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Further Validation of a Marijuana Purchase Task

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Abstract

Background—A valid measure of the relative economic value of marijuana is needed to characterize individual variation in the drug's reinforcing value and inform evolving national marijuana policy. Relative drug value (demand) can be measured via purchase tasks, and demand for alcohol and cigarettes has been associated with craving, dependence, and treatment response. This study examined marijuana demand with a marijuana purchase task (MPT).

Methods—The 22-item self-report MPT was administered to 99 frequent marijuana users (37.4% female, 71.5% marijuana use days, 15.2% cannabis dependent).

Results—Pearson correlations indicated a negative relationship between intensity (free consumption) and age of initiation of regular use ($r=-0.34$, $p<0.001$), and positive associations with use days ($r=0.26$, $p<0.05$) and subjective craving ($r=0.43$, $p<0.001$). $O_{\max}$ (maximum expenditure) was positively associated with use days ($r=0.29$, $p<0.01$) and subjective craving ($r=0.27$, $p<0.01$). Income was not associated with demand. An exponential demand model provided an excellent fit to the data across users ($R^2=0.99$). Group comparisons based on presence or absence of DSM-IV cannabis dependence symptoms revealed that users with any dependence symptoms showed significantly higher intensity of demand and more inelastic demand, reflecting greater insensitivity to price increases.

Conclusions—These results provide support for construct validity of the MPT, indicating its sensitivity to marijuana demand as a function of increasing cost, and its ability to differentiate

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Contributors

Dr. Metrik conducted the study from which these data were obtained. Drs. Aston and MacKillop conducted the statistical analyses. Dr. Aston wrote the manuscript and all authors edited the manuscript together. All authors significantly contributed to and have approved the final manuscript.

Conflict of Interest

All authors declare that they have no personal or financial conflict of interest.

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between users with and without dependence symptoms. The MPT may denote abuse liability and is a valuable addition to the behavioral economic literature. Potential applications to marijuana pricing and tax policy are discussed.

Keywords

marijuana; behavioral economics; cannabis dependence; purchase task; demand curve

1. INTRODUCTION

Marijuana is the most frequently used illicit drug in the United States (Substance Abuse and Mental Health Services Administration, 2012), although its illicit status may change as States continue to adopt legislation to decriminalize, medically legalize, and recreationally legalize the drug. Since 1996, 23 states and Washington, DC have legalized and enacted medical marijuana programs. Legislation in 11 additional States permit use of “low tetrahydrocannabinol, high cannabidiol” products for medical reasons (National Conference of State Legislatures, 2014). Both Washington and Colorado passed legislation to allow use of marijuana for recreational purposes in 2012 (Office of National Drug Control Policy, 2013), and both Oregon and Alaska have passed similar legislation set to become effective in 2015 (Ferner, 2014a, 2014c). In addition, Washington D.C. constituents voted to allow use and cultivation of small amounts of marijuana for recreational purposes (Ferner, 2014b). If these trends in marijuana legislation continue, the production, advertisement, and sale of marijuana are likely to commence across the United States. The relative ease of accessibility to inexpensive marijuana is a considerable risk factor for heavy use, as is the case with alcohol (Murphy and MacKillop, 2006), and legalization may intensify the initiation and progression of marijuana use (Palamar et al., 2014). Due to the shift toward positive normative perception surrounding marijuana use (Center for Substance Abuse Research, 2013), an approach to analyze the value of this drug is essential.

