Experimental and Clinical Psychopharmacology
2002, Vol. 10, No. 1, 26–38

1064-1297/02/$5.00 DOI: 10.1037//1064-1297.10.1.26

Possible Amotivational Effects Following Marijuana Smoking Under Laboratory Conditions

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Human participants earned money by responding on a progressive-ratio (PR) schedule (initial value $50) or received money without responding on a fixed-time (FT) schedule. During the session, participants could terminate the PR schedule and initiate an FT 200-s schedule. In Experiment 1, increases in monetary value produced increased number of responses, time spent, and money earned in the PR component. In Experiment 2, marijuana smoking produced potency-related reductions in the number of responses, time spent, and money earned in the PR component, effects that can be interpreted as amotivational. Increasing the monetary value of the reinforcer diminished the acute marijuana effects on PR responding, suggesting that marijuana exerted an effect primarily on reinforcers of a smaller magnitude.

The *amotivational syndrome* is a set of characteristics that frequently have been associated with chronic marijuana use (McGlothlin & West, 1968; Smith, 1968). Specific characteristics of the amotivational syndrome that have been noted are general apathy (Bindelglas, 1973; Kolansky & Moore, 1972, 1975; Smith, 1970), loss of productivity (McGlothlin & West, 1968; Nahas, 1976; Soueif, 1976), difficulty in carrying out long-range plans (Page, 1983), lethargy (Brill et al., 1970; Kolansky & Moore, 1975), depression (Bindelglas, 1973; Kolansky & Moore, 1975), inability to concentrate (Bindelglas, 1973, Soueif, 1976), and inability to sustain attention (Kolansky & Moore, 1972; Smith, 1970).

However, the amotivational phenomenon has been difficult to define and remains one of considerable debate. Kupfer, Detre, Koral, and Fajans (1973) suggested that the amotivational syndrome might be a manifestation of underlying mood disorders (i.e. anxiety, depression) that may have existed before use of marijuana, predisposing individuals to an amotivational syndrome or possibly mimicking symptoms of the syndrome. Kupfer et al. (1973) examined psychological and somatic symptoms associated with marijuana use and found that frequent users (i.e. three or more times a week) had distinguishable characteristics such as depression, lower energy levels, tiring easily, and a tendency to smoke to escape problems. A more recent study of frequent versus occasional marijuana smokers in a clinical sample reported amotivational symptoms (e.g., apathy and low need for achievement) among frequent marijuana smokers (Musty & Kaback, 1995). The authors concluded that the amotivation symptoms were primarily due to coexisting depressive symptoms. Anthropologic studies of daily, long-term smokers in Jamaica (Comitas, 1976) and Costa Rica (Carter & Doughty, 1976) did not find evidence for an amotivational syndrome. Clearly, data associated with possible amotivational effects of marijuana are difficult to evaluate and interpret.

One factor potentially contributing to conflicting or negative data on the amotivational syndrome in marijuana users is the descriptive nature of the data. As a dependent variable, motivation was largely inferred from participants' self-reports, affective states, and work histories. Furthermore, these data were not collected under experimentally controlled conditions. One way to control for these extraneous variables, and thus reduce variability in findings, is to use the laboratory setting. Unfortunately, little research has directly examined possible amotivational effects of marijuana under controlled laboratory conditions (Page, 1983; Bindelglas, 1973; Mellinger, Somers, Davidson, & Manheimer, 1976).

Foltin et al. (1990) examined the effects of marijuana smoking on behaviors maintained by contingencies in a residential laboratory. This study required participants to engage in instrumental behavior (low probability activities, like reading) to receive contingency activities (high probability activities, like games). Under active marijuana-smoking conditions, Foltin et al. (1990) found that, compared with placebo conditions, participants spent more time in instrumental activities and less subsequent time in contingency activities (i.e., little evidence of amotivation). The authors had difficulty reconciling the results but speculated that "instructional control" may have augmented the instrumental activity performance and overridden the effects of marijuana on behavior (e.g., Baron & Galizio, 1983; Catania, Matthew, & Shimoff, 1982). Pihl and Sigal (1978) found that acute marijuana administration produced decreases in performance on a laboratory-based task; however, introducing monetary rewards for performance reversed

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This research was supported by National Institute on Drug Abuse Grants DA 10592 and DA 12968.

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marijuana-related decrements on performance. A study by Kagel, Battalio, and Miles (1980) showed no change in total work output by individuals in a controlled residential setting but did show a reallocation of behavior away from work and toward leisure activities. Kagel et al. also found that introducing monetary rewards could reverse marijuana's effects on performance decrement. Thus, despite being conducted under laboratory conditions, previous studies seem unclear regarding the amotivational effects of marijuana. In these studies, a description of motivation was inferred from response output or response allocation. An operational definition of motivation was not provided, which could be a source of variance affecting the previous inconsistent results, in that a common definition of motivation did not exist across studies.

An operational definition of motivation provides increased precision in measurement and understanding of outcomes by establishing a formal structure for interpreting behavior change in the context of the experiment. As an initial condition, it is asserted here that motivation is a property of behavior, in which responding produces specific consequences, and that motivation can be measured via changes in the properties of responding (e.g., rates, allocations, reinforcers obtained; Killeen, 1992; Michael, 1993). Accordingly, motivation will be operationally defined as a change in responding that is functionally related to a change in the consequences for that responding, such that (a) increases in responding that follow increases in the properties of a reinforcing consequence (e.g., magnitude, frequency) represent increased motivation and (b) decreases in responding under unchanging reinforcement conditions, or unchanged responding following increases in reinforcement, represent decreased motivation, or amotivation.

Experiment 1: Demonstration of Motivation

Motivation is a difficult concept to address both theoretically and methodologically (Killeen & Hall, 2001; Peters, 1958). One reason motivation is theoretically problematic is that the term implies a trait-like characteristic to which behaviors are sometimes falsely attributed. Behavioral scientists reject this notion in favor of more objectively measured properties of behavior that can be attributed to response history and reinforcement contingencies, thus avoiding the problems associated with attributing behavior to an internal construct of motivation. A primary reason motivation is problematic methodologically is that there are many types of paradigms that have been used to measure motivation; depending on one's own theoretical orientation, motivation can be measured in very different ways (Higgins & Sorrentino, 1986). In the present article, a behavioral approach to measuring motivation was taken, allowing quantification of changes in the properties of responding as a function of independent variable manipulation (as noted above and in accord with our operational definition of motivation).

Among the empirical measures that have been used to assess behaviors categorized as motivational, the progressive-ratio (PR) schedule is probably the most often used. It has provided measures of behavior categorized as motivation (Hughes, Pleasants, & Pickens, 1985), reinforcer strength (Hodos, 1961; Hodos & Kalman, 1963), and response perseveration (Ferguson, Holson, & Paule, 1994). Progressive-ratio schedules have been used to study the efficacy of money versus points (Bennett & Samson, 1987), motivation to earn different monetary amounts in depressed individuals (Hughes et al., 1985), and reinforcer preference in children with severe developmental disabilities (Nunes, Murphy, & Doughty, 1980).

