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Performance of heavy marijuana-smoking adolescents on a laboratory measure of motivation

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Abstract

Marijuana smoking produces effects that may persist for hours or days beyond the period of acute intoxication. Despite evidence that adolescence represents a period of heightened exposure to marijuana, little research exists regarding possible impairment in adolescents who smoke marijuana regularly, and none exists regarding basic behavioral processes. In the present study, adolescents who smoked marijuana on a regular basis (near daily) were compared to a control group of adolescents on a two-option experimental task designed to measure motivation. The contingencies were arranged such that one option (work), which required systematically increasing response output, initially produced greater rates of monetary reinforcement than an alternative option (non-work) that required no response output to earn money. Switching to the non-work option was interpreted as a measure of reduced motivation. Significant differences were found between the groups: the marijuana-smoking participants switched earlier to the non-work option, and derived a greater percentage of their earnings from the non-work option. These differences existed when controlling for differences in cognitive aptitude, gender, and the presence of conduct disorder. A significant correlation between cannabinoid levels and percent of earnings derived from the non-work option suggests that these effects could be associated with the presence of cannabinoids in the marijuana-smoking group.

Keywords: Marijuana; Motivation; Adolescent; Cannabinoids; Laboratory task; Reinforcement; Progressive ratio

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Current scientific evidence suggests that marijuana smoking produces detrimental effects that may persist for several hours or days beyond the period of acute intoxication from delta-9 tetrahydrocannabinol, e.g., Δ^9-THC (Heishman, Huestis, Henningfield, & Cone, 1990; Pope & Yurgelun-Todd, 1996; Pope, Gruber, Hudson, Huestis, & Yurgelun-Todd, 2001; Solowij et al., 2002; Varma, Malhotra, Dang, Das, & Nehra, 1988). These effects may be due to cannabinoids that are still present in the CNS (Pope, 2002; Pope, Gruber, & Yurgelun-Todd, 1995), demonstrated by impairments in tasks of working memory and cognitive function (Bolla, Brown, Eldreth, Tate, & Cadet, 2002; Pope & Yurgelun-Todd, 1996; Solowij et al., 2002), or by altered brain activity patterns as measured by imaging techniques (Loeber & Yurgelun-Todd, 1999; Solowij, Michie, & Fox, 1995; Wilson et al., 2000).

To date, the majority of laboratory-based or clinical studies on marijuana effects have included adult participants, but a few studies suggest deleterious effects of marijuana in adolescents (Crowley, Macdonald, Whitmore, & Mikulich, 1998a; Schwartz, Gruenewald, Klitzner, & Fedio, 1989). The omission of adolescent populations is a clear shortcoming of the existing research. Adolescents account for approximately 30% of all marijuana users in the US, and use rates among adolescents have continued to increase over the past decade (SAMSA, 2001). Equally compelling is recent epidemiological evidence revealing that peak risk for marijuana dependence occurs at age 17 (Wagner & Anthony, 2002). Collectively, these data suggest that adolescence represents a period of heightened exposure to marijuana, increased risk for heavy marijuana use, and perhaps a "critical period" for deleterious marijuana effects (see Pope et al., 2003). All adolescents in the marijuana-use group reported current smoking, verified by daily urinalyses estimating cannabinoid content; thereby eliminating the examination of (possible) irreversible deficits resulting from chronic use (e.g., Bolla et al., 2002; Pope et al., 2001; Solowij et al., 2002). Instead, our focus was to study this group of adolescents at the time of peak use and, possibly, greatest vulnerability.

Studies to date have employed either neuropsychological test batteries or brain imaging techniques to measure marijuana effects related to heavy use. These methods have not examined reinforcement contingencies, and little is known about the enduring effects marijuana may have on basic behavioral processes organized and maintained by consequences. Such behavioral processes are important for adaptive behavior, with implications in areas such as social interaction and academic performance, domains of foremost importance during adolescents.