The measurement of a drug’s relative value falls within the purview of a behavioral approach to drug addiction, which proposes that a drug’s relative reinforcing value is a powerful determinant of its use and abuse (Bickel et al., 2014; Higgins et al., 2004; Hursh et al., 2005). In this regard, the relative degree of effort employed to successfully attain a certain reinforcer is a good indicator of its reinforcing value (Vuchinich and Tucker, 1983). Illicit drugs tend to be very salient reinforcers, thus drug users put forth much time and energy trying to obtain them (Tucker et al., 2002). Relative drug value can be measured by laboratory self-administration paradigms or self-reported estimated consumption of a substance at a range of prices via a behavioral economic purchase task (MacKillop and Murphy, 2013; Plebani et al., 2012). Purchase tasks quantify substance demand, or the association between drug consumption and drug cost (Hursh et al., 2005; MacKillop and Murphy, 2013; Plebani et al., 2012). These tasks are analogous to behavioral operant self-administration methods (Hodos, 1961) but offer a more efficient assessment. Further, such tasks can be used to measure drug value in treatment-seeking or dependent samples for whom self-administration paradigms may raise ethical issues. Laboratory paradigms allow for examination of several behavioral economic drug demand indices, including intensity (the amount of drug consumed at zero cost), $P_{\max}$ (price at maximum expenditure), $O_{\max}$

(peak expenditure for a drug), breakpoint (cost at which consumption is suppressed to zero), and elasticity of demand (the degree to which consumption decreases with increasing price; Bickel et al., 2014).

Purchase tasks have been used extensively to measure the reinforcing nature of alcohol. Indices of alcohol reinforcement from an alcohol purchase task (APT) have been significantly associated with level of alcohol consumption and severity of alcohol problems (MacKillop et al., 2010a; Murphy et al., 2009; Murphy and MacKillop, 2006; Smith et al., 2010), and have been shown to predict treatment response (MacKillop and Murphy, 2007). Moreover, performance for hypothetical alcohol has been shown to be highly correlated with performance for actual alcohol (Amlung et al., 2012). In addition, state-oriented purchase tasks capture cue-elicited increases in motivation for alcohol (MacKillop et al., 2010b, 2007).

Purchase tasks have also been used to quantify demand for tobacco cigarettes. Compared to findings from APT research, studies utilizing cigarette purchase tasks (CPTs) have produced similar results. CPT performance has been significantly related to daily smoking level, nicotine dependence, and smoking cessation intent (Chase et al., 2013; MacKillop et al., 2008; MacKillop and Tidey, 2011; Murphy et al., 2011). In addition, CPTs have been used to assess cue-induced craving (Acker and MacKillop, 2013; MacKillop et al., 2012a) and demand for potentially less harmful drug substitutions (O'Connor et al., 2014, 2012). Moreover, tobacco demand outcomes have been used translationally to effectively advise public policy regarding sale of tobacco cigarettes (Hursh and Roma, 2013). Studies using purchase tasks also suggest that relatively small increases in taxation of cigarettes may significantly decrease the economic burden of smoking (MacKillop et al., 2012b).

Though the utility of measuring substance demand is clear from research on the relative value of alcohol and nicotine, there is a dearth of research employing behavioral economics to examine marijuana demand. The first study examining the behavioral economics of marijuana utilized a novel marijuana purchase task (MPT) to investigate simulated demand for marijuana (Collins et al, 2014). Collins and colleagues (2014) administered a MPT to 59 recreational marijuana users, asking them to estimate the number of marijuana joints they would purchase at increasing prices. The study employed ecological momentary assessment to collect real-time marijuana use data and subsequently investigated the associations between marijuana use and MPT demand indices. Marijuana users were sensitive to the price of marijuana, consuming the highest number of joints at no cost, and eventually suppressed demand to zero at approximately \$38 per joint.

In the current investigation, we sought to extend previous findings regarding substance demand by employing a purchase task to examine marijuana demand in a sample of frequent marijuana users. In an effort to establish the smallest measurable unit of marijuana consumed, a “hit” on a marijuana joint was used as the unit of expenditure for the task, with ten hits being equivalent to one marijuana joint. It can be difficult to quantify and characterize consumption of marijuana and smoking behavior due to a lack of established quantity standards, varying self-administration tools (e.g., “joints,” “blunts,” pipes, or vaporizers), and individual differences in marijuana use practices (Mariani et al., 2011).