In nonhuman studies, the PR is frequently used as a measure of response strength–motivation (Baron, Mikorski, & Schlund, 1992; Stafford & Branch, 1998), particularly in studies of drug effects and drug self-administration (Ferguson & Paule, 1996; Winger & Woods, 1985; Woolverton, 1995). Relevant to the present study, Paule et al. (1992) employed a PR schedule and demonstrated an amotivational syndrome in rhesus monkeys chronically exposed to marijuana smoke. In this study, monkeys were exposed via a face mask to smoke from one marijuana cigarette daily for 365 days. During this same 365-day period, each monkey worked on a food-reinforced PR task. When compared with placebo and sham exposure, marijuana exposure reduced time spent responding on the PR task (e.g., break point from responding) and number of reinforcers earned. In accord with both the operational definition offered above and the authors' conclusions, this reduction in responding despite no change in reinforcement contingencies can be interpreted as reduced motivation.

Consistent with the operational definition of motivation, Experiment 1 focused on changes in responding following changes in reinforcer magnitude in order to later evaluate the effects of marijuana smoking under similar conditions. An earlier attempt to manipulate point value had no effect on responding on a progressive interval schedule (Dougherty, Cherek, & Roache, 1994). In this experiment, we selected a PR schedule, which is used extensively to evaluate the relative reinforcing efficacy of a variety of stimuli. In addition, a concurrently available fixed-time (FT) schedule was added as an alternative means for participants to earn money. During the FT schedule, money would simply be added to the counter (no response requirement), but less frequently than could be obtained in the PR schedule. The procedure established a measurable break point for PR responding, while still providing money accumulation for the participant. The purpose of this experiment was thus to define and measure motivation by measuring changes in PR responding across changes in reinforcer magnitude.

Method

Participants. Five male participants between 21 and 31 years old (M = 23.4 years) participated after giving their informed consent. All participants reported occasional marijuana use defined as one to four times per month. They also reported current alcohol use and prior use of other drugs, most typically cocaine. The educational level of participants ranged from 11 to 13 years. None of these participants had previously participated in research studies.

Apparatus. During sessions, participants sat in a sound-attenuated chamber (1.32 × 1.62 × 2.23 m) containing a chair, response panel, and computer monitor. The response panel consisted of a metal box (43.2 × 26.0 × 10.2 cm) with three microswitch push buttons labeled A, B, and C. A VGA Monitor was located approximately at eye level. Continuous masking noise was provided by a fan motor located at the top of the rear chamber wall. A 60-W light mounted in the ceiling provided illumination. Experimental events were controlled and recorded by an IBM-compatible PC computer equipped with a MED (St. Albans, VT) Associates Model 750B card located outside the chamber.

Procedure. Participants were recruited via advertisements for paid volunteers "for behavioral research" placed in city newspapers. Potential participants were screened during subsequent telephone calls to the laboratory. On the basis of information provided, appropriate volunteers were scheduled for an in-person interview. Participants were screened for medical and psychiatric illness. Exclusion criteria included (a) current or past medical problems (e.g., seizures, high blood pressure, asthma), (b) current use of any medications, (c) current ongoing drug use, and (d) current or past history of an Axis I disorder, as defined by the Structured Clinical Interview for the *Diagnostic and Statistical Manual of Mental Disorders* (SCID-I, Version 2.0; First, Spitzer, Gibbon, & Williams, 1996). This exclusion included prior treatment for substance abuse or dependence.

Participants were instructed to abstain from illicit drug use during the study, and alcohol abstinence was suggested. Alcohol drinking was monitored by requiring a zero alcohol level of an expired air sample obtained each morning on arrival in the laboratory. Extraneous drug use was monitored by collecting urine samples each morning. Temperature monitoring and creatinine determinations were performed to detect attempts to alter urine samples. Each urine sample was subjected to the Enzyme Multiple Immunoassay Technique–Drug Abuse Urine assay (EMIT; SYVA, Palo Alto, CA). This procedure screens for several classes of psychoactive drugs and drugs of abuse, including opiates, benzodiazepines, barbiturates, cocaine, stimulants, marijuana, and phencyclidine. The cutoff for urinary cannabinoids was less than 100 ng/ml. If drugs were detected in the urine or alcohol in the expired air sample on two occasions, participants were removed from the study.

Participants participated in five 1-h sessions each day, Monday through Friday. Morning sessions were conducted at 8:30, 10:00, and 11:30 a.m., and afternoon sessions were conducted at 1:30 and 3:00 p.m., with rest periods between sessions and a lunch period at 12:30 p.m. Between sessions, participants waited in a common area that contained a television and magazines.

Instructions. During the first few sessions, participants had only the PR schedule available and the letter *A* on the computer screen. They received the following instructions prior to the first session.

"You can earn points exchangeable for money during these sessions. The value of the point will be briefly displayed on the computer screen whenever you earn money."

When the FT schedule was made available, the letters *A*, *C*, and the word *Change* appeared on the computer screen, and participants received the following instructions:

> When the letter C and the word Change appear on the left side of the computer screen, you can change from the letter A condition to the letter B. Pressing button C will cause the removal of letter A and the appearance of letter B. You do not need to press any buttons to earn money when the letter B is on the screen. Once you have switched to the B condition, you can not return to the A condition until the beginning of the next session.

Participants were not told that, generally, the earlier they switched to the B (FT) option, the less money they would make during that session. Note that there is a theoretically optimal switch point on this task—based on the participants' response rate and scheduled ratio size—in which the time required to complete the next and all subsequent PRs would exceed the reinforcer rate on the FT option (e.g., completing the PR would take longer than 200 s). At that point, more money could be earned on the FT option. However, on the basis of obtained response rates, this change point could not be reached until the PR ratio became very large and would only occur later in the session. It is important to note that none of the participants in this study exceeded this change point, and thus it was always optimal (from a reinforcer–motivational perspective) to remain on the PR option. The response options are described below.

PR schedule. Responding on Button A was maintained by a progressive ratio schedule of monetary reinforcement. The letter *A* was displayed on the computer screen when the PR schedule was in effect. The initial ratio requirement was 50 responses, which produced a reinforcer of \$0.10, \$0.20, or \$0.40, depending on the condition in effect (see Table 1). Following completion of the ratio requirement, the letter *A* was removed from the screen and the monetary value of the reinforcer was flashed on the screen for 1 s. The letter *A* reappeared after 10 s and the next response requirement was in effect. After each reinforcer presentation, the response requirement was increased by 10% (e.g., 55 responses for the second ratio, 61 for the third, etc.). The initial response requirement and percentage increase were selected to allow earnings that would maintain participation and avoid extremely large ratio sizes prior to the end of the session.