There is evidence that marijuana use may disrupt behavioral processes involving learning and motivation (Paule et al., 1992; Stiglick & Kalant, 1983). Studies with human participants have demonstrated that reinforced behavior patterns can be altered by acute Δ^9-THC administration (Foltin et al., 1989; Kamien, Bickel, Higgins, & Hughes, 1994; Lane & Cherek, 2002; Lane et al., 2004). The effects of marijuana on motivation have been studied experimentally (Foltin et al., 1989; Mendelson et al., 1976; Pihl & Sigal, 1978), but not in adolescent populations. Paule et al. (1992) tested the performance of chronically exposed monkeys on a progressive-ratio task (an index of motivation) and found that "during chronic exposure, MJ appears to induce an amotivational-like syndrome in the rhesus monkey" (Paule et al., 1992, p. 217). In a study of acute marijuana effects on motivation in humans, we

introduced a procedure that provided participants with "work" (progressive ratio) and "non-work" (fixed time) alternatives (Cherek, Lane, & Dougherty, 2002). Motivation was operationally defined as responding that was functionally related to its consequences: increases in responding following increases in reinforcement (e.g., magnitude or frequency) represented motivational behavior; and unchanged or decreased responding following increases in reinforcement represented decreased motivation. Thus, switching to the non-work option early in the session was defined as an index of reduced motivation. Response output and time spent in the work option were decreased as a function of dose (Δ^9-THC content).

In the present study, we retained this operational definition and employed a variation of the procedure used in Cherek et al. (2002) to study motivation in a group of adolescents who were current, regular marijuana smokers and a group of control adolescents with little drug use history. Based on previous results, we expected to find indices of reduced motivation in the marijuana smokers.

1. Method

1.1. Participants

Male and female adolescent participants (14–18 years old) responded to local newspaper advertisements. All participants were recruited via ads seeking "individuals between age 14 and 40 for behavioral research." No specific details were provided regarding desired participant characteristics or the nature of the study. Based on information obtained during initial telephone interviews, potential participants were brought to the laboratory for more extensive interviews covering physical and mental health status, and drug and alcohol use history.

Exclusionary criteria included: (a) current medical problems (e.g., seizures, diabetes, history of head injury); (b) current use of any medications; (c) current drug use other than marijuana, defined by drug-positive urine samples (see below); (d) past history of substance dependence other than marijuana, as measured by the Structured Clinical Interview module for drug and alcohol dependence (SCID-I, version 2.0, First, Spitzer, Gibbon, & Williams, 1996) for the DSM-IV (American Psychiatric Association, 1994); and (e) no diagnosis of any other lifetime Axis I disorder as measured by the Children's Interview for Psychiatric Syndromes (Weller, Weller, Fristad, & Rooney, 1999). The ChIPS is a structured diagnostic interview, similar in modular format to the SCID, designed for children and adolescents aged 6–18 years. A ChIPS diagnosis of conduct disorder was supplemented by the relevant module of the SCID-II, version 1.0 for Axis II disorders (Spitzer, Williams, Gibbon, & First, 1990).

Prior to entering the study, participants read and signed a detailed consent form and a parent or legal guardian signed a parental consent form. The final sample included 34 participants. One group (N=14) constituted regular marijuana smokers, and included 10 males and four females; hereafter referred to as the MJ+ group. Participants in this group had to meet the following criteria: (a) report current marijuana smoking of at least 4 days/

week (most reported daily use); and (b) provide cannabinoid-positive urine samples during participation in the experiment. All subjects in this group met DSM-IV criteria for current marijuana abuse or dependence. A post-experimental questionnaire provided a list of substances including nicotine, alcohol, and classes of illicit substances, and asked participants to check off any days in the last seven in which they had used any of these substances. Two participants who reported chronic marijuana smoking provided cannabinoid-negative urines during the experiment. Their data were not included in the final sample of 14 participants. No subjects in the MJ+ group met criteria for abuse or dependence on any other drug.

Urine drug screen analysis for all major classes of drugs was carried out using enzyme multiple immunoassay (EMIT d.a.u®—SYVA). Cannabinoid-positive urine samples were subjected to creatinine-corrected quantitative estimation using an Olympus AU400 automated analyzer to obtain a numerical value on cannabinoid levels (ng/ml). Each day residual urinary cannibinoid levels were documented in all participants in the MJ+ group. Levels averaged 709.25 ng/ml (see Table 1) and ranged from approximately 88 to >3000 ng/ml.