However, the use of hits to characterize marijuana use events has been employed recently and appears to be a valid measurement of level of use within an episode (Shrier et al., 2013). We predicted that consumption of marijuana would decrease as a function of increasing price on a MPT. In addition, we sought to examine the measure's convergent validity (i.e., correspondence between the measure and potentially related variables) and divergent validity (i.e., ability of the measure to identify relevant group differences; Nunnally and Bernstein, 1994). We examined convergent validity by assessing correlational relationships between marijuana demand indices and marijuana use variables (i.e., subjective craving, marijuana dependence symptoms, percent marijuana use days, age of initiation of regular marijuana use). We also examined the measure's divergent validity by dividing the sample according to presence or absence of DSM-IV cannabis dependence symptoms (0 versus 1+) and conducting group comparisons among demand indices. This grouping rationale takes into consideration a subthreshold indication of addiction vulnerability rather than characterization based on the now-obsolete DSM-IV diagnosis of cannabis dependence (presence of 3+ symptoms). The two categories created an optimal distribution of the dependence symptom count measure. We predicted greater marijuana demand among participants with any marijuana dependence symptoms. In addition, we investigated the associations between marijuana demand metrics and income due to the conceivable relevance of income to perceived marijuana value.

2. MATERIALS AND METHODS

2.1 Participants

Data were obtained from participants who completed baseline assessments during an experimental study investigating cannabinoid-related genetic variation and variability in marijuana's acute and cue-elicited effects. Participants were 104 (36.5% female) non-treatment seeking frequent marijuana users recruited through newspaper advertisements, flyers, and social media websites who met the following inclusion criteria: native English speakers, 18–44 years of age, non-Hispanic Caucasian (due to genetic aims of the parent study), marijuana use at least 2 days per week in the past month and at least weekly in the past 6 months, and self-reported ability to abstain from marijuana for 24 hours without withdrawal. Exclusion criteria were: intent to quit or receive treatment for cannabis abuse, positive urine toxicology test result for drugs other than marijuana, pregnancy, nursing, past month affective or panic disorder, psychotic or suicidal state assessed by psychiatric interview, contraindicated medical issues assessed by physical exam, body mass index > 30, and smoking more than 20 tobacco cigarettes per day. Five participants showed evidence of low effort on the MPT (e.g., inconsistent responding across prices) and were excluded from subsequent analysis (Amlung et al., 2012). The final sample included 99 participants (37.4% female) with a mean age of 21.4 ($SD=4.4$; range=18–42) years and mean age of initiation of regular marijuana use of 16 years. Participants reported using marijuana a mean of 2.0 ($SD=1.2$) times per day on 71.5% ($SD=21.7\%$) of the past 60 days (approximately 5 days per week). Positive THC urine screens were obtained from 83% of participants. Typical endorsed mode of marijuana administration is presented in Table 1. Participants endorsed a mean of 1.2 ($SD=1.3$) of the six DSM-IV cannabis dependence symptoms, 15.2% ($n=15$) met criteria for past year DSM-IV cannabis dependence (3+ dependence symptoms), and

21.2% met criteria for lifetime DSM-IV cannabis dependence. The average reported family income bracket of participants was \$50,000–59,000 annually. Participants were paid \$30 upon completion of the baseline session.

2.2 Procedure

Study procedures were approved by the Institutional Review Board of Brown University, and all participants provided informed consent prior to participating in the study. Participants abstained from marijuana and tobacco smoking for 12 hours before the session. A conservative alveolar carbon monoxide (CO) reading of 6 ppm was used to confirm no recent smoking (Cooper and Haney, 2009; Metrik et al., 2012) with a Bedfont Scientific Smokelyzer®. Tobacco smokers were permitted to smoke a tobacco cigarette following the CO test to prevent nicotine withdrawal. Zero breath alcohol concentration was verified with an Alco-Sensor IV (Intoximeters, Inc., St Louis, MO., USA). Participants completed self-report measures during a baseline laboratory session.

2.3 Measures

DSM-IV Axis I diagnoses were determined with the Structured Clinical Interview for DSM-IV Non-Patient Edition (SCID; First et al., 2002). The Time-Line Follow-Back Interview (TLFB; Dennis et al., 2004) was used to assess past 60-day number of marijuana use days. Subjective marijuana craving was assessed via a 10-item *Marijuana Craving Questionnaire* (MCQ; Budney et al., 2003). Participants were asked to respond to items according to how they were thinking or feeling “right now,” and MCQ items were rated on a 1=“strongly disagree” to 7=“strongly agree” scale, with higher scores indicating greater subjective marijuana craving, and summed to yield a total craving score ($\alpha=.90$). The *Marijuana History and Smoking Questionnaire* was used to assess age of onset of marijuana use, typical marijuana use quantity, typical mode of self-administration, amount of money spent monthly on marijuana, and other questions related to marijuana use patterns (Metrik et al., 2009).