Table 1
Sequence of Conditions, Monetary Reward Amounts, and Marijuana Doses in Experiments 1 and 2

Schedule in effect	Reinforcer amount	Marijuana dose
	Experiment 1	
PR only	\$0.10	
PR–FT	\$0.10	
PR only	\$0.10	
PR only	\$0.20	
PR–FT	\$0.20	
PR only	\$0.10	
PR only	\$0.40	
PR–FT	\$0.40	
	Experiment 2	
	Phase 1	
PR only	\$0.10	
PR–FT	\$0.10	Placebo
PR–FT	\$0.10	Half of 1.77% Δ^9-THC
PR–FT	\$0.10	Placebo
PR–FT	\$0.10	1.77% Δ^9-THC
PR–FT	\$0.10	Placebo
PR–FT	\$0.10	3.58% Δ^9-THC
	Phase 2	
PR–FT	\$0.20	Placebo
PR–FT	\$0.20	3.58% Δ^9-THC
PR–FT	\$0.40	Placebo
PR–FT	\$0.40	3.58% Δ^9-THC
PR–FT	\$0.10	Placebo
PR–FT	\$0.10	3.58% Δ^9-THC

Note. PR = progressive ratio; FT = fixed time.

FT schedule. The FT schedule presented reinforcers of the same monetary value as those available in the PR component ($0.10, $0.20, or $0.40) at intervals of at least 200 s. The FT value was never less than the time taken to complete the last ratio in the PR component. Thus, if the participant took 210 s to complete the last ratio, then when the participant switched to FT component, the FT value would be 210 s. If the participant switched following any PR that took less than 200 s, the FT was set at 200 s for the remainder of the session. No responses were required during the FT schedule. The letter *B* was displayed on the computer screen while the FT schedule was in effect.

Change button. When the letter *C* and the word *Change* were displayed on the computer monitor, 10 presses on Button C changed the schedule from PR to FT. This was signaled by the removal of letters *A* and *C* and the word *Change* and the appearance of letter *B*. Once the participant switched to the FT schedule, this schedule remained in effect for the rest of the 60-min session. Each session began in the PR component and with the letters *A* and *C* and word *Change* displayed on the monitor.

Sequence of conditions. Each participant began the experiment with only the PR schedule available and at a reinforcer value of $0.10. Participants remained in this condition until responding stabilized over five successive sessions. The criterion for response stabilization was established as an $SD \leq 15\%$ of the mean value of PR responses per session with no trends of increased or decreased number of responses. All changes in conditions occurred only after the stability criterion for the number of responses in PR component was achieved. Each participant went through the sequence of conditions described in Table 1 under the section headed Experiment 1. Participants completed five sessions per day and required an average of 13.75 days (range = 11–19) to complete the study.

Results

Because participants received minimal instructions at the beginning of the first session, one to two sessions were required to acquire the button-pressing response. Once participants began to associate pressing of Button A with the presentation of money, typical ratio responding was maintained throughout sessions. High, sustained rates of responding under the PR component were observed (range = 214–334 responses per minute).

Figure 1 shows three measures of PR performance under the PR only and the PR–FT conditions. The top graph of Figure 1 shows the largest ratio completed by participants under PR only and PR–FT conditions at all three monetary reward conditions. The data points represent the mean value for the last three sessions at each condition for all 5 participants. The size of the largest ratio completed typically increased as the monetary value increased and was substantially reduced by the introduction of the FT schedule. There was a close correspondence between the number of responses emitted and the value of the largest ratio completed, indicating that participants typically switched to the FT schedule after completing a ratio and earning a reinforcer. A repeated measures analysis of variance (ANOVA) analysis of the highest ratio completed indicated a significant main effect of condition (PR vs. PR–FT), $F(1, 4) = 19.55$, $p < .012$. The main effect of the monetary value of the reinforcer was also significant, $F(2, 8) = 8.28$, $p < .011$. The Condition × Monetary Value interaction was not significant, $F(2, 8) = 0.90$, $p < .443$.

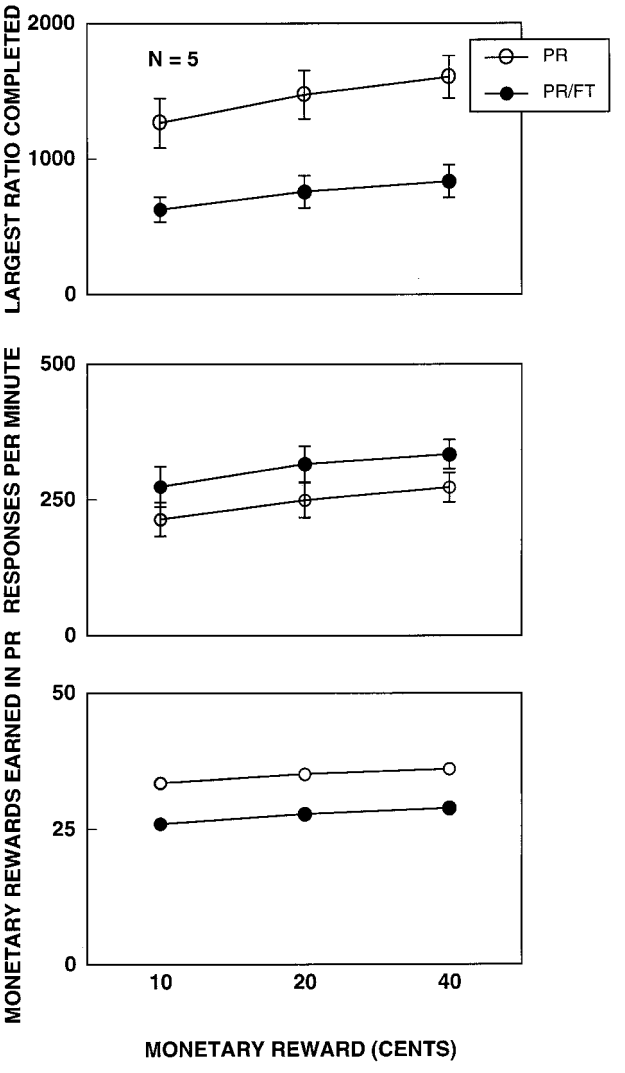

Figure 1. The largest ratio completed, the rate of responding, and the number of monetary rewards earned in the progressive-ratio (PR) and progressive-ratio–fixed-time (PR–FT) schedules at three monetary reward values of 10, 20, and 40 cents. The data points represent the mean value of all 5 participants for the last three sessions at each monetary reward condition (the PR only at 10, 20, and 40 cents represent the first presentation). Error bars represent 1 *SEM*.

The rate of button pressing (responses per minute) during the PR schedule and the PR component of the PR–FT schedule are shown in the middle graph of Figure 1. Response rate for the PR only condition was calculated as the number of responses emitted divided by the session time. Response rate for the PR–FT condition was calculated as the number of responses emitted divided by the total time spent in the PR component. The rate of button pressing was higher in the PR–FT schedule than in the PR schedule, and under both schedules the response rate increased as the value of the monetary reinforcer increased. A repeated measures ANOVA analysis of response rate found a signif-

icant main effect of condition (PR vs. PR–FT), $F(1, 4) = 38.51$, $p < .003$. The main effect of monetary value was also significant, $F(2, 8) = 10.16$, $p < .006$. The Condition × Monetary Value interaction was not significant, $F(2, 8) = 0.12$, $p < .891$.

