HHS Public Access
Author manuscript
Psychopharmacology (Berl). Author manuscript; available in PMC 2018 August 01.

Published in final edited form as:
Psychopharmacology (Berl). 2017 August ; 234(16): 2421–2429. doi:10.1007/s00213-017-4633-6.

Latent Factor Structure of a Behavioral Economic Marijuana Demand Curve

Elizabeth R. Aston[1,*], **Samantha G. Farris**[3,4,5], **James MacKillop**[6,7,1], and **Jane Metrik**[2,1,3]

[1]Center for Alcohol and Addiction Studies, Brown University School of Public Health, Providence, RI, 02903

[2]Providence Veterans Affairs Medical Center, Providence, RI, 02908

[3]The Warren Alpert Medical School of Brown University, Department of Psychiatry and Human Behavior, Providence, RI, 02906

[4]The Miriam Hospital, Centers for Behavioral and Preventative Medicine, Providence, RI, 02906

[5]Butler Hospital, Providence, RI, 02906

[6]Peter Boris Centre for Addictions Research, McMaster University/St. Joseph's Healthcare Hamilton, Hamilton, ON L8N 3K7 Canada

[7]Home wood Research Institute, Guelph, ON N1E 6K9

Abstract

Rationale—Drug demand, or relative value, can be assessed via analysis of behavioral economic purchase task performance. Five demand indices are typically obtained from drug purchase tasks.

Objectives—The goal of this research was to determine whether metrics of marijuana reinforcement from a marijuana purchase task (MPT) exhibit a latent factor structure that efficiently characterizes marijuana demand.

Methods—Participants (*n*=99; 37.4% female, 71.5% marijuana use days [5 days/week], 15.2% cannabis dependent) were regular marijuana users who completed study assessments, including the MPT, during a baseline session. Principal components analysis was used to examine the latent structure underlying MPT indices. Concurrent validity was assessed via examination of relationships between latent factors and marijuana use, past quit attempts, and marijuana expectancies.

Results—A two-factor solution was confirmed as the best fitting structure, accounting for 88.5% of the overall variance. Factor 1 (65.8% variance) reflected "Persistence", indicating sensitivity to escalating marijuana price, which comprised four MPT indices (elasticity, O_{max}, P_{max}, and breakpoint). Factor 2 (22.7% variance) reflected "Amplitude", indicating the amount consumed at unrestricted price (intensity). Persistence factor scores were associated with fewer past marijuana quit attempts and lower expectancies of negative use outcomes. Amplitude factor scores were

CORRESPONDENCE TO: Elizabeth R. Aston, Center for Alcohol and Addiction Studies, Brown University School of Public Health, Box G-S121-5, Providence, RI 02912 USA, Elizabeth_Aston@Brown.edu, Phone: (401) 863-6668, Fax: (401) 863-6697.

associated with more frequent use, dependence symptoms, craving severity, and positive marijuana outcome expectancies.

Conclusions—Consistent with research on alcohol and cigarette purchase tasks, the MPT can be characterized with a latent two-factor structure. Thus, demand for marijuana appears to encompass distinct dimensions of price-sensitivity and volumetric consumption, with differential relations to other aspects of marijuana motivation.

Keywords

marijuana; behavioral economics; demand curve; purchase task; exploratory factor analysis

Introduction

Behavioral economic demand curves can be used to assess the relative reinforcing value of addictive substances (Hursh et al. 2005). Relative reinforcing value refers to the behavior-maintaining or behavior-strengthening properties of a given substance (Johnson and Bickel 2006), and can be assessed via administration of a drug purchase task. Substance purchase tasks have been used to quantify demand (Bickel et al. 2011), or drug consumption as a function of escalating price (Murphy and MacKillop 2006; MacKillop et al. 2008). Five distinct metrics of substance demand can be obtained by analyzing purchase task performance including intensity (i.e., consumption when cost is unrestricted), P_{max} (i.e., price at peak expenditure for a drug), O_{max} (i.e., peak expenditure for a drug), breakpoint (i.e., price at which consumption for a drug is suppressed to zero), and elasticity (i.e., the degree to which consumption decreases with increasing price). All five metrics comprise a multidimensional conceptualization of substance demand wherein each index explains a key element of relative substance value and the motivation to obtain and use drugs (MacKillop et al. 2009). However, though each index represents a unique component of relative drug value, there has been increased interest in determining whether all five indices are better described by shared underlying dimensions of demand.

