: 12472629]

Nigg JT, Wong MM, Martel MM, Jester JM, Puttler LI, Glass JM, Adams KM, Fitzgerald HE, Zucker RA. Poor response inhibition as a predictor of problem drinking and illicit drug use in adolescents at risk for alcoholism and other substance use disorders. J Am Acad Child Adolesc Psychiatry. 2006; 45:468–75.10.1097/01.chi.0000199028.76452.a9 [PubMed: 16601652]

Patton JH, Stanford MS, Barratt ES. Factor structure of the Barratt Impulsiveness Scale. J Clin Psychology. 1995; 51:768–774.10.1002/1097-4679(199511)51:6<768::AID-JCLP2270510607>3.0.CO;2-1

Peterson LR, Peterson MJ. Short-term retention of individual verbal items. J Exp Psychol. 1959; 58:193–198.10.1037/h0049234 [PubMed: 14432252]

Pope HG, Gruber AJ, Hudson JI, Cohane G, Huestis MA, Yurgelun-Todd D. Early-onset cannabis use and cognitive deficits: What is the nature of the association? Drug Alcohol Depend. 2003; 69:303–310.10.1016/S0376-8716(02)00334-4 [PubMed: 12633916]

Pope HGJ, Gruber AJ, Hudson JI, Huestis MA, Yurgelun-Todd D. Neuropsychological performance in long-term cannabis users. Arch Gen Psychiatry. 2001; 58:909–915.10.1001/archpsyc.58.10.909 [PubMed: 11576028]

Pope HG Jr, Yurgelun-Todd D. The residual cognitive effects of heavy marijuana use in college students. JAMA. 1996; 275:521–527.10.1001/jama.1996.03530310027028 [PubMed: 8606472]

Psychological Corporation. Wechsler Abbreviated Scale of Intelligence®. Harcourt Brace and Company; San Antonio, TX: 1999.

Rubio G, Jimenez M, Rodriguez-Jimenez R, Martinez I, Avila C, Ferre F, Jimenez-Arriero MA, Ponce G, Palomo T. The role of behavioral impulsivity in the development of alcohol dependence: a 4-year follow-up study. Alcohol Clin Exp Res. 2008; 32:1681–7.10.1111/j.1530-0277.2008.00746.x [PubMed: 18631324]

Rubino T, Zamberletti E, Parolaro D. Adolescent exposure to cannabis as a risk factor for psychiatric disorders. J Psychopharmacol. 2012; 26:177–88.10.1177/0269881111405362 [PubMed: 21768160]

SAMHSA - Substance Abuse and Mental Health Services Administration. NSDUH Series H-25, DHHS Publication No SMA 04-3964. Office of Applied Studies; Rockville, MD: 2004. Results from the 2003 National Survey on Drug Use and Health: National Findings.

SAMHSA - Substance Abuse and Mental Health Services Administration. NSDUH Series H-36, HHS Publication No SM 09-4434. Office of Applied Studies; Rockville, MD: 2009. Results from the 2008 National Survey on Drug Use and Health: National Findings.

SAMHSA - Substance Abuse and Mental Health Services Administration. NSDUH Series H-38A, HHS Publication No SMA 10-4586 Findings. Office of Applied Studies; Rockville, MD: 2010. Results from the 2009 National Survey on Drug Use and Health: Volume I. Summary of National Findings.

Saunders B, Farag N, Vincent AS, Collins FL Jr, Sorocco KH, Lovallo WR. Impulsive errors on a Go-NoGo reaction time task: disinhibitory traits in relation to a family history of alcoholism. Alcohol Clin Exp Res. 2008; 32:888–94.10.1111/j.1530-0277.2008.00648.x [PubMed: 18373725]

Schneider M. Puberty as a highly vulnerable developmental period for the consequences of cannabis exposure. Addict Biol. 2008; 13:253–263.10.1111/j.1369-1600.2008.00110.x [PubMed: 18482434]

Schwartz RH, Gruenewald PJ, Klitzner M, Fedio P. Short-term memory impairment in cannabis-dependent adolescents. Am J Dis Child. 1989; 143:1214–1219.10.1001/archpedi.1989.02150220110030 [PubMed: 2801665]