Marijuana Purchase Task (MPT)—The MPT measure was developed to assess behavioral economic marijuana demand and was based on Jacobs and Bickel’s procedure (1999) and validated alcohol (Murphy and MacKillop, 2006) and tobacco (MacKillop et al., 2008) purchase tasks. Participants were provided with the following task instructions:

Imagine a TYPICAL DAY over the last month when you would use marijuana. You can only get marijuana from this source. You can’t get it for cheaper and you cannot use any marijuana you may have saved or kept from previous episodes. You have the typical amount of money available to you to purchase marijuana. You did NOT use marijuana or use any other drugs before you are making these decisions. You will NOT have an opportunity to use marijuana elsewhere. You would consume all the marijuana that you request. Think about how much marijuana you would smoke if it were of average quality. For this task: there are 10 hits of marijuana in a joint. There is no limit on hits or joints (1 joint=1/32nd of an ounce=0.9 grams). Given the previous conditions, how many hits of marijuana would you take ON A TYPICAL DAY at the following prices: \$0, \$0.25, \$0.50,

\$0.75, \$1, \$1.25, \$1.50, \$1.75, \$2, \$2.50, \$3, \$3.50, \$4, \$4.50, \$5, \$5.50, \$6, \$6.50, \$7, \$8, \$9, \$10?

Five metrics of marijuana demand were obtained from the MPT: (a) breakpoint, (i.e., cost at which consumption is suppressed to zero), (b) intensity of demand (i.e., the amount of drug consumed at zero cost), (c) elasticity of demand (i.e., the sensitivity of marijuana consumption to increases in cost), (d) $P_{\max}$ (i.e., price at maximum expenditure), and (e) $O_{\max}$ (i.e., peak expenditure for a drug). Observed values for breakpoint, intensity, $P_{\max}$, and $O_{\max}$, were estimated by directly examining MPT performance. Elasticity of demand was empirically derived using values generated from a nonlinear exponential demand curve model. A multiple correlation value reflecting the percentage of variance accounted for by the demand curve model was also generated from the MPT to provide an index of the adequacy of the fit of the model to the data.

2.4 Statistical Analyses

Calculations of demand indices were obtained using the following methods. Price elasticity was generated using the following nonlinear exponential demand curve model (Hursh and Silberberg, 2008): $\log_{10}Q = \log_{10}Q_0 + k(e^{-\alpha Q_0 C} - 1)$, where Q =quantity consumed, Q_0 =derived intensity, k =a constant across individuals that denotes the range of the dependent variable (marijuana hits) in logarithmic units, C =the cost of the commodity, and α =elasticity or the rate constant determining the rate of decline in log consumption based on increases in price (i.e., essential value). The overall best-fitting k parameter was determined to be 2. An R^2 value was generated to reflect percentage of variance accounted for by the demand equation (i.e., the adequacy of the fit of the model to the data). Consistent with procedures employed by Jacobs and Bickel (1999), when fitting the data to the demand equation, breakpoint consumption was coded as an arbitrarily nonzero value of 0.1 to provide an x -axis intercept of the demand curve that was amenable to logarithmic transformation. Similarly, the initial price (i.e., marijuana at zero cost) was replaced by a value of one cent (1¢) (i.e., \$.01) to permit the use of the logarithmic transformation in the demand curve model. Following the calculation of all demand metrics, each was examined for adequacy of distribution and outliers.