Purchase tasks have been extensively used to assess demand for alcohol (Murphy and MacKillop 2006) and tobacco (MacKillop et al. 2008). Substance demand indices derived from purchase tasks for general preferences are related to frequency of substance use and dependence symptoms (MacKillop et al. 2010a; Aston et al. 2015; MacKillop et al. 2016) and are predictive of therapeutic treatment response (MacKillop and Murphy 2007; Murphy et al. 2015; MacKillop et al. 2016). State-orientated purchase tasks have been found to complement other state measures of acute motivation (MacKillop et al. 2010b; Acker and MacKillop 2013; Metrik et al. 2016).

Emerging work also suggests that demand for marijuana measured by the Marijuana Purchase Task (MPT) is associated with frequency of marijuana use assessed by self-report and ecological momentary assessment (Collins et al. 2014). Our previous work provided support for construct validity of the MPT, indicating its sensitivity to marijuana demand as a function of increasing cost, and its ability to differentiate between users with and without dependence symptoms (Aston et al. 2015). Intensity of demand exhibited significant relationships with initiation of regular marijuana use, and both intensity and O_{max} were significantly related to frequency of marijuana use, and subjective craving.

While indices of substance demand tend to be moderately-to-highly inter-correlated (e.g., Murphy et al. 2011; Murphy et al. 2013; Aston et al. 2015), they are often differentially related to key indices of addiction. Theoretically, the demand metrics are conceptually related to each other, but nonetheless represent separate features of substance demand (Bickel et al. 2000; O'Connor et al. 2016). Indeed, researchers who have developed and adapted behavioral economic demand equations over time have consistently asserted that features of demand (i.e., intensity and elasticity) are independent of one another (e.g., Hursh 1984; Hursh and Winger 1995; Hursh and Silberberg 2008; Hursh and Roma 2013). The original linear-elasticity equation (Hursh et al. 1989) was unable to define a single parameter for modeling demand curve elasticity, and thus could not effectively neutralize the influence of amplitude. Hursh and Winger (1995) proposed a way to eliminate scalar differences in a new model by expressing price in terms of the number of responses per 1% of maximal consumption (i.e., Q_0 or derived intensity), effectively normalizing amplitude. This change was carried forward to the exponential demand equation used in the current study that was originally proposed by Hursh and Silberberg (2008) and includes only one free parameter defining changes in elasticity of demand (i.e., k) used in the current investigation. Factor-analytic studies of alcohol and tobacco demand suggest that the five demand metrics can be characterized by two latent factors (MacKillop et al. 2009; Bidwell et al. 2012; O'Connor et al. 2016) that reflect sensitivity to cost and volumetric motivation. The latent factors are putatively thought to characterize "persistence" (i.e., maintenance of consumption despite increases in cost) and "amplitude" (i.e., maximum level of *ad libitum* consumption), and empirically hold distinct predictive associations with aspects of addictive behavior. For example, "persistence" of demand is a robust predictor of alcohol problems (Skidmore et al. 2014), and appears to be uniquely positively related to essential cognitive determinants of tobacco addiction, including higher normative perceptions of smoking prevalence and smoking identity (O'Connor et al. 2016). In contrast, "amplitude" of demand is more strongly associated with quantity and frequency of substance use (MacKillop et al. 2009; Bidwell et al. 2012; Skidmore et al. 2014) and indices of substance dependence (MacKillop et al. 2009; O'Connor et al. 2016), and negatively associated with motivation for smoking cessation (Bidwell et al. 2012; O'Connor et al. 2016). Thus, it is theorized that persistence of demand may represent likelihood of changing patterns of drug use (i.e., attempts to cease or reduce use; e.g., MacKillop and Murphy 2007) and amplitude of demand may reflect volumetric differences (e.g., heavy use) in demand (MacKillop et al. 2009). Consequently, isolating latent factors that more parsimoniously characterize substance demand may help elucidate a clearer interpretation of the relationships between aspects of demand with other known and purported substance use and psychosocial processes. From a statistical perspective, reducing the number of demand variables allows for the ability to examine similar empirical associations with fewer statistical tests, which reduces risk of multicollinearity and Type I errors (Bidwell et al. 2012; Amlung et al. 2015; Aston et al. 2016b).