The number of reinforcers earned in the PR schedule and the PR component of the PR–FT schedule are shown in the bottom graph of Figure 1. Again, the number of reinforcers earned increased as the monetary value was increased in the PR schedule and the PR component of the PR–FT schedule. The introduction of the FT component reduced the number of reinforcers earned in the PR component compared with the PR schedule. Similar results were obtained in a repeated measures ANOVA of the number of reinforcers earned in the PR schedule and the PR component of the PR–FT schedule. There was a significant main effect of condition, $F(1, 4) = 19.68$, $p < .011$, and of monetary value, $F(2, 8) = 18.48$, $p < .026$. The Condition × Monetary Value interaction was not significant, $F(2, 8) = 0.04$, $p < .965$.

Discussion

Each of the measures, highest ratio completed, response rate, and number of reinforcers earned, increased as a function of monetary value. This effect was observed in both the PR and PR–FT conditions. These results are consistent with the proposed operational definition of motivated behavior: The properties of responding increased as a function of increases in the monetary value of the reinforcer.

Experiment 2: Effects of Acute Marijuana Smoking

Having demonstrated changes in response rate and ratios completed consistent with the operational definition of motivation proposed at the outset, the second experiment was initiated to determine the effects of smoking marijuana on the measures employed in Experiment 1. In the first phase of Experiment 2, we attempted to assess acute marijuana effects on responding across three potencies of Δ^9-THC while holding reinforcer value constant. Consistent with the proposed operational definition, decreases in PR responding following acute marijuana administration, despite no change in reinforcer value, would be taken as an index of decreased motivation. In the second phase, we attempted to attenuate the acute effects of marijuana on reinforced responding by holding the marijuana dose (of the highest potency) constant while increasing the monetary value of the reinforcer.

Method

Participants. Five male participants between 18 and 31 years old ($M = 24.6$ years) participated after giving their informed consent. Female participants were not excluded; however, none were successfully recruited into the study. One participant had previously participated in cooperation research 1.5 years earlier and 1 participant had participated in Experiment 1. The other 3 participants reported no previous experimental history. The educational level of these participants ranged from 10 to 14 years ($M = 11.5$ years).

Only participants reporting current marijuana use were allowed to participate. These participants reported currently using marijuana one to three times per month. Participants reporting minimal current marijuana use were selected for two reasons. First, moderate to heavy users were excluded to avoid the possible confound of behavioral tolerance to the effects of acute marijuana observed in regular users. Second, we wished to avoid the difficulty inherent in obtaining cannabinoid-free urine samples—both initially and over the 4 weeks of the study—from regular marijuana smokers. Four participants reported drinking beer (4–12 per week). Three participants also reported use of cocaine (< 10 times), diazepam (Valium; < 5 times), or both. Drug use information was collected using a lifetime drug use history questionnaire developed in our laboratory and the SCID-I, Version 2.0, (First et al., 1996)

Apparatus and behavioral testing. The same apparatus was used as in Experiment 1. Participants were recruited, screened, and provided the same instructions as in Experiment 1. Breath alcohol measures and urine drug screen analyses were performed daily. The PR–FT schedule previously described was used. The monetary reinforcer value remained at \$0.10 until all three potency marijuana cigarettes were smoked. Participants then smoked the highest potency marijuana cigarettes on three other occasions at reward values of \$0.20, \$0.40 and a return to \$0.10.

Marijuana cigarettes and smoking procedure. All marijuana cigarettes used were obtained from the National Institute on Drug Abuse. As shown in Table 2, four doses were administered: placebo cigarettes containing 0.0001% wt/wt Δ^9-THC and three active doses using 1.77% or 3.58% Δ^9-THC cigarettes. To obtain a low dose (M1), the administration consisted of a 1.77% cigarette and a placebo cigarette. Cigarettes were stored at −20 °C and humidified for 16 hr before smoking. Cigarettes were smoked in a ventilated, enclosed chamber. Participants took 10 inhalations on one cigarette, that is, 5 on each half. Cued by a series of three lights, participants took a 3-s inhalation every 30 s, followed by a 10-s breathhold before exhaling. These procedures are commonly used in marijuana smoking experiments (Higgins & Stitzer, 1986; Kelly, Foltin, & Fischman, 1993; Renault, Schuster, Heinrich, & Freedman, 1971).

Participants smoked the two halves of one marijuana cigarette immediately prior to the beginning of the second session of the day. Smoking took place in a booth, which exhausted air to the outside of the building. Blood pressure and heart rate were measured before and immediately after smoking.

Participants smoked placebo (0.00001% THC) cigarettes until their responding stabilized and EMIT analyses registered a cannabinoid-negative urine sample. An active marijuana cigarette was then smoked for a single day, and participants subsequently returned to placebo cigarettes until responding was stable and a cannabinoid-negative urine (< 100 ng/ml) sample was obtained. Participants smoked each active cigarette for 1 day in an ascending sequence of potency, with typically 3 to 4 placebo days between active cigarettes.

Cardiovascular measures. Immediately before and after marijuana smoking, the participant's heart rate and systolic and dia-

Table 2
Potency of Two Halves of Marijuana Cigarettes Smoked Under Four Conditions

Condition	First half	Second half
Placebo	0.00001%	0.00001% wt/wt Δ^9-THC
Marijuana Dose 1	1.77%	0.00001% wt/wt Δ^9-THC
Marijuana Dose 2	1.77%	1.77% wt/wt Δ^9-THC
Marijuana Dose 3	3.58%	3.58% wt/wt Δ^9-THC

stolic blood pressures were measured using an automatic oscillometric digital blood pressure and pulse monitor (Marshall Electronics, Lincolnshire, IL). These cardiovascular measures were taken as soon as the participant exhaled from the last inhalation and butted out the remainder of the cigarette, typically within 10 s.

Self-report measures. Immediately after smoking, marijuana participants completed a symptom questionnaire. Participants were asked to rate on a 5-point scale the effect of the marijuana cigarette ("I feel an effect of the marijuana smoke") and whether they were experiencing heart pounding ("My heart is pounding faster than normal"), lightheadedness ("I feel dizzy, light-headed"), or a typical marijuana "high" ("I feel a typical marijuana high"). The self-report measures were taken as soon as the cardiovascular measures had been completed, typically within 2 min of the completion of smoking.

Sequence of conditions. Table 1 shows the sequence of conditions for Experiment 2, Phases 1 and 2. In Phase 1 (acute dose–response determination), participants began in PR condition for 1 day and then were changed to the PR–FT condition for the remainder of the experiment. The monetary value was fixed at $0.10 across the placebo and the three active doses. Participants participated in five 1-hr sessions each day, following the same schedule used in Experiment 1. After Phase 1, participants participated in a second phase of the study (assessing changes in the monetary value of the reinforcer). Under these conditions, participants smoked the most potent marijuana cigarette (3.58%) under the following monetary value conditions: $0.10 (end of the dose–response determination), $0.20, $0.40, and $0.10. This second phase was conducted to determine if increasing the monetary value would alter the effects of marijuana smoking on PR–FT schedule performance. Participants smoked placebo cigarettes until response parameters at a given monetary condition were stable (*SD* $<$ 15% of mean, no linear trends in the data). Next, a 3.58% dose was administered. On subsequent days, placebos were administered until behavior stabilized. Active doses were separated by at least 1 week. Participants completed five sessions per day and required an average of 29.40 days (range = 27–33) to complete the study.