Convergent validity of the MPT was examined via Pearson correlations between indices of marijuana demand and self-reported subjective craving, number of current DSM-IV marijuana dependence symptoms, percent of TLFB marijuana use days, and age of initiation of regular marijuana use. Divergent validity was examined by dividing the sample according to presence or absence of current DSM-IV cannabis dependence symptoms (0 versus 1+) and subsequently examining elasticity as a function of dependence symptom group. The relationship between MPT performance and income was assessed via Pearson product-moment correlations. For all analyses, statistical significance was defined as $\alpha < 0.05$. Analyses were conducted using SPSS 22.0 and GraphPad Prism 6.0.

3. RESULTS

3.1 Preliminary Analyses

Raw MPT data were examined for outliers using standard scores, with a criterion of $Z=3.29$ to retain maximum data. A small number of outliers were detected ($<2.5\%$). The outliers were determined to be legitimate high-magnitude values and were recoded one unit higher than the next lowest non-outlying value (Tabachnick and Fidell, 2000). All data were examined for distribution normality using histograms. Variable distributions were positively skewed for indices of marijuana demand. A cube root transformation was used to transform elasticity of demand which improved the distribution substantially. Skewness for the remaining indices of demand was determined to be negligible, thus non-transformed indices were used in analyses.

3.2 Adequacy of the Model

Figure 1 illustrates the mean number of marijuana hits that participants reported that they would consume at 22 different prices (log-transformed). As hypothesized, marijuana consumption decreased as a function of increasing price. Figure 2 depicts the expenditure associated with each price. The Exponential Demand Equation (Hursh and Silberberg, 2008) provided an excellent fit to the overall demand data ($R^2=0.99$) and a very good fit to the individual data (median $R^2=0.81$, interquartile range= $0.74-0.85$). Indices of marijuana demand for the total sample are presented in Table 2.

3.3 Relationships Among Marijuana Demand Indices

Pearson's product-moment correlations were calculated among the marijuana demand indices and revealed several significant associations (see Table 3). All demand metrics were highly correlated with one another, with the exception of $P_{\max}$ and intensity.

3.4 Convergent Validity: Relationships Among Demand Indices and Marijuana Use Variables

As predicted, several metrics of marijuana demand were associated with marijuana use variables (see Table 3). Pearson product-moment correlations displayed revealed significant associations between intensity and age of initiation of regular marijuana use ($r=-0.34$, $p<0.001$), percent of marijuana use days ($r=0.26$, $p<0.05$) and baseline subjective craving for marijuana ($r=0.43$, $p<0.001$; mean (SD) subjective craving score= 2.6 (1.2), range= $1-6$). $O_{\max}$ was positively associated with percent of marijuana use days ($r=0.29$, $p<0.01$) and subjective craving ($r=0.27$, $p<0.01$). Elasticity was negatively associated with subjective craving ($r=-0.21$, $p<0.05$). Income was not associated with any of the demand indices.

3.5 Divergent Validity: Demand as a Function of Presence or Absence of Cannabis Dependence Symptoms

With respect to divergent validity, the sample was categorized into two groups based on presence of any DSM-IV cannabis dependence symptoms (0 vs. 1+). Marijuana users endorsing one or more cannabis dependence symptoms (61%; $n=60$) did not significantly differ in gender ($\chi^2=0.37$, $df=1$, $p=0.55$) compared to marijuana users who did not endorse

any symptoms. As expected, marijuana users endorsing one or more cannabis dependence symptoms reported using marijuana more frequently (mean=75.6%, SD=20.6%, $p=0.019$), exhibited higher baseline subjective marijuana craving scores (mean=3.0, SD=1.3, $p<0.001$), and spent significantly more on marijuana in the past 30 days (mean=\$97.7, SD=\$79.3, $p=0.020$) as compared to marijuana users who did not endorse any symptoms. Participants endorsing cannabis dependence symptoms showed significantly more inelastic demand (insensitivity to price increase; mean=0.038, SEM=0.005) than users without current dependence symptoms (mean=0.055, SEM=0.007, $p=0.041$; see Figure 3). Participants with cannabis dependence symptoms also displayed significantly higher intensity of demand ($p=0.021$). MPT performance for each group is presented in Table 4.