The existence of a latent factor structure has not yet been examined for the MPT. As demand indices for alcohol and tobacco are structurally similar, it is possible that marijuana demand

Author Manuscript

Author Manuscript

Author Manuscript

may a) similarly be represented by two latent factors (persistence and amplitude), or alternatively b) may exhibit a divergent structure given its illicit status in many parts of the world, including the location of data collection in the current study. As an important extension of previous work validating the MPT, this secondary analysis sought to examine the latent factor structure of the MPT using exploratory factor analysis in a sample in which the MPT has been previously validated (Aston et al. 2015). Given the relevance of marijuana demand to the maintenance of problematic use, MPT factors may be related to important aspects of addictive behavior including use, cessation attempts, and cognitions. We hypothesized that an underlying latent structure would exist for marijuana demand indices, though we did not predict a specific number of factors as this is the first study to evaluate for the presence of such a structure within the MPT. Additionally, we aimed to examine the associations among the identified factors with frequency of marijuana use, cannabis dependence symptoms, past marijuana quit attempts, and cognitions related to marijuana use (use expectancies).

Methods

Participants and Procedures

The current study utilized data from an experimental study investigating variability in marijuana's acute and cue-elicited effects (Metrik et al. 2015, 2016) from which baseline data from 99 (37.4% female) participants were used in the initial validation of an MPT (Aston et al. 2015). Participants were recruited in Rhode Island and marijuana use for recreational purposes was illegal at the time when these data were collected. As previously reported, participants were frequent marijuana users recruited from the community 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 atleast two days per week in the past month and atleast weekly in the past 6 months, and self-reported ability to abstain from marijuana for 24 h without withdrawal. Exclusion criteria were: intent to quit or receive treatment for cannabis use, 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. The median reported family income bracket of participants was $60,000–69,999 annually. Approximately half of the sample (58.6%) reported at least one lifetime attempt to cut down or stop marijuana use. Other demographic information is reported in Table 1. All procedures were approved by the Institutional Review Board of Brown University and all participants provided informed consent prior to the commencement of study procedures. Participants were compensated upon completion of the baseline session.

Measures

The number of DSM-IV cannabis dependence symptoms was assessed with the *Structured Clinical Interview for DSM-IV Non-Patient Edition* (SCID; First et al. 2002). Cannabis withdrawal was included as a symptom per the DSM-5 (American Psychiatric Association 2013), thus the possible range was 0–7 symptoms. The calendar-assisted *Timeline Follow-Back Interview* (TLFB; Dennis et al. 2004) was used to assess the percentage of days participants reported marijuana use during the 60 days prior to baseline. Subjective marijuana craving following an overnight (15-hour) deprivation period was assessed via a 10-item *Marijuana Craving Questionnaire* adapted from a tobacco-smoking urges questionnaire (Tiffany and Drobes 1991) and validated for use with marijuana (MCQ; Budney et al. 2003). Participants were asked to respond to items (rated on a 1= “strongly disagree” to 7= “strongly agree” scale) according to how they were thinking or feeling “right now,” with higher scores indicating greater subjective marijuana craving. Items were averaged to yield a total craving score (possible range 1–7; observed range 1–6).

Marijuana quit history was assessed as part of the *Marijuana Smoking History Questionnaire*. This measure includes questions regarding age of onset, number of hours spent smoking per day, amount of money spent monthly on marijuana, and marijuana quit attempts (Metrik et al. 2009). Specifically, participants were asked two questions about lifetime attempts to cut down or quit their use of marijuana. Because of the substantial overlap in the participants’ cessation and reduction attempts, the two questions were combined into a single composite score of marijuana quit history (i.e., cut down or stop) that was used as a dichotomous (yes versus no) variable.

The *Marijuana Effect Expectancy Questionnaire* (MEEQ; Schafer and Brown 1991) was used to assess expectancies of the effect of marijuana use. The MEEQ is a 48-item self-report assessment, with items rated on a five-point Likert scale, which assesses negative and positive expectancies from use. Negative expectancies include: Cognitive and Behavioral Impairment, Global Negative Effects, and Craving and Physical Effects. Positive expectancies include: Relaxation and Tension Reduction, Social and Sexual Facilitation, and Perceptual and Cognitive Enhancement.