The second group of participants (N=20, 13 males and 7 females) served as a control group. None met criteria for abuse or dependence on any drug. Seven participants in this group reported past cigarette smoking. Twelve participants reported past alcohol drinking, with less than 15 lifetime episodes on average. Two reported current alcohol drinking (2–4 drinks/week). Five control participants reported past marijuana use, all on less than 10 occasions. No control participants reported current illicit drug use, and none tested positive during the study.

Table 1
Demographic and psychometric data for marijuana smoking and control adolescent groups

Variable	Marijuana	Control	t-score[a]	p-value
Gender (male/female)	10:4	13:7	–	
Age	16.79±0.44	16.15±0.33	1.22	<.23
Education (years completed)	9.79±0.43	9.85±0.30	0.13	<.91
Number of years of MJ use	2.96±0.45	–	–	
Urine cannabinoid level (ng/ml)	709.25±165.34 0	–		
Number of conduct disorder	8	4	–	
Shipley (Intelligence test)[b]	48.14±2.28	54.75±1.62	2.52	<.02
Youth self-report:				
Withdrawn	4.43±0.71	2.90±0.53	1.76	<.09
Somatic complaints	1.64±0.31	1.20±0.35	0.91	<.38
Anxious/depressed	5.21±0.79	3.60±0.86	1.32	<.20
Social problems	2.64±0.56	1.45±0.39	1.81	<.08
Thought problems	2.14±0.29	1.45±0.31	1.55	<.14
Attention problems	4.07±0.54	3.40±0.52	0.87	<.39
Delinquent behavior	6.71±0.84	3.05±0.63	3.59	<.002
Aggressive behavior	9.07±1.27	8.70±1.21	0.21	<.84

Values represent the mean±S.E.M.
[a] t-test scores presented as absolute values.
[b] Age-equivalent Shipley t-score.

To measure aspects of social and cognitive function, participants were administered the Youth Self-Report (Achenbach, 1991) and the Shipley Institute of Living Scale (Shipley-Boyle, 1967). These tests were administered on the final day to prevent bias or interpretation on the part of the participants as to the purpose of the study. The Achenbach Youth Self-Report (YSR) was used to assess behavior characteristics and social functioning. This instrument has been used in previous studies to provide profiles of psychiatric syndromes in both high- and low-risk/typically developing adolescents (Achenbach 1991; Bender & Loesel, 1997). The Shipley Institute of Living Scale is a test of general intellectual aptitude that includes a 40-item vocabulary test and a 20-item abstraction test. The Shipley scale has been age-normed for adolescents and adults and provides an age-adjusted *t*-score. In young adult populations, Shipley score estimates of WAIS IQ correlate highly (0.76–0.87) with actual WAIS IQ scores (Zachary, Paulson, & Gorsuch, 1985). It is considered appropriate for adults and adolescents age 14 and older (Zachary, 1986).

Participant demographics including age, gender, education level, marijuana smoking characteristics, and psychometric outcomes are summarized in Table 1. There were no statistically significant differences between the two groups with regard to age, education level, or most subscales of the Youth Self-Report. However, the groups differed on the number meeting criteria for conduct disorder, the delinquency subscale of the YSR, and on general cognitive ability. These differences were factored into the data analyses, described below.

1.2. Participant payment and daily schedule

Participants were paid daily for performance during experimental sessions, non-contingent bonus payments for urine samples, alcohol-free breath samples, and attendance, and a completion bonus on the last day. Breath alcohol samples were collected each morning upon arrival at the laboratory and measured by an Alco-sensor III (Intoximeters, St. Louis, MO). Each day of the study, participants arrived at approximately 8:00 am. After collection of breath and urine samples, participants completed four experimental sessions, each lasting 35 min, and beginning at 8:30, 10:00, 1:00 pm, and 2:30 pm. Between sessions, participants stayed in a waiting room with magazines, books, and a TV. Lunch was provided at 12:00 pm. Participants arrived at the laboratory either by bus or car, and travel time from home to the laboratory ranged from 30 to 75 min. Many participants indicated smoking marijuana on the evening preceding experimental testing. None reported smoking on the morning of testing.

1.3. Apparatus

During experimental sessions, participants worked alone in 1.2×1.8 m, sound-attenuating test chamber equipped with a 36.5 cm (14 in.) VGA color monitor, and a 10.0×43.0×25.0 cm response panel with three Microswitch buttons labeled A, B, and C. Experimental events and data collection were handled by a remote MS Windows-based PC and a Med Associates model 750 interface card, using custom software written in Microsoft Visual Basic.