All placebo values used in the data analyses for Phases 1 and 2 of Experiment 2 reflect the placebo days that immediately preceded the active dose administration days.

Results

Phase 1: Cardiovascular and subjective measures. Large increases in heart rate were observed immediately after smoking active marijuana cigarettes. The mean ($\pm$ 1 *SEM*) increases in heart rate were 2.9 $\pm$ 1.2 beats per minute following placebo cigarettes and 27.8 $\pm$ 6.8, 31.7 $\pm$ 12.5, and 37.3 $\pm$ 4.7 beats per minute following the smoking of ½ of 1.77%, 1.77%, and 3.58% Δ^9-THC cigarettes, respectively. The effect of marijuana potency on heart rate was significant, $F(3, 12) = 11.00$, $p < .001$. Post hoc analyses examined all pairwise comparisons using the Tukey honestly significant difference (HSD) Test. The results indicated that the increases in heart rate following smoking of the 1.77% ($p < .05$) and 3.58% ($p < .05$) Δ^9-THC cigarettes were significantly greater than those following smoking of placebo cigarettes.

Three of the four items on the smoking questionnaire, completed immediately after smoking, were increased. The effect of marijuana potency was significant on three of four items: (a) effect of smoke, $F(3, 12) = 4.18$, $p < .03$; (b) heart pounding, $F(3, 12) = 5.48$, $p < .01$; (c) light-headed, $F(3, 12) = 2.94$, $p < .07$, *ns*; and (d) typical marijuana high, $F(3, 12) = 3.91$, $p < .002$. Post hoc analyses examined all pairwise comparisons using the Tukey HSD Test. The results indicated that ratings of effect of smoke, heart pounding, and typical marijuana high were significantly increased ($p < .05$) after smoking all potencies of active marijuana cigarette compared with placebo.

Phase 1: Behavioral measures. Figure 2 depicts behavior from three of the dependent measures taken in the PR component of the PR–FT condition. The mean of all 5

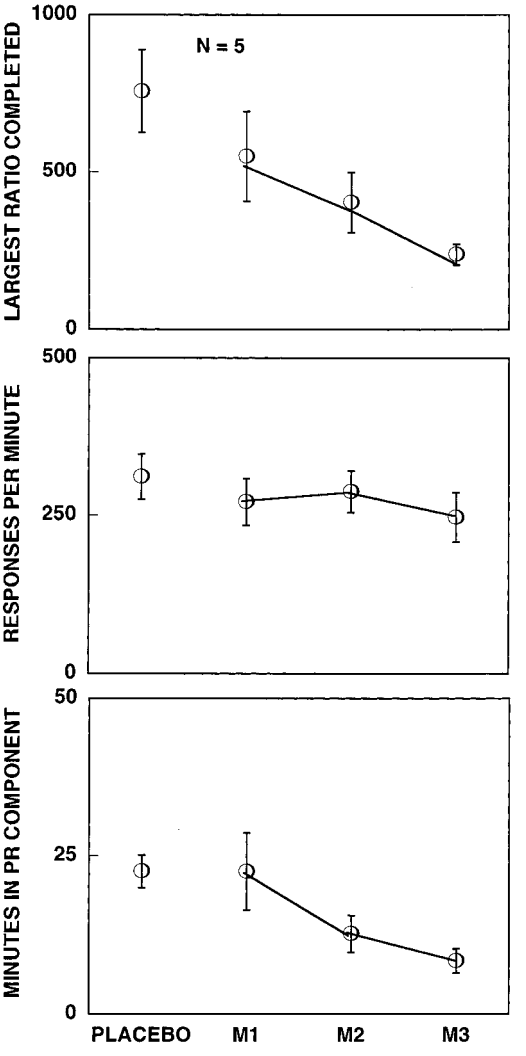

Figure 2. The largest ratio completed, the rate of responding, and the time (in minutes) spent in the progressive-ratio (PR) component of the PR–fixed-time schedule across three different marijuana doses (M1 = half of 1.77%; M2 = 1.77%; M3 = 3.58% Δ^9-THC). The data points represent mean value of all 5 participants for the session initiated immediately after marijuana smoking. The placebo point represents the mean value for the sessions following smoking of placebo cigarettes conducted on days immediately preceding the smoking of active marijuana cigarettes. Error bars represent 1 *SEM*.

participants is shown. The top graph of Figure 2 shows the largest ratio completed in the 1-hr session immediately following smoking of placebo or one of the three active-potency marijuana cigarettes. All participants decreased the size of the largest ratio completed in the PR component after smoking active marijuana cigarettes. The decrease in the size of the highest ratio completed was related to the potency of the marijuana cigarette smoked. A repeated measures ANOVA indicated a significant main effect of marijuana potency, $F(3, 12) = 4.05$, $p < .033$. Post hoc analyses examined all pairwise comparisons using the Tukey HSD test. The results indicated that, compared with placebo, the highest ratio completed in the PR component was significantly reduced after smoking the 1.77% ($p < .05$) and 3.58% ($p < .01$) Δ^9-THC cigarettes. The close relationship between the number of responses emitted and the value of the highest ratio completed indicates that participants typically switched out of the PR to the FT schedule after completing a ratio and earning a reinforcer, rather than during the middle of a progressive ratio.

The middle graph of Figure 2 shows the effects of smoking placebo and three potencies of marijuana cigarettes on the rate of responding in the PR component during the 1-hr session that immediately followed smoking. All three potencies produced small decreases in response rate. A repeated measures ANOVA indicated a significant main effect of marijuana potency, $F(3, 12) = 4.72$, $p < .021$. Post hoc analyses examined all pairwise comparisons using the Tukey HSD test. The results showed that response rate was decreased significantly after smoking the ½ of 1.77% and 3.58% Δ^9-THC cigarettes, compared with placebo.

The bottom graph of Figure 2 shows the minutes participants spent in the PR component during the 1-hr session that immediately followed smoking. Smoking the active marijuana cigarettes produced a decrease in the time spent in the PR component, which was related to potency. A repeated measures ANOVA revealed a significant effect of marijuana potency, $F(3, 12) = 5.29$, $p < .015$. Paralleling these changes was a decrease in the number of reinforcers earned in the PR component, which was related to marijuana potency, $F(3, 12) = 5.37$, $p < .014$.

Phase 2: Varying monetary value. Phase 2 involved determining the effects of varying monetary value ($0.10, $0.20 or $0.40) on the changes observed after smoking the highest potency marijuana cigarette during the 1-hr session that immediately followed. These data are shown in Figure 3. The top graph of Figure 3 displays the largest ratio completed after smoking placebo or the highest potency marijuana cigarette at three monetary values of $0.10, $0.20, or $0.40. The initial data points at $0.10 are the last part of the previous dose–response curve. After exposure to monetary rewards of $0.20 and $0.40, participants were returned to $0.10 for a repeat determination of the effects of marijuana. Smoking the highest potency marijuana cigarette produced a substantial decrease in the size of the largest ratio completed in the PR component. This effect was diminished when the monetary value was increased to $0.20 and $0.40. A repeat determination of the effect of marijuana at the $0.10 value indicated a reduced effect, but still a marked decrease in the highest ratio completed compared with placebo conditions. A repeated measures ANOVA indicated a significant main effect of marijuana, $F(1, 4) = 22.98$, $p < .009$. The main effect of monetary value was not significant, $F(2, 8) = 2.42$, $p < .15$, but the interaction of Marijuana × Monetary Value was significant, $F(2, 8) = 4.80$, $p < .043$.