The *Marijuana Purchase Task* (MPT; Aston et al. 2015) was developed to assess behavioral economic marijuana demand based on Jacobs and Bickel’s procedure (Jacobs and Bickel 1999) and validated alcohol (Murphy and MacKillop 2006) and tobacco (MacKillop et al. 2008) purchase tasks. The MPT assesses how many marijuana hits one would smoke at 22 escalating prices ($0 to $10 per hit). Participants were asked to respond to items as if it were a typical marijuana use day and were informed that the marijuana available for purchase was of average quality.

Data Analytic Approach

MPT scoring—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 calculated by directly examining MPT performance. Elasticity of demand was empirically derived using values generated from a 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 ($.01) to permit the use of the logarithmic transformation in the demand curve model.

Factor Analysis—Exploratory factor analysis was conducted using a principal components analysis (PCA) method of estimation with oblique (oblimin) rotation to permit multifactorial solutions with correlated factors. This approach is consistent with other exploratory studies of the latent factor structure of purchase tasks (MacKillop et al. 2009; Bidwell et al. 2012). The entered variables were breakpoint, observed P_{max}, observed O_{max}, observed intensity, and elasticity (α). Originally proposed by Hursh and Silberberg (2008), the inverse value for elasticity was used (1/α; i.e., essential value) in order to make interpretation of the factor structure more intuitive, consistent with previous work (Banks et al. 2011; Bidwell et al. 2012; O'Connor et al. 2016). The following transformations were used in order to meet normality assumptions: breakpoint (square-root), observed P_{max} (log_{10}), observed O_{max} (log_{10}), observed intensity (log_{10}), and elasticity (cube-root). The factor structure was determined by examination of the scree plot for clear discontinuities of Eigenvalues, and Eigenvalues > 1 (Goldberg and Velicer 2006). Parallel analysis (Horn 1965) and the minimum average partial (MAP) test (Velicer 1976) were used to confirm the number of factors to retain, as recommended (Zwick and Velicer 1986). These analyses were conducted using procedures outlined by O'Connor (2000). A factor loading of .40 on the pattern matrix was used as the criterion for determining if an item significantly loaded on a given factor (Tabachnick and Fidell 2000; Stevens 2001). Demand indices were permitted to load onto multiple factors given the exploratory aim of determining the latent structure of the MPT. Factor scores were derived by use of standardized regression coefficients.

Correlation Analyses—Bivariate correlations were conducted to examine the associations between the extracted factor scores with indices of marijuana use (frequency of use, number of cannabis dependence symptoms, and cravings severity), marijuana quit attempts), and marijuana expectancies (per the MEEQ). All analyses were conducted using SPSS 22.0 and GraphPad Prism 7.0.

Results

Factor Analytic Findings

The first three Eigenvalues were 3.29, 1.14, and 0.31. Examination of the scree plot indicated that a two-factor structure was the best solution. The two-factor solution explained 88.5% of the total variance. The two-factor structure was confirmed by the parallel analysis with 1000 random sample datasets. The MAP test indicated a solution of one component, which had the lowest average squared correlation (r^2 = .26). It is recommended that, when the MAP test and parallel analysis methods do not converge, the number of simulated random data sets in the parallel analyses should be increased (O'Connor 2000). Results from the parallel analysis were replicated with 5000 random datasets, in support of a two-factor solution. Additionally, upon inspection of the average squared correlations from the MAP test, the two-component solution resulted in the second lowest squared correlations ($r^2 = .20$). Taken together, the two-factor solution was determined to be the best fitting structure.

Table 2 provides the significant loadings of the five MPT demand indices on each of the rotated factors. The inter-correlations between MPT demand indices for this sample are reported elsewhere (see Aston et al. 2015). The first factor reflects "Persistence" of demand, which accounted for 65.8% of variance and included four MPT indices: elasticity (1/α), P_{max}, O_{max}, and breakpoint. The second factor reflects "Amplitude" of demand, which accounted for 22.7% of the variance and included one MPT index: intensity of demand. The correlation between the two factors was small in size ($r = .177$, $p = .080$).