4. DISCUSSION

In the current study, we aimed to validate a MPT as an effective measure of the relative value of marijuana. MPT data were consistent with previous research employing purchase tasks to assess drug demand (e.g., Collins et al., 2014; MacKillop et al., 2008; Murphy and MacKillop, 2006), as estimated consumption of marijuana hits decreased as price per hit increased. Moreover, the MPT demonstrated robust convergent validity, as demand metrics (i.e., intensity, $O_{\max}$, and elasticity) were significantly associated with marijuana use variables (i.e., subjective marijuana craving, age at initiation of regular marijuana use, marijuana dependence symptoms, and percent of marijuana use days). The MPT measure also displayed initial divergent validity, as it was capable of demonstrating differences in intensity and elasticity based on presence or absence of cannabis dependence symptoms. Notably, household income was not significantly related to marijuana demand, resonating with findings from similar research (e.g., Collins et al., 2014). These results provide initial support for construct validity of the MPT, indicating its sensitivity to the relative value of marijuana as a function of increasing cost, and its ability to differentiate between users with no dependence symptoms versus those with greater vulnerability for development of a cannabis use disorder (CUD).

Marijuana users endorsing one or more symptoms of dependence indicated that they would smoke the equivalent of approximately three joints or take almost twice as many hits as those without any symptoms when marijuana was free (at \$0/hit). This finding is consistent with the results from the first MPT study (Collins et al., 2014), as well as research on non-treatment seeking regular marijuana users who self-administer active marijuana nearly every time it is made available (Kelly et al., 1997). Moreover, marijuana self-administration studies have demonstrated that marijuana is strongly reinforcing. Despite this, imposing a financial cost to smoking can decrease marijuana self-administration (Haney, 2009). Our data on MPT elasticity resonate closely with these laboratory findings and may offer a cost-effective alternative for characterizing the often compulsive nature of drug use.

It is important to note that this is the second study to examine a measure of marijuana demand. Collins and colleagues (2014) determined that elasticity and other demand indices from a MPT can be used to characterize drug use, and findings from the current investigation align well with these results. Notably, MPT results appear to be robust across the two studies despite utilization of different methodologies. Data from our laboratory

indicate that marijuana users utilize diverse and often overlapping usual modes of marijuana administration (e.g., joints, pipes, bongs, one-hitters, blunts, tobacco-marijuana joints, and hash-brownies), and a majority of marijuana users report typically using marijuana with others, further highlighting the importance of quantifying the smallest measurable unit of use and cost (Metrik et al., 2012). Marijuana joints were used as the unit of purchase for the task developed by Collins and colleagues (2014), however, only 4% of the sample reported using joints as their usual administration mode. In this regard, a marijuana hit may be the optimal unit for a MPT. Alternatively, marijuana is typically purchased in units of weight, such as grams, eighths, and quarters (of ounces), thus such units may be the most compatible with purchasing behavior. Beyond conjecture, though, these are empirical questions that should be addressed in future studies.

While the current study employed a similar data analytic plan as compared to previous research on purchase tasks for alcohol and tobacco (e.g., MacKillop et al., 2008; Murphy and MacKillop, 2006), other analytic strategies have been successfully utilized in the literature. It has been argued that the demand equation used in the current investigation may be sensitive to the specific nonzero values (i.e., 0.1) chosen to replace zero values which occur at and after each participant's breakpoint. Therefore, use of nonzero values may have the potential to affect the fit of the demand curve. However, for some participants, the information loss which results from removing zero values is not trivial, thus a significant portion of the demand curve may be lost. Furthermore, alternative statistical techniques exist for the analysis of behavioral economic data. Collins and colleagues (2014) successfully implemented a novel approach using a nonlinear mixed effects model to analyze MPT data from their research (Yu et al., 2014). In this regard, there are a number of strategies for the analysis of demand data, each with strengths and limitations; therefore the optimal strategy remains an open question. Despite the promising initial findings of our investigation, the following methodological limitations are worth noting. The instructions specified that the marijuana purchased during the task would be of average quality, and not of the user's typical quality or strain. Similarly, Collins and colleagues (2014) specified that the marijuana available for purchase in their MPT was "high grade." However, desired potency or purity of other drugs (e.g., cocaine) has been related to purchase frequency and amount (Greenwald and Steinmiller, 2014), thus the same may be true for marijuana. Future studies could consider employing an individualized approach to marijuana potency via instruction to complete the task for marijuana of one's own typical grade and potency. Further, the time period specified in the instructions was "amount smoked in a typical day", however, this timeframe may have been too broad, leading to extreme values for purchase at zero cost in 10% of the sample and failure to suppress demand to zero in 15% of the sample. Failure to suppress demand to zero in some participants may also indicate that the range of prices in the task was too constrained. Moreover, due to the genetic aims of the parent study, the recruited sample in the current study was exclusively Caucasian. Subsequent investigations should aim to recruit a racially diverse sample of marijuana users as typical mode of marijuana administration may differ as a function of race (Mariani et al., 2011), which may in turn impact unit of administration selected for a purchase task.