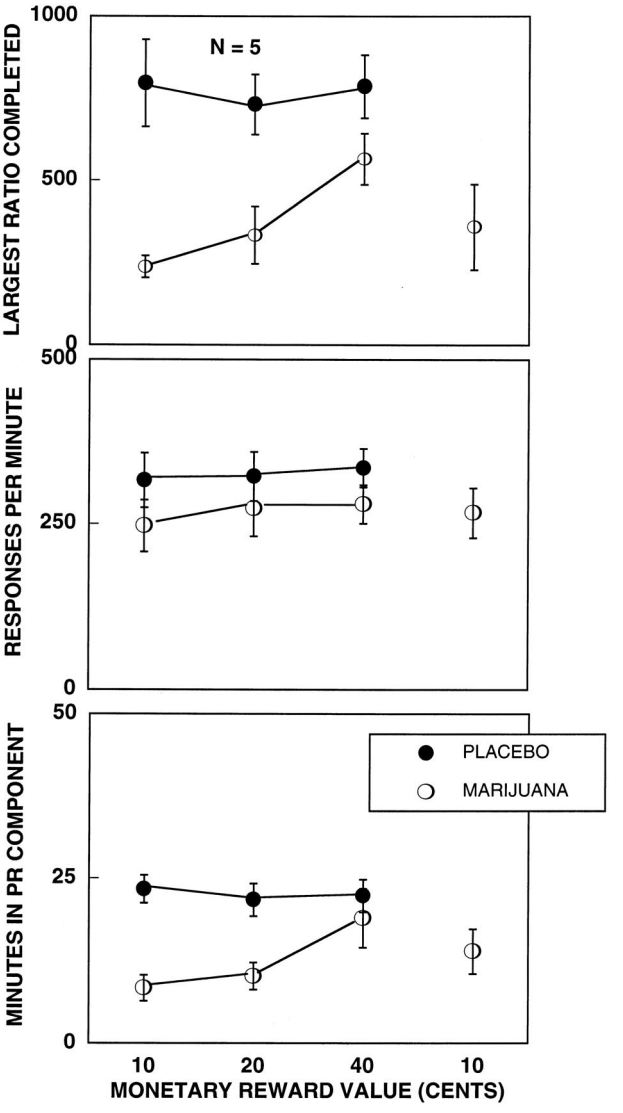

Figure 3. The largest ratio completed, the rate of responding, and the time (in minutes) spent in the progressive-ratio (PR) component of the PR–fixed-time schedule across three different monetary reward values and a final return to the lowest monetary value. Data are shown after smoking of either placebo or the highest potency marijuana cigarette of 3.58% Δ^9-THC. The data points represent the mean value of all 5 participants for the session initiated immediately after marijuana smoking. The placebo point represents the mean value for the sessions following smoking of placebo cigarettes conducted on days immediately preceding the smoking of active marijuana cigarettes. Error bars represent 1 *SEM*.

The middle graph of Figure 3 displays the response rate in the PR component after smoking placebo or the highest potency marijuana cigarette at three monetary values. The response rate was lower after smoking the highest potency marijuana cigarette and did not change as a function of monetary reward value. A repeated measures ANOVA found that the main effect of marijuana was significant, $F(1, 4) = 12.64$, $p < .024$. The main effect of monetary value was not significant, $F(2, 8) = 2.34$, $p < .158$, nor was the Marijuana × Monetary Value interaction, $F(2, 8) = 0.06$, $p < .938$.

The bottom graph of Figure 3 shows the amount of time in minutes that participants spent in the PR component after smoking placebo or the highest potency marijuana cigarette at three monetary values. The amount of time in the PR component was reduced after smoking the highest potency marijuana cigarette. Increasing the monetary value attenuated this effect. A repeated measures ANOVA indicated a significant main effect of marijuana, $F(1, 4) = 14.53$, $p < .019$. The main effect of monetary value was not significant, $F(2, 8) = 3.77$, $p < .07$, but the interaction of Marijuana × Monetary Value was significant, $F(2, 8) = 7.90$, $p < .013$. The number of reinforcers earned in the PR component was significantly affected by marijuana, $F(1, 4) = 18.60$, $p < .013$. However, the main effect of monetary value on number of rewards earned in the PR component was not significant, $F(2, 8) = 2.46$, $p < .147$, and the interaction of Monetary Value × Marijuana was not significant, $F(2, 8) = 3.39$, $p < .085$.

Phase 2: Cardiovascular effects, subjective effects, and tolerance. The repeated presentation of the most potent dose (3.58%) raised the possibility that tolerance to the effects of marijuana may have developed. To that end, separate one-way repeated measures ANOVAs and individual post hoc comparisons were performed on all behavioral, cardiovascular, and subjective effects data from the four active marijuana doses of 3.58% given across Phase 2. Tolerance might be observed through a significant decrease in subjective and cardiovascular effects over the four administrations. Thus, a repeated measures ANOVA was performed on all cardiovascular and subjective effects data from the three 3.58% Δ^9-THC doses. There were no significant effects of repetitions on heart rate or on any of the subjective reports, suggesting that tolerance to the cardiovascular and subjective effects did not develop.

Behavioral tolerance would be suggested by a linear increase in PR responding across the four doses, with a continued increase during the return to the \$0.10 condition. One-way repeated measures ANOVAs on the behavioral data did reveal significant differences. There was a significant effect for the largest PR completed, $F(3, 4) = 7.314$, $p = .005$. Tukey post hoc analyses of all pairwise comparisons revealed significant differences ($p < .05$) between the first \$0.10 and the \$0.40 conditions and between the \$0.20 and \$0.40 conditions. There was not a significant effect for the measure of responses per minute, $F(3, 4) = 0.590$, $p = .633$. There was a significant effect for time spent in the PR component, $F(3, 4) = 5.586$, $p = .012$. Tukey post hoc comparisons revealed significant differences ($p < .05$) between the first \$0.10 and the \$0.40 conditions and between the \$0.20 and \$0.40 conditions only. There was a significant effect for the number of reinforcers earned in the PR component, $F(3, 4) = 5.795$, $p = .011$. Tukey post hoc comparisons revealed a significant difference ($p < .05$) between the first \$0.10 and the \$0.40 conditions only. It is important to note that although behavior in the final \$0.10 condition did not return entirely to the initial level, it was not significantly different from that of any of the other conditions, suggesting only partial, if any, behavioral tolerance.

Switch point, time in FT, and reinforcers earned. The data revealed variability in response rates, earnings, and switch points (time in the PR condition) across experiments and conditions. One possibility, given that response rates decreased after marijuana smoking, was that switching to the FT component was controlled by an attempt to optimize reinforcement rate, rather than by a decrease in reinforcer efficacy following acute marijuana intoxication. Specifically, if responding decreased in the PR component of PR–FT conditions following marijuana smoking, it would lead to increases in inter-reinforcement intervals. When the time required to complete a PR interval exceeded 200 s (the minimum FT value), then participants could maximize reinforcer rates by switching to the FT component—offering a counter argument for the observed decreases in largest ratio completed and minutes in PR.