Correlation Results

Table 3 presents the bivariate associations between factors scores and marijuana use variables, quit attempts, and marijuana use expectancies. Results indicated that Factor 1 "Persistence" scores were negatively associated with an attempt to quit or reduce marijuana use in the past 6 months ($r = −19$, $p = .054$), at a trend level. Specifically, higher Persistence in demand (i.e., insensitivity to price increases) was associated with lower likelihood of a quit attempt. Additionally, Factor 1 scores were uniquely negatively associated with negative use expectancies from marijuana ($r = −.31$, $p = .002$), which was driven by the negative association with expectancies of cognitive and behavioral impairment ($r = −.35$, $p < .001$). In contrast, Factor 2 "Amplitude" scores were uniquely positively associated with indices of marijuana use and dependence, including percent marijuana use days ($r = .32$, $p = .001$), craving severity following a 15-hour deprivation period ($r = .49$, $p < .001$), and greater number of cannabis dependence symptoms ($r = .24$, $p = .016$). Additionally, Factor 2 scores were positively associated with positive expectancies from marijuana use. Specifically, higher Amplitude in demand was significantly correlated with expectancies of social/sexual facilitation ($r = .21$, $p = .038$) and relaxation/tension reduction expectancies from marijuana use ($r = .21$, $p = .035$).

Post-hoc Analyses

Post-hoc exploratory analyses were conducted to examine the extent to which Amplitude and Persistence factors were related to marijuana craving severity, above the effects of gender, marijuana use frequency, and marijuana use expectancies. This model was conducted to examine the unique and incremental predictive ability of the factor scores on a marijuana craving. Regression results indicated that the overall model was significant ($F(4,94) = 8.64$, $p < .001$; $adj\ R^2 = .33$). Specifically, the covariates entered in step 1 of the model accounted for 20.8% of variance in marijuana craving, which was driven by the significant effects of marijuana frequency ($b = 0.02$, $se = .01$, $t = 3.44$, $p = .001$) and positive use expectancies ($b = 0.89$, $se = .26$, $t = 3.48$, $p = .001$). The effects of gender and negative use expectancies were non-significant. Amplitude and Persistence factor scores were added in step 2, which accounted for 12.7% of unique additional variance. This was driven by the significant effect of Amplitude ($b = 0.42$, $se = .11$, $t = 3.86$, $p < .001$) but not Persistence ($b = 0.14$, $se = .11$, $t = 1.31$, $p = .194$).

Discussion

We investigated the latent factor structure of a marijuana demand curve generated from the MPT. Principal components analysis indicated presence of a latent two-factor structure which accounted for 88.5% of the total variance. The factor structure of the MPT presented here is consistent with the latent structure documented in previous research on the alcohol purchase task (MacKillop et al. 2009) and cigarette purchase task (Bidwell et al. 2012; O'Connor et al. 2016). Specifically, with the MPT, four demand indices (elasticity, P_{max}, O_{max}, and breakpoint) mapped on to a factor representing "Persistence" of marijuana demand, and intensity of demand mapped on to its own separate factor representing "Amplitude" or volumetric motivation for marijuana. The two factors were not significantly correlated, which indicates that these latent factors represent distinct aspects of marijuana demand. Of note, in contrast to previous studies, we found that O_{max} did not cross-load on both factors, but displayed a clear loading on the factor reflecting Persistence. Thus, it appears that persistent demand for marijuana may be conceptualized as the intersection of both consumption and cost, or, alternatively, sensitivity to price, cost, or perceived consequences of use. In contrast, Amplitude of marijuana demand may be conceptualized as consumption when cost is completely unrestricted – that is, when consequences (i.e., cost) are not present. It is possible that differences in societal and legal characteristics associated with marijuana that do not exist for alcohol or tobacco influence cost-related aspects of demand.