The observed rate of DSM-IV cannabis dependence diagnosis in this study is representative of the 9% among the general population of individuals who report lifetime prevalence of

CUD (Stinson et al, 2006). However, this study was not designed to specifically examine group differences based on the DSM-IV cannabis dependence diagnosis with an n of 15. Subsequent research could consider examining construct validity of the MPT in relation to updated CUD criteria with 11 possible symptoms based on the new DSM-5 diagnostic approach to classifying substance use disorders. In addition, while use of marijuana for recreational purposes is legal in several States, recreational marijuana use is currently illegal in the rest of the United States. Furthermore, its legal status remains tenuous as marijuana use and possession remain illegal at the federal level. Adapting a purchase task for an illicit substance is complicated and likely involves a multitude of additional considerations as compared to licit substances (i.e., alcohol and cigarettes). Qualitative research may provide invaluable information regarding potential MPT improvements via provision of a unique perspective into the decision to seek, purchase, and use a given substance, and may also provide critical insight regarding manipulation of drug demand (Neale et al., 2005). Demonstration of correspondence between MPT performance and actual marijuana use has been accomplished via real-time data collection methodology (Collins et al., 2014). Additional controlled research using micro-level analysis of the association between MPT performance and observed marijuana use behavior in the laboratory is the logical next step in this line of research, as has been done with the alcohol purchase task (Amlung et al., 2012).

Apart from the described limitations, the findings from the current investigation suggest that a MPT may have a number of experimental and clinical applications. Marijuana demand is likely an informative individual difference variable and may predict important features of treatment response, as has been found with alcohol (MacKillop and Murphy, 2007). Moreover, similar to alcohol (MacKillop et al., 2010b; Mackillop et al., 2007) and nicotine (MacKillop et al., 2012a), an MPT may be a valuable tool to indicate state or cue-elicited alterations in substance demand as a function of drug cues or subjective state. In addition, future research should aim to confirm that MPT performance is highly correlated with demand for actual marijuana, a crucial component in establishing the substitutability of an MPT for drug administration. Neuroeconomic assessment of marijuana demand via an fMRI demand paradigm could also provide key information regarding multiple aspects of the decision-making process underlying marijuana purchase and use. The first neuroeconomic study of alcohol demand indicated that different types of cost-benefit decisions on purchase tasks elicit distinct brain activation profiles (Mackillop et al., 2014).

There are important gaps in the literature regarding marijuana use and purchase behavior that must be clarified to inform subsequent research. Little is known about potential alterations in use and purchase patterns that may occur as a function of marijuana legalization. Information regarding demand for marijuana is of immediate public health relevance as it will help to explain the impact of environmental marijuana cues (e.g., advertisements, retail sale locales, marijuana paraphernalia) on drug value and may inform development of efficacious treatment for CUDs. Furthermore, behavioral economic analysis of marijuana value could inform recreational marijuana taxation policy as such regulations will ultimately serve to limit marijuana purchase while sustaining black market competition (Room, 2013). Pending further validation and refinement, a MPT may help determine price

sensitivity and abuse liability across disparate regulatory environments and subjective drug states, and appears to be a valuable addition to the behavioral economic drug demand literature.