Prior to the first testing session, participants were read a set of instructions describing how money could be earned by responding on the response panel buttons, the requirements for switching from the progressive ratio (work) to fixed time (non-work) alternative, and the contingencies on each option (see below). No information regarding payment amounts was provided, and instructions were purposely limited to the technical requirements of button pressing and switching. Participants were presented with minimal information to decrease the probability that the instructions would influence their behavior on the task. If participants raised questions, the instructions were repeated.

1.4. Motivation task

The task was modified from a previous version developed in our laboratory to study acute marijuana effects on motivation (Cherek et al., 2002). The procedure presented subjects with two mutually exclusive response options: a progressive-ratio (PR) reinforcement schedule and a fixed time (FT) reinforcement schedule. Reinforcers were monetary amounts, shown in dollars and cents, periodically represented by a counter located near the top of the on-screen display.

The PR schedule was programmed on button A. On the first trial of each session, only the PR schedule was available, and only the letter A was visible on the screen. The first response on the A button placed a square around the letter A on the screen. The initial response requirement was 10 responses, and produced a reinforcer of US$0.01. After each reinforcer presentation, the response requirement was increased by 10% of the previous value and the reinforcer amount was increased by US$0.01. Thus, each subsequent reinforcer was larger than the previous one, but more responses were required to obtain it. These parameters were selected to produce earnings that would maintain attendance, maintain PR responding well into each session, and avoid exceptionally large ratio sizes. Following completion of the first PR ratio requirement, the A letter was removed from the screen and the earned monetary amount (US$0.01) was presented on the screen for 3 s. After a 3-s intertrial interval in which the screen was blank, the letter A, the letter C, and the word “change” directly under the letter C were then visible at the start of each trial. Responding on the A button again placed a square around the letter A. The letter C and the word “change” remained on the screen, indicating that this option was available at any time. Thus, the C option could be selected at any time during the session starting with the second trial.

The fixed time (FT) schedule was programmed on button C. Once the FT schedule was in effect, no responses were required to earn reinforcers—money simply accumulated by being added to the counter after fixed intervals of time elapsed. Beginning with the second trial, button C could be selected at any time. The first response on button C placed a square around the letter C and the word “change.” Ten responses on button C produced the following changes: (a) the letter A and the word “Change” were removed from the on-screen display, leaving only the letter C and the box around it; and (b) the FT schedule was in effect for the remainder of the session and was non-reversible. The FT reinforcement amount and schedule value were yoked to the performance on the PR. Specifically, the amount of the reinforcer was identical to that earned on the last completed PR, and the time interval for each reinforcer

delivery was either the time that was required to complete the last PR or 120 s, whichever was larger. Thus, the FT interval duration was never less than the time taken to complete the last PR, and always delivered a smaller amount of money than the next scheduled PR.

The PR and FT schedules can be thought of as work and non-work, options, respectively. The contingencies were arranged such that it was always advantageous to remain on the work option, except when the PR requirement reached very high values near the end of the session. Corresponding to the operational definition of motivation proposed above, earlier switching to the non-work option was considered an index of decreased motivation. Each experimental session lasted 35 min. Participants completed eight sessions, four per day for two consecutive days. Testing was extended over 2 days to minimize extra-experimental variability that might have contributed to the data on the first day.

1.5. Dependent measures and data analyses

There were two primary dependent variables of interest: the largest PR completed (work option); and the percent of total earnings derived from the FT (non-work) option. These two measures are correlated. However, response rates and switch points varied across subjects, so each measure provides a different index of performance. For both dependent measures, the mean values from each of the two test days were analyzed by two-way analysis of variance (ANOVA) with SAS Proc GLM (SAS, Cary, NC), assessing the effects of group and day, with repeated measures over the 2 days. Because the Shipley scores revealed group differences in cognitive aptitude, data were also analyzed by two-way repeated-measures analysis of covariance (ANCOVA) with Shipley *t*-score as the covariate, using SAS Proc GLM. These analyses were performed for both of the dependent measures. As evident in Table 1, the groups were not equally balanced by gender or diagnosis of conduct disorder. Because these factors were unbalanced, their effects were also evaluated using ANCOVA for both dependent measures.