Shannon EE, Mathias CW, Marsh DM, Dougherty DM, Liguori A. Teenagers do not always lie: characteristics and correspondence of telephone and in-person reports of adolescent drug use. Drug Alcohol Depend. 2007; 90:288–291.10.1016/j.drugalcdep.2007.03.011 [PubMed: 17475417]

Solowij N, Jones KA, Rozman ME, Davis SM, Ciarrochi J, Heaven PC, Lubman DI, Yücel M. Verbal learning and memory in adolescent cannabis users, alcohol users and Non-users. Psychopharmacology. 2011; 216:131–144.10.1007/s00213-011-2203-x [PubMed: 21328041]

Solowij N, Michie P. Cannabis and cognitive dysfunction: Parallels with endophenotypes of Schizophrenia. J Psychiatry Neurosci. 2007; 32:30–52. [PubMed: 17245472]

Solowij N, Stephens RS, Roffman RA, Babor T, Kadden R, Miller M, Christiansen K, McRee B, Vendietti J. for the Marijuana Treatment Project Research Group . Cognitive functioning of long-term heavy cannabis users seeking treatment. JAMA. 2002; 287:1123–1131.10.1001/jama.287.9.1123 [PubMed: 11879109]

Stanford MS, Mathias CW, Dougherty DM, Lake SL, Anderson NE, Patton JH. Fifty years of the Barratt Impulsiveness Scale: An update and review. Pers Indiv Diff. 2009; 47:385–395.10.1016/j.paid.2009.04.008

Steinberg L. Risk taking in adolescence: What changes, and why? Ann N Y Acad Sci. 2004; 1021:51–58.10.1196/annals.1308.005 [PubMed: 15251873]

Steinberg L, Albert D, Cauffman E, Banich M, Graham S, Woolard J. Age differences in sensation seeking and impulsivity as indexed by behavior and self-report: Evidence for a dual systems model. Dev Psychol. 2008; 44:1764–1778.10.1037/a0012955 [PubMed: 18999337]

Tapert SF, Schweinsburg AD, Drummond SP, Paulus MP, Brown SA, Yang TT, Frank LR. Functional MRI of inhibitory processing in abstinent adolescent marijuana users. Psychopharmacology (Berl). 2007; 194:173–183.10.1007/s00213-007-0823-y [PubMed: 17558500]

Tarter RE, Kirisci L, Mezzich A, Cornelius JR, Pajer K, Vanyukov M, Gardner W, Blackson T, Clark D. Neurobehavioral disinhibition in childhood predicts early age at onset of substance use disorder. Am J Psychiatry. 2003; 160:1078–1085.10.1176/appi.ajp.160.6.1078 [PubMed: 12777265]

Tau GZ, Peterson BS. Normal development of brain circuits. Neuropsychopharmacology. 2010; 35:147–68.10.1038/npp.2009.115 [PubMed: 19794405]

Trezza V, Cuomo V, Vanderschuren LJ. Cannabis and the developing brain: insights from behavior. Eur J Pharmacol. 2008; 585:441–452.10.1016/j.ejphar.2008.01.058 [PubMed: 18413273]

van Laar M, van Dorsselaer S, Monshouwer K, de Graaf R. Does cannabis use predict the first incidence of mood and anxiety disorders in the adult population? Addiction. 2007; 102:1251–60.10.1111/j.1360-0443.2007.01875.x [PubMed: 17624975]

Wesley MJ, Hanlon CA, Porrino LJ. Poor decision-making by chronic marijuana users is associated with decreased functional responsiveness to negative consequences. Psychiatry Res. 2011; 191:51–59.10.1016/j.pscychresns.2010.10.002 [PubMed: 21145211]

Wilson WH, Ellinwood EH, Mathew RJ, Johnson K. Effects of marijuana on performance of a computerized cognitive-neuromotor test battery. Psychiatry Res. 1994; 51:115–125.10.1016/0165-1781(94)90031-0 [PubMed: 8022946]

Whitlow CT, Liguori A, Livengood LB, Hart SL, Mussat-Whitlow BJ, Lamborn CM, Laurienti PJ, Porrino LJ. Long-term heavy marijuana users make costly decisions on a gambling task. Drug Alcohol Depend. 2004; 76:107–111.10.1016/j.drugalcdep.2004.04.009 [PubMed: 15380295]

Table 1

Demographic characteristics of adolescent marijuana users and Non-users.