Table 3 shows the time required to complete the last PR (e.g., the one that immediately preceded the switch to the FT component), the FT value that was in effect, the number of reinforcers earned in the PR and FT components, and the total reinforcers earned for each participant under each PR–FT condition in Experiments 1 and 2. The data clearly show that participants did not switch in order to maximize reinforcement rates; across all participants and conditions, in only two instances (Participant 916 in Experiment 1 and Participant 822 in Experiment 2, Phase 1) did switching occur after the PR value exceeded 200 s. As can be seen in both phases of Experiment 2, participants tended to switch out of the PR very early after high-THC content doses, compared with corresponding placebo conditions. This early switching was far from optimal and typically produced decreases in total reinforcers earned compared with placebo conditions.

Discussion

The results of Experiment 1 demonstrated changes in responding consistent with an operationally defined interpretation of motivation. Changes in ratios completed, response rate, and reinforcers earned uniformly increased as a function of increases in reinforcer value. The results of Phase 1 of Experiment 2 indicated that acute marijuana smoking produced changes in behavior (decreases in largest ratio completed, reinforcers earned, and time spent in the PR component). However, the follow-up pairwise statistical comparisons showed that these effects were not uniformly dose dependent. One interpretation of these data is a decrease in the ability of the \$0.10 monetary reinforcer to maintain responding in the PR component. Although not the

Table 3
Time to Complete the Last Progressive Ratio (PR), Actual Fixed-Time (FT) Value, the Number of Reinforcers Earned in the PR and FT Conditions, and the Total Reinforcers Earned for Each Participant and Condition in Experiments 1 and 2

Participant	Condition[a]	Time in last PR (s)	FT value (s)	Reinforcers in PR	Reinforcers in FT	Total reinforcers
			Experiment 1			
818	10/None	72.86	200.00	23.67	12.00	35.67
	20/None	81.74	200.00	26.00	11.67	37.67
	40/None	108.99	200.00	28.33	10.00	38.33
822	10/None	165.37	200.00	31.00	8.00	39.00
	20/None	143.05	200.00	31.00	9.00	40.00
	40/None	139.13	200.00	31.00	9.00	40.00
916	10/None	214.40	219.31	29.33	2.67	32.00
	20/None	194.47	201.23	31.33	3.33	34.67
	40/None	226.25	234.46	32.00	2.00	34.00
950	10/None	95.66	200.00	19.33	12.33	31.67
	20/None	70.89	200.00	24.00	12.67	36.67
	40/None	75.31	200.00	20.00	13.00	33.00
958	10/None	117.55	200.00	27.33	9.67	37.00
	20/None	144.88	200.00	30.33	8.00	38.33
	40/None	139.90	200.00	30.33	7.67	38.00
			Experiment 2: Phase 1			
657	10/Plc	107.15	200.00	22.33	11.00	33.33
	10/½ of 1.77	133.52	200.00	23	10	33
	10/1.77	122.67	200.00	22	9	31
	10/3.58	127.51	200.00	18	13	31
822	10 /Plc	142.75	200.00	33.00	7.33	40.33
	10/½ of 1.77	264.07	264.07	38	1	39
	10/1.77	100.19	200.00	28	10	38
	10/3.58	62.53	200.00	19	13	32
911	10/Plc	87.09	200.00	27.00	11.33	38.33
	10/½ of 1.77	15.41	200.00	8	16	24
	10/1.77	16.60	200.00	10	16	26
	10/3.58	60.25	200.00	15	14	29
1026	10/Plc	153.93	200.00	30.67	7.00	37.67
	10/½ of 1.77	174.60	200.00	30	7	37
	10/1.77	82.77	200.00	23	12	35
	10/3.58	78.44	200.00	18	12	30
1041	10/Plc	133.86	200.00	26.00	9.00	35.00
	10/½ of 1.77	151.31	200.00	23	10	33
	10/1.77	78.54	200.00	19	13	32
	10/3.58	29.34	200.00	9	16	25
			Experiment 2: Phase 2			
657	10/Plc	119.00	200.00	23	11	34
	20/Plc	121.23	200.00	24	9	33
	40/Plc	122.89	200.00	28	10	38
	10/3.58	127.51	200.00	18	13	31
	20/3.58	113.54	200.00	21	13	34
	40/3.58	194.81	200.00	29	7	36
	10/3.58	113.82	200.00	26	10	36
822	10/Plc	124.26	200.00	34	7	41
	20/Plc	123.63	200.00	31	9	40
	40/Plc	137.58	200.00	32	8	40
	10/3.58	62.53	200.00	19	13	32
	20/3.58	73.81	200.00	25	12	37
	40/3.58	116.35	200.00	30	9	39
	10/3.58	67.82	200.00	24	12	36
911	10/Plc	77.40	200.00	26	12	38
	20/Plc	74.71	200.00	25	12	37
	40/Plc	78.43	200.00	25	12	37
	10/3.58	60.25	200.00	15	14	29
	20/3.58	28.29	200.00	14	15	29
	40/3.58	28.67	200.00	12	16	28
	10/3.58	31.18	200.00	14	10	24

Table 3 (*continued*)

Participant	Condition[a]	Time in last PR (s)	FT value (s)	Reinforcers in PR	Reinforcers in FT	Total reinforcers
			Experiment 2: Phase 2 (*continued*)			
1026	10/Plc	142.36	200.00	29	9	38
	20/Plc	145.44	200.00	29	9	38
	40/Plc	146.66	200.00	31	8	39
	10/3.58	78.44	200.00	18	12	30
	20/3.58	81.19	200.00	23	12	35
	40/3.58	79.70	200.00	26	10	36
	10/3.58	107.11	200.00	28	10	38
1041	10/Plc	132.82	200.00	25	10	35
	20/Plc	167.43	200.00	30	7	37
	40/Plc	138.47	200.00	27	8	35
	10/3.58	29.34	200.00	9	16	25
	20/3.58	35.91	200.00	9	15	24
	40/3.58	120.76	200.00	22	9	31
	10/3.58	39.15	200.00	13	15	28

Note. Values represent the stable data used in the figures and statistics.
[a] 10 = $0.10 reinforcer; 20 = $0.20 reinforcer; 40 = $0.40 reinforcer; None = Experiment 1, no drug administration; Plc = placebo; 1.77 = 1.77% THC; 3.58 = 3.58% THC.

only possible interpretation, this interpretation is consistent with a decrease in motivation as operationally defined in the context of these experiments. Data from Phase 2 of Experiment 2 suggest that these marijuana-induced decreases in responding can be overcome by increasing the reinforcer magnitude.