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Highlights

- This study examined marijuana demand with a marijuana purchase task (MPT).
- The MPT is sensitive to marijuana demand as a function of increasing cost.
- The MPT can differentiate between users with and without dependence symptoms.
- The MPT may help to denote abuse liability.

Figure 1.

Demand curve for consumption of marijuana hits, with the x-axis providing price in dollars (\$) and the y-axis providing self-reported consumption in marijuana hits. Conventional log coordinates are used on the x-axis to accommodate large inter-price intervals, with zero values replaced by trivial nonzero values (0.1).

Figure 2.

Expenditure curve for purchase of marijuana hits, with the x-axis providing price in dollars (\$) and the y-axis providing expenditure in dollars (\$). Values are presented in actual units rather than conventional logarithmic units for interpretational clarity.

Figure 3.

Demand curves for No Dependence Symptoms (0 DSM-IV symptoms) and Any Dependence Symptoms (1+ DSM-IV symptoms) Groups. Conventional log coordinates are used on the x-axis to accommodate large inter-price intervals, with zero values replaced by trivial nonzero values (0.1).

Table 1

Self-Reported Marijuana Use Descriptives (n = 99)

<u>Self-Reported Mode of Usual Marijuana Administration</u>	
<i>Mode</i>	<i>% (n)</i>
Pipe	70 (69)
Bong (water pipe)	64 (63)
Blunt (marijuana in hollowed out cigars)	63 (62)
Joint	60 (59)
Joint with Tobacco	21 (21)
One-Hitter	18 (18)
Hash Brownies	13 (13)

<u>Average Ounces of Marijuana Used Per Week</u>	
<i>Ounces</i>	<i>% (n)</i>
Less than 1/16 th	9 (9)
1/16 th	21 (21)
1/8 th	30 (30)
1/4	19 (19)
More than 1/4	20 (20)

^aEndorsed modes of administration were not mutually exclusive.

Table 2

Indices of Marijuana Demand for the Total Sample (n = 99)

Metric	Mean	SEM
Intensity	23.71	2.830
$O_{\max}$	16.13	2.372
$P_{\max}$	2.32	0.209
Breakpoint	4.24	0.305
Elasticity	0.04	0.004

^aMean and SEM presented for elasticity are non-transformed values.

Table 3

Correlations Among Demand Indices and Marijuana Use Variables

Variable	1	2	3	4	5	6	7	8	9
1. Intensity	-	-	-	-	-	-	-	-	-
2. $O_{\max}$	.466***	-	-	-	-	-	-	-	-
3. $P_{\max}$	-.107	.249*	-	-	-	-	-	-	-
4. Breakpoint	.198*	.579***	.759***	-	-	-	-	-	-
5. Elasticity	-.286**	-.663***	-.630***	-.898***	-	-	-	-	-
6. Income	.068	-.038	.075	.037	-.178	-	-	-	-
7. Subjective Craving	.426***	.265**	.051	.162	-.206*	.005	-	-	-
8. Age of Regular Use	-.344***	-.123	-.053	-.090	.089	.106	-.410***	-	-
9. %Marijuana Use Days	.256*	.293**	-.026	.123	-.133	-.156	.356***	-.244*	-
10. Dependence Symptom Count	.132	.138	-.066	.056	-.077	-.077	.463***	-.241*	.212*

^aContinuous variable was used for #Dependence Symptoms. Cube root transformed elasticity was used in correlational analyses.^b*** $p < 0.001$,** $p < 0.01$,* $p < 0.05$

Table 4

Indices of Demand as a Function of Marijuana Dependence Symptom Count

Metric	0 Dependence Symptoms (n=39)		1+ Dependence Symptoms (n=60)		<i>p</i>
	Mean	SEM	Mean	SEM	
Elasticity	.055	.007	.038	.005	.041*
Intensity	16.180	3.470	28.600	3.984	.021*
$O_{\max}$	11.962	2.402	18.833	3.562	.113
$P_{\max}$	2.167	.328	2.417	.273	.562
Breakpoint	3.590	.470	4.658	.394	.087

^aMean and SEM presented for elasticity are non-transformed values.