	Group				
	Non-users *n* = 48	**Marijuana users *n* = 45**			
Characteristics	***Mean (SD)***	***Mean (SD)***	t	df	***p*-value**
Age (years)	16.1 (1.0)	16.2 (0.9)	0.8	91	.404
BIS-11 attentional	14.9 (4.0)	17.4 (9.5)	3.2	91	.002
BIS-11 motor	21.5 (3.8)	23.5 (4.1)	2.5	91	.016
BIS-11 nonplanning	23.7 (5.3)	27.6 (4.6)	3.8	91	.000
BMI (females n=27)	23.0 (6.3)	27.6 (9.5)	1.5	25	.145
BMI (males n=64)	22.8 (4.6)	24.0 (6.0)	0.9	62	.374
Gender	**N (%)**	**N (%)**	χ^2	df	***p*-value**
Female	15 (31.3)	12 (26.7)	.24	1	.627
Male	33 (68.8)	33 (73.3)			
Ethnicity	**N (%)**	**N (%)**	χ^2	df	***p*-value**
African-American	18 (37.5)	21 (46.7)	1.6	3	.654
Caucasian	28 (58.3)	23 (51.1)			
Indian	1 (2.1)	0 (0.0)			
Bi-racial	1 (2.1)	1 (2.2)			

Table 2

Substance use characteristics of adolescent marijuana users and Non-users.

	Non-users n = 48	Marijuana users n = 45			
Current Marijuana & other drug use	**N (%)**	**N (%)**	χ^2	*df*	*p*-value
Marijuana			85.31	2	.000
0 joints/week	48 (100)	0 (0.0)			
0–3 joints/week	0 (0.0)	9 (20.0)			
> 3 joints/week	0 (0.0)	36 (80.0)			
Alcohol			23.63	2	.000
0 drinks/week	43 (89.6)	19 (42.2)			
1–7 drinks/week	3 (6.3)	19 (42.2)			
> 7 drinks/week	2 (4.2)	7 (15.6)			
Cigarettes			42.00	3	.000
0/day	47 (97.9)	16 (35.6)			
1–4/day	0 (0.0)	13 (28.6)			
5–10/day	1 (2.1)	12 (26.7)			
> 10/day	0 (0.0)	4 (8.9)			
Lifetime other drug use	**N (%)**	**N (%)**	χ^2	*df*	*p*-value
Alcohol			27.41	2	.000
Never used	28 (58.3)	7 (15.6)			
1–10 uses	12 (25.0)	7 (15.6)			
> 10 uses	8 (16.7)	31 (68.9)			
Cigarettes			60.56	2	.000
Never used	36 (75.0)	1 (2.2)			
1–50 uses	11 (22.9)	14 (31.1)			
> 50 uses	1 (2.1)	30 (66.7)			
Stimulants			2.18	1	.140
Ever used	0 (0.0)	2 (4.4)			
Narcotics			9.34	1	.002
Ever used	0 (0.0)	8 (17.8)			

	Non-users n = 48	Marijuana users n = 45			
Current Marijuana & other drug use	**N (%)**	**N (%)**	χ^2	***df***	***p*-value**
Benzodiazepines			10.63	1	.001
Ever used	0 (0.0)	9 (20.0)			

Table 3

Scores of adolescent marijuana users and Non-users on cognitive measures.