Additional analyses revealed distinct associations between MPT Persistence and Amplitude factors with marijuana indices. Higher Persistence scores were related to lower expectancies of negative marijuana effects. This effect was specifically driven by expectancies pertaining to cognitive-behavioral impairment from marijuana use. This may be attributed to tolerance that develops to some of marijuana's acute effects over periods of chronic use (Volkow et al. 2014). This expectancy set is particularly troublesome as it may be associated with the perception of lower behavioral risk from marijuana use, reflected by behaviors such as increased likelihood of driving during and after marijuana use (Aston et al. 2016a). This patterning of results is broadly consistent with one prior study that found the Persistence factor of cigarette demand was associated with cognitive processes related to stable use (i.e., identifying as a smoker and perceptions of higher smoking prevalence; O'Connor et al. 2016). Additionally, we found that Persistence scores were related to lower likelihood of lifetime attempts to cease or cut down marijuana use, which was significant at a trend level. This aligns with the notion that Persistence of demand reflects stable substance use patterns (in contrast to attempts to change substance use).

Amplitude of demand was uniquely and differentially associated with marijuana use variables. Mapping on to what has been previously shown with individual MPT indices with these data, higher Amplitude scores (i.e., intensity of demand) were associated with greater frequency of marijuana use, craving severity, and number of cannabis dependence symptoms (Aston et al. 2015). This is likely a reflection of the volumetric nature of this latent factor (i.e., hits consumed and money spent). Additionally, Amplitude scores were positively associated with greater expectancies of positive consequences from marijuana use, including social/sexual facilitation and relaxation/tension reduction. Thus, Amplitude of demand appears to be linked to frequency of substance use, dependence measures, and positive expectancies from use, whereas Persistence may be more closely related to the absence of change behavior and holding fewer negative expectancies regarding the consequences of substance use. This set of findings is broadly consistent with prior work that have documented stronger associations of Amplitude scores with indices related to frequency and quantity of substance use (MacKillop et al. 2009; Bidwell et al. 2012) and dependence (MacKillop et al. 2009; Bidwell et al. 2012; O'Connor et al. 2016), relative to Persistence scores, although the current study documented unique associations with these indices. That is, the latent MPT Persistence and Amplitude scores do not appear to overlap in their associations with marijuana use or expectancy variables, further confirming that these latent factors are unique components of marijuana demand. Indeed, post-hoc analyses revealed that Amplitude, but not Persistence, was uniquely associated with marijuana craving severity, above and beyond the effects of gender, marijuana use frequency, and marijuana use expectancies.

Existing data on the latent factors derived from alcohol and tobacco purchase tasks have not similarly demonstrated clear distinct associations with related substance use or cessation indices. For example, Bidwell and colleagues (2012) found that both Amplitude and Persistence factors were similarly related to frequency of smoking and level of nicotine dependence, albeit slightly stronger-sized associations emerged between Amplitude and higher smoking frequency and lower motivation for quitting. MacKillop et al. (2009) also reported significant correlations between Amplitude and key alcohol use variables including frequency and quantity of use, heavy use, and alcohol problems, although did not find that Persistence was uniquely associated with any measured indices. In fact, one study suggested that the five individual purchase task indices may better reflect the multidimensional nature of substance demand, relative to two factors, due to the lack of distinct associations between the latent factor scores and other variables of interest (Bidwell et al. 2012). However, there may be several reasons for these disparate findings. First, because O_{max} loaded on to both latent factors in previous research, it is possible that the distinction between the factors became less clear, resulting in overlapping associations in many cases. Second, it is possible the latent factors are uniquely associated with aspects of substance use that were not assessed in previous studies, such that differences in these latent factors only emerged when considering additional processes related to addiction (e.g., cognitive processes). Third, there may be unique aspects of marijuana (relative to tobacco and alcohol) that lend more to clear separation between the two latent factors, such as unique purchasing requirements and circumstances, price-setting that is often related to availability and legal consequences rather than consumer demand, and the inability to use in public settings expressly designated for such purposes as is the case with tobacco and alcohol.