The results of Phase 1 of Experiment 2 are similar to previous laboratory studies showing a decrease in reinforced responding following acute marijuana smoking. Miles et al. (1974) evaluated the effects of chronic marijuana smoking over successive days on paid-work productivity and observed a marked decrease in work productivity and time spent working during the first day of marijuana smoking, indicating an acute effect. In another study, participants were required to increase the amount of time spent in their least preferred activity (reading, for most of the participants) in order to have access to their most preferred (e.g., reinforcing) recreational activity in a common social area (Foltin et al., 1989). Compared with placebo smoking conditions, smoking of active marijuana cigarettes decreased time spent in the least preferred activity, which in turn resulted in diminished time available for the more preferred activities. Pihl and Sigal (1978) observed that performance on paired-associate and reaction time tasks was superior when maintained by monetary reinforcement versus instructions or no consequence. This difference was eliminated following acute marijuana smoking. Consistent with the proposed operational definition, all of the above-noted studies suggest motivational effects. In each case, behavior maintained by reinforcement contingencies was diminished by acute marijuana smoking.

In Phase 2 of Experiment 2, the highest dose of marijuana (3.58% Δ^9-THC) produced significant differences from placebo under reward conditions of $0.10 and $0.20, but these differences were attenuated when the reward amount was increased to $0.40. A similar finding was noted by Miles et al. (1974), who reported that rates of working were reduced following marijuana smoking, but increasing wages for production partially reversed these effects. Similar conclusions were reached in a study examining marijuana effects in a context that required completion of low-probability behaviors to access high-probability behaviors (Foltin et al., 1990). One collective implication of these studies is that the amotivational syndrome represents a change in the efficacy of reinforcers in maintaining behavior, which can be overcome when reinforcers of sufficient value are available. This should be taken as a tentative interpretation in light of alternative hypotheses regarding the present experiments (discussed below).

The present results stand in contrast to other studies in this area. A series of studies employing operant tasks—which allowed participants to work on a single response option in order to accumulate points to be exchanged for money or marijuana at the end of the study—found no evidence for acute amotivational effects, for example, no change in responding (Mello & Mendelson, 1985; Mendelson, Kuehnle, Greenberg, & Mello, 1976; Mendelson, Rossi, & Meyer, 1974). In these studies, participants often responded at high rates while smoking marijuana, and responding did not decrease as a function of amount of marijuana smoked. More recently, Kelly et al. (1993) employed an operant task that required participants to respond at a slow consistent rate but still found no evidence of reduced responding.

What are the differences between the present study (and others suggestive of amotivational-type effects) and those noted above that have not observed marijuana-related behavior change? One important distinction may be the availability of an alternative response option. The availability of at least one alternative response option provides increased sensitivity in measurement of behavior maintained by reinforcement contingencies (Herrnstein, 1997; Heyman, 1983). The ability of participants to terminate the PR component and still receive monetary reinforcement may have contrib-

uted to the increased sensitivity to the acute effects of marijuana smoking. It is therefore possible that such effects are influenced by the contingency under which a task is being performed, and certain experimental contexts and contingencies may be required to examine amotivational behavior. Indeed, one may need to study a range of reinforcers that vary in strength and a range of response requirements to detect an effect.

Other differences between this study and previous studies include the frequency of marijuana use by participants, the educational level of participants, and the environment in which responding occurred after smoking. We selected very infrequent marijuana users (one to four times per month), while previous studies have recruited participants smoking from 8 to 33 times per month (e.g., Mendelson et al., 1974, 1976). Differences in behavioral tolerance, based on preexperimental smoking history, may have contributed to the conflicting results. The educational level of participants in previous studies averaged 2–3 years of college (Mello & Mendelson, 1985; Mendelson et al., 1974, 1976), whereas many of our participants had not completed high school (11.5 years). Baseline differences in motivation between college student volunteers and less-educated participants may also explain differences between studies. College students may well be more motivated to do well (work hard) in the context of an experiment than community volunteers. In the present study, participants smoked marijuana in a special ventilated chamber and were then escorted to a separate test chamber. In contrast, in some previous studies, participants' responding (or work output) and their marijuana smoking occurred in the same environment (Mello & Mendelson, 1985; Mendelson et al., 1974, 1976). This similarity in context may have diminished the behavioral effects of marijuana. Notably, the Miles et al. (1974) study, which reported effects similar to those found here, also involved participants smoking marijuana in an area different from the one in which they worked.

In the present study, smoking active marijuana on 6 separate days across both phases of Experiment 2 raises the possibility that acute behavioral, subjective, or physiological tolerance developed. With respect to physiological and subjective effects, the data do not indicate that tolerance developed. No significant changes in these measures were observed across successive exposures to active marijuana. With respect to the behavioral data, the possibility of tolerance is less clear. Significant differences were found on all three primary measures (largest ratio completed, reinforcers earned, and time spent in the PR component), but only between the first \$0.10 versus \$0.40 and the \$0.20 versus \$0.40 monetary value conditions. Because the \$0.10 condition was presented first and last, behavioral tolerance would have been indicated by significantly higher measures in the last \$0.10 condition. The last \$0.10 condition was associated with higher, but not significantly higher, behavioral measures than the first \$0.10 condition. This suggests that partial behavioral tolerance may have developed over the course of smoking the active Δ^9-THC cigarette on six separate occasions. This partial tolerance may account for the lack of a statistically significant difference between measures at \$0.40 and the second repeat exposure to the \$0.10 condition.

In addition to the unresolved influence of partial tolerance, one might conclude that the present experimental design contributed to the observed behavior patterns. Specifically, the increasing order of reinforcer magnitude (Experiment 1 and Phase 2 of Experiment 2) may have shaped response patterns. In a similar manner, the increasing order of marijuana dose (Phase 1 of Experiment 2) may have had a systematic effect on responding. The ascending order of doses was used to minimize the effects of behavioral tolerance, and the generally unchanged response patterns under placebo conditions in Experiment 2 indicate that an effect of dose order was unlikely, but the present design does not fully resolve the possibility.

In accord with the proposed operational definition, the present results can be construed as indicating reduced motivation following marijuana smoking. However, this interpretation may be subject to further argument, given the limitations of the present study. In addition to the uncertain influences of the ascending dose order and partial behavioral tolerance, the significant effect of dose on response rate introduces another alternative interpretation. Specifically, because acute smoking produced decreases in response rates (necessarily corresponding to decreased reinforcement rates under the PR condition), it is unclear whether switching to the FT component was controlled in part by this decrease in response rate, by a decrease in the reinforcing properties of the monetary reward (e.g., decreased "motivation"), or by some interaction of those two factors. This possibility is highlighted by the main effect of dose on response rate. However, careful inspection of the data in Table 3, showing the time values for the PR and FT components and reinforcers earned in each component, argue against this interpretation. Participants almost always switched out of the PR component well before it was optimal to do so (e.g., before the PR required more than 200 s to complete), and this effect was most pronounced at the highest THC doses.

These present results address acute effects only and do not provide information about whether residual effects following chronic use can produce similar behavior patterns. Such information has important clinical implications, in part because the amotivation syndrome is commonly associated with long-term chronic use. Residual impairments have been demonstrated on tests of cognitive function (Pope & Yurgelun-Todd, 1996); do they extend to behavior maintained by reinforcement contingencies? Work in our laboratory is underway to test for this effect in adolescent chronic marijuana smokers.

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Received January 2, 2001
Revision received October 25, 2001
Accepted October 29, 2001 ■