2. Results

2.1. Largest progressive ratio completed

The top panel of Fig. 1 shows the largest PR completed for each group across the two testing days. The control group completed a larger average PR on both days. The data were analyzed via two-way ANOVA with repeated measures on day. There was a significant main effect of group, $F(1,32)=5.99$, $p<.02$; and a significant main effect of day $F(1,1)=8.35$, $p<.007$. There was not a significant group×day interaction $F(1,1)=0.15$, $p<.70$. The means were 429.80 ± 36.38 for the control group and 300.10 ± 37.53 for the MJ+ group on day 1 and 497.57 ± 36.72 for the control group and 388.58 ± 44.93 for the MJ+ group on day 2. Because of group differences in cognitive aptitude, gender, and conduct disorder, additional analyses were performed using analysis of covariance (ANCOVA). In general, these covariates added little to the original model.

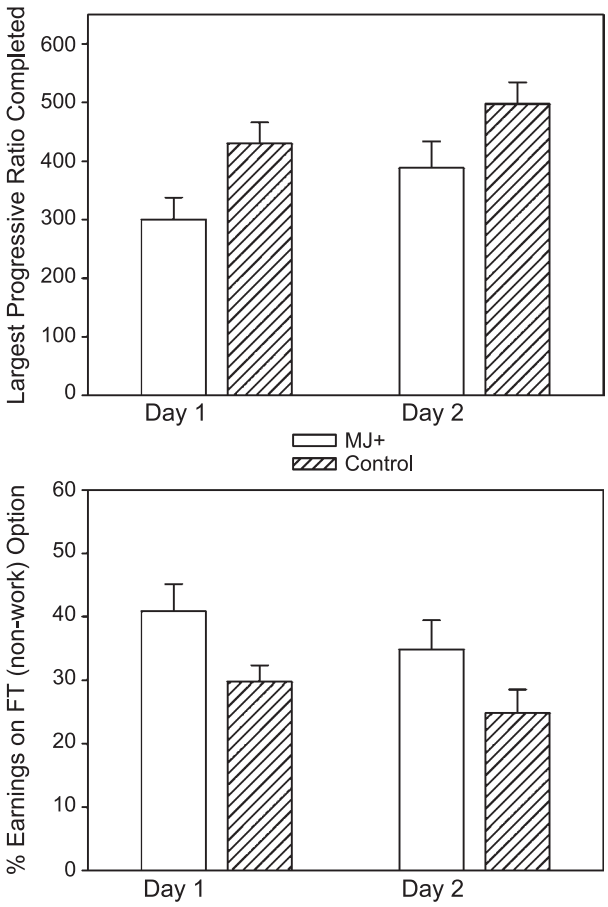

Fig. 1. Top panel: The *Y*-axis depicts the largest ratio completed on the progressive ratio (PR, or work) option of the experimental task that was designed to measure motivation. PR size is represented as the number of responses required to complete the ratio. The *X*-axis represents the average four daily sessions per day, across two experimental test days. Unfilled bars represent a group of adolescent participants who were chronic marijuana smokers. Hatched bars represent a control group. Each session lasted 35 min. Bottom panel: The *Y*-axis depicts percent of total earnings derived from the fixed time (FT, or non-work) option of the experimental task that was designed to measure motivation. The *X*-axis represents the average four daily sessions per day, across two experimental test days. Unfilled bars represent a group of adolescent participants who were chronic marijuana smokers. Hatched bars represent a control group. Each session lasted 35 min.

An ANCOVA with Shipley *t*-score as a covariate showed no main effect of Shipley score on largest PR completed, $F(1,30)=0.73$, $p<.40$, and no Shipley×group interaction, $F(1,30)=0.78$, $p<.38$. The interaction effects of *t*-score, day, and group were all nonsignificant (F values <1, p values >.35). An ANCOVA on the longest PR completed with gender as a covariate showed no main effect of gender, $F(1,30)=0.01$, $p<.91$, no gender×group interaction, $F(1,30)=0.00$, $p<.98$, and no gender×day interaction, $F(1,1)=0.06$, $p<.81$. The gender×day×group interaction was not significant, $F(1,1)=3.36$,

$p<.09$. An ANCOVA on the longest PR completed with conduct disorder (CD) as a covariate revealed no main effect of CD, $F(1,30)=0.02$, $p<.91$, and no CD×group interaction, $F(1,30)=0.82$, $p<.38$. The interaction effects of CD, day, and group were all nonsignificant (F values <1, p values >.84).