	Group				
	Non-users *n* = 48	**Marijuana Users *n* = 45**			
Cognitive Domain/Testing Instruments	***Mean (SD)***	***Mean (SD)***	***t***	***df***	***p*-value**
Attention					
RVP Total Correct Identifications	16.7 (4.5)	15.6 (4.4)	1.6	91	.111
IMT Correct Detections	83.7 (8.8)	78.4 (10.8)	2.6	91	.011
Memory					
B-P Total Recall	32.6 (8.7)	25.1 (8.2)	4.3	91	.000
BSRT Total Recall	121.2 (15.1)	112.5 (18.2)	2.5	91	.014
BSRT CLTR	90.7 (36.1)	79.0 (35.8)	1.6	91	.121
Decision Making					
ID/ED Total Errors (Adj.)	25.3 (21.6)	37.5 (22.0)	2.7	91	.008
IGT Total Difference Score	−5.9 (27.4)	−8.9 (22.1)	.59	91	.559
Impulsivity					
IMT Commission Errors	38.9 (12.4)	36.6 (13.7)	.86	91	.395
GoStop Inhibition Failures-150 ms	5.0 (3.5)	6.5 (4.1)	1.9	91	.058
TCIP Total Short Responses	9.7 (11.0)	19.2 (15.2)	3.5	91	.001
SKIP Total Responses	438.2 (1034.4)	249.5 (584.9)	1.1	91	.286
General Intellectual Ability					
WASI Full-Scale Score	100.1 (13.9)	95.4 (10.5)	1.9	91	.066

Table 4

Performance differences between the marijuana user and Non-user groups were determined using logistic regression. The resulting odds ratios indicate the magnitude of the difference in performance between the groups. Two procedures were used: first, each of the 12 variables was tested separately to determine how well each measure by itself would distinguish between groups (Separate Variable Analyses, left); second, all measures were combined into a single analysis to control for overlap among the variables (e.g., measurement of common qualities) and determine which measure or combination of the measures best captures the unique characteristics that differentiate the two groups (Combined Variable Analyses, right).

	Separate Variable Analyses		Combined Variable Analyses	
Cognitive Domain/Testing Instruments	**B SE**	**Odds Ratio (95%CI)**	**B SE**	**Odds Ratio (95%CI)**
Attention				
RVP Total Correct Identifications	−.34 (.22)	.71 (.47–1.08)	.03 (.31)	1.03 (.56–1.90)
IMT Correct Detections	−.56 (.23)	.57 * (.37–.89)	−.31 (.30)	.73 (.41–1.33)
Memory				
B-P Total Correct Trigrams Recalled	−.94 (.26)	.39 *** (.24–.64)	−.98 (.43)	.38 * (.16–.87)
BSRT Total Words Recalled	−.56 (.24)	.57 * (.36–.91)	−.52 (.71)	.60 (.15–2.40)
BSRT Consistent Long-Term Retrieval	−.33 (.21)	.72 (.47–1.09)	.65 (.62)	1.92 (.57–6.52)
Decision Making				
IDED Total Errors (Adjusted)	.57 (.22)	1.76 * (1.15–2.71)	.30 (.31)	1.35 (.74–2.49)
IGT Total Difference Score	−.12 (.21)	.88 (.58–1.34)	−.16 (.27)	.85 (.50–1.44)
Impulsivity				
IMT Commission Errors	−.18 (.21)	.83 (.55–1.26)	−.39 (.30)	.68 (.37–1.23)
GoStop Inhibition Failures – 150 ms	.38 (.22)	1.46 † (.95–2.22)	.48 (.27)	1.61 † (.94–2.75)
TCIP Total Short Responses	.78 (.25)	2.18 ** (1.34–3.55)	.82 (.30)	2.28 ** (1.26–4.11)
SKIP Total Responses	−.24 (.23)	.79 (.50–1.24)	−.32 (.34)	.72 (.37–1.40)
General Intellectual Ability				
WASI Full-Scale Score	−.40 (.22)	.67 † (.44–1.03)	.16 (.34)	1.18 (.61–2.28)

Significant group differentiations are denoted by:

† $p < .10$,

* $p < .05$,

** $p < .01$,

*** $p < .001$, all two-tailed. OR values > 1= marijuana users have higher average scores than do Non-users; OR values < 1= marijuana users have lower average scores than do Non-users.