2.2. Earnings derived from the non-work option

The bottom panel of Fig. 1 shows the percent of total earnings derived from the FT (non-work) option for each group across the two testing days. The MJ+ group derived proportionally more earnings from the FT option on both days. The data were analyzed via two-way ANOVA with repeated measures on day. There was a significant main effect of group $F(1,32)=4.67$, $p<.04$; and a significant main effect of day $F(1,1)=6.72$, $p<.02$. There was not a significant group×day interaction $F(1,1)=0.07$, $p<.80$. The means were 29.76±2.58 for the control group and 40.85±4.57 for the MJ+ group on day 1 and 24.84±3.71 for the control group and 34.85±4.58 for the MJ+ group on day 2. As with largest PR completed, ANCOVAs were conducted to assess possible covariates.

An ANCOVA on percent of earnings derived from the FT option with Shipley t-score as a covariate showed no main effect, $F(1,30)=2.67$, $p<.12$, and no significant t-score×group interaction, $F(1,30)=2.57$, $p<.12$. The interaction effects of t-score×day, $F=2.05$, $p<.17$, and t-score×day×group, $F=0.13$, $p<.72$, were also nonsignificant. For the ANCOVA with gender as a covariate, there was no main effect, $F(1,30)=1.07$, $p<.31$, and no significant gender×group interaction, $F(1, 30)=0.36$, $p<.56$. The interaction effects of gender×day, and gender×day×group also were nonsignificant: $F(1,1)=0.13$, $p<0.73$, and $F(1,1)=2.32$, $p<.14$, respectively. Similarly, with CD as a covariate, no significant main effects or interactions were found (all F scores <2.0).

2.3. Correlations with cannabinoid levels

To evaluate the relationship between the cannabinoid levels measured in the participants' urine (MJ+ group only) and their performance on the motivation task, Pearson correlation coefficients were determined between cannabinoid levels and the two primary dependent measures. To determine the correlations, mean values across the four sessions of each experimental day were correlated with the cannabinoid level for each day. There was not a significant outcome for the largest PR completed $r=-0.22$, $p=.26$. A significant correlation was found for the percent of earnings derived from the FT (non-work) option, $r=0.52$, $p<.005$. Fig. 2 shows a scatter plot of the relationship between cannabinoid levels and the percent of earnings derived from the FT (non-work) option and reveals a positive linear relationship.

3. Discussion

Adolescents who smoked marijuana on a regular basis (4–7 days/week) and met abuse or dependence criteria were compared to a control group of adolescents with little

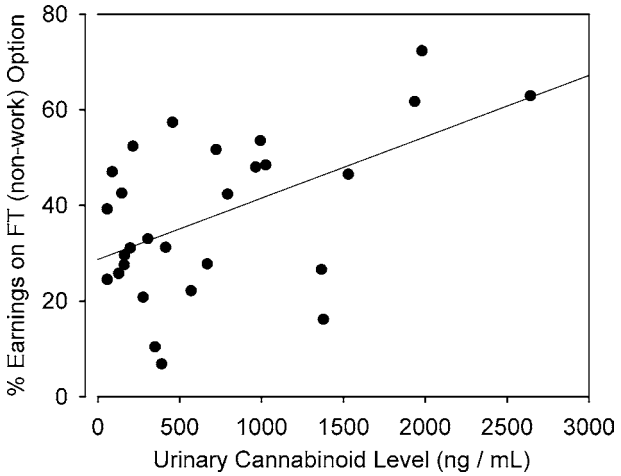

Fig. 2. A scatterplot with least-squares linear regression line fitted to the data, depicting the relationship between urinary cannabinoid levels (*X*-axis) and % of total earnings derived from the FT (non-work) option (N=14, MJ-smoking participant group only). The regression equation parameters were y=28.93x+0.01, r^2=0.37. There was a significant positive correlation between the two variables, r=0.52, p<.005.

drug use history on an experimental task designed to measure motivation. We operationally defined motivation based on response patterns under a two-choice (work vs. non-work) task in which the reinforcement contingencies maximized earnings by responding on the work option. When controlling statistically for differences in conduct disorder and cognitive aptitude, significant differences in motivation were found between the groups. One interpretation of these data is reduced motivation in the chronic-smoking participants. Due to study limitations and several possible alternative explanations, the data may be seen as preliminary. Below we discuss correspondences with previous data and limitations of the study.

The present data are consistent with the acute effects of marijuana observed in a previous experiment in our laboratory (Cherek et al., 2002), and with data from a study of chronic marijuana smoke exposure in rhesus monkeys (Paule et al., 1992). One consistent feature across these studies is the use of a progressive ratio schedule to measure motivation, a procedure with a long history in experimental psychology (Baron, Mikorski, & Schlund, 1992; Stafford & Branch, 1998; Woolverton, 1995). The data are also in line with demonstrated alterations of reinforced behavior by marijuana (Cherek et al., 2002; Dougherty, Cherek, & Roache, 1994; Foltin et al., 1989; Lane & Cherek, 2002; Lane et al., 2004; Paule et al., 1992). To the extent that motivation is a measurable property of behavior, motivational differences between the marijuana-smoking and control groups were observed. In addition, we found an intriguing, if modest, relationship between urinary cannabinoid levels and performance on the motivation task. Due to the host of factors that may influence cannabinoid levels in urine (e.g., recency of smoking, amount smoked, body fat composition, metabolic rates), this relationship should be interpreted cautiously.

The present data are, on face, consistent with previous studies showing that adults who (a) retrospectively reported early-onset marijuana use before age 17 and (b) reported several thousand lifetime use episodes, scored significantly lower than both late-onset/less frequent users and controls on a battery of neuropsychological tests (Bolla et al., 2002; Pope et al., 2003; Solowij et al., 2002). Despite this possible connection, several limitations of this study temper the conclusion that the observed differences between the groups were specifically related to marijuana use. Pope and colleagues have provided a thorough discourse on the host of potential confounding variables that could contaminate studies of the effects of chronic marijuana smoking, as well as the research designs appropriate for clarifying some of the unresolved questions that remain (Pope, 2002; Pope et al., 1995, 2003). The design and sample size of this study did not afford partitioning the data in a manner that would allow for proper examination of many of these factors, e.g., age of first use, socio-demographic differences, levels of marijuana use in the control group, and documentation of functioning prior to marijuana exposure. Other unexamined factors that could have played a role include attention, baseline differences in the efficacy of money as a reinforcer, and measurement error related to related to extra-experimental factors such as sleep deprivation, fatigue, and stress. It is even feasible that some of these variables may contribute to heavy marijuana use in adolescence.

Given the extremely high prevalence of marijuana abuse and dependence in adolescents with conduct disorder (Crowley, Mikulich, MacDonald, Yuong, & Zerbe, 1998b), it is unlikely that a control group with limited drug-use history but matched for the presence of conduct disorder could be obtained. The optimal experiment would require a within-subject, repeated measures design with control over duration, length, onset and abstinence of marijuana use, but such an experiment would not be ethical or feasible with human adolescent participants. Clarification of these results will require additional experimentation outside our laboratory and implementation of creative research approaches.

The difficulties faced in conducting research in this area should not detract from the importance of collecting data related to the potential sequelae of heavy marijuana use during adolescence. Despite the prevalence of marijuana abuse and dependence during 8th through 12th grade and the fact that it remains the most common illicit drug used by adolescents (Wagner & Anthony, 2002; Wallace et al., 2003), laboratory studies of this age group are rare. Adolescence may represent a critical period of sensitivity to drug exposure. Substance abuse during this developmental stage may have severe effects on behavioral, social, and cognitive functioning via alteration of critical neural development (Spear, 2000). Previous studies support this hypothesis with evidence from epidemiological (Kandel, Simcha-Fagan, & Davies, 1986; Wagner & Anthony, 2002), clinical (Crowley et al., 1998a), cognitive function (Pope et al., 2003; Bolla et al., 2002), and neurobiological studies (see Spear, 2000). Though these data represent an initial step, the outcomes provide further support, suggesting behavioral differences between heavy marijuana users and non- or infrequent users during adolescence.

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