There are several study limitations that are important to address. The sample size in the current investigation was modest for exploratory factor analysis, therefore subsequent research should attempt to replicate and expand on these effects with a larger sample of frequent marijuana users. The small number of indices mitigates this limitation somewhat but the point stands. Moreover, the cross-sectional nature of this examination does not allow for causal inferences to be made regarding the relationships between demand features and marijuana use patterns and associated variables. The sample in the current investigation reported a relatively high median income level. This may be a function of household income rather than individual income, thus future studies should assess discrete income variables including discretionary expenditures allocated to marijuana purchase as has been examined in the alcohol purchase task literature (e.g., Skidmore et al. 2014). In the current investigation, lifetime attempts to cease or reduce marijuana use was included in analyses as a dichotomous yes/no variable. Consequently, it is important to extend this research to examine how demand may influence marijuana change efforts in individuals with different histories of change behavior. In addition, because the current sample was exclusively Caucasian due to genetic aims of the parent study, results may not generalize to racially diverse samples of marijuana users. These data were collected in Rhode Island during a time when marijuana was considered an illicit substance. Future studies conducting systematic comparisons between states in which marijuana is legal versus illegal may uncover unique influences of legal environment on marijuana demand.

The version of the MPT administered in the current study utilized marijuana hits as the unit of purchase and consumption. Other research has employed joints as the unit of marijuana purchase on the MPT (Collins et al. 2014). Use of hits or joints of marijuana might differentially impact the latent variables uncovered here, particularly Amplitude. Additional research in this area is crucial for improving knowledge regarding appropriate unit of marijuana purchase. Ongoing qualitative research in our laboratory was designed to evaluate optimal unit of marijuana use and purchase and will ultimately inform MPT development. The instructional set also influences substance demand, with small alterations in instructions often eliciting large changes in substance demand (Skidmore and Murphy 2011). Key instructional differences in marijuana quality (e.g., Collins et al. 2016), timeframe of marijuana use, and unit of purchase may have the propensity to alter demand as well. Additional research is needed to improve existing MPT measures. Finally, this study was not designed to specifically examine demand as a function of cannabis dependence diagnosis. It is important for future studies to examine whether the two-factor structure of the MPT revealed within this community sample of marijuana users is invariant across individuals with and without a cannabis use disorder. Consideration of both latent dimensions of marijuana demand may contribute to improved prediction of risk factors for elevated use, marijuana problems, and therapeutic and pharmacological treatment response for cannabis use disorder. For marijuana, Amplitude of demand appears to reflect unrestricted substance access when the commodity is free, wherein the concept of cost is irrelevant. Given cost is used as a proxy for consequences in behavioral economics, it can be inferred that the absence of perceived consequence/barriers is an important driver of volumetric motivation for use. The absence of such perceived consequences may explain the presence of positive expectancies surrounding marijuana use. Conversely, Persistence has been described as how far one is willing to go for a substance despite the cost. Therefore, greater Persistence is likely a reflection of lower likelihood for changing substance use patterns, and may represent a more compulsive feature of substance-seeking behavior (MacKillop et al. 2009), including cognitive processes underlying dependence (e.g., fewer expectancies of negative consequences from use).

In terms of applications, when examining marijuana demand, utilization of latent MPT factor scores may be considered over individual MPT indices to reduce Type I error inflation. Alternatively, it may be useful to treat factor scores as an omnibus test and only examine the elements of Persistence when the factor is significantly implicated. The predictive utility of this two-factor MPT structure could also be meaningfully explored in laboratory studies examining *ad libitum* marijuana consumption, marijuana smoking topography, and prospective studies that seek to predict changes in marijuana use over time.

Acknowledgments

Financial Support: K01DA039311 (Aston), T32HL076134 (Farris), R03DA27484 (Metrik, Knopik), Peter Boris Chair in Addictions Research (MacKillop)

References

Acker J, MacKillop J. Behavioral economic analysis of cue-elicited craving for tobacco: a virtual reality study. Nicotine Tob Res Off J Soc Res Nicotine Tob. 2013; 15:1409–1416.

American Psychiatric Association. Diagnostic and Statistical Manual of Mental Disorders DSM-5 5th Edition. 5. American Psychiatric Publishing; Washington, D.C: 2013.

Amlung MT, Yurasek A, McCarty KN, et al. Area under the curve as a novel metric of behavioral economic demand for alcohol. Exp Clin Psychopharmacol. 2015; 23:168–175. [PubMed: 25895013]

Aston ER, Merrill JE, McCarthy DM, Metrik J. Risk Factors for Driving After and During Marijuana Use. J Stud Alcohol Drugs. 2016a; 77:309–316. [PubMed: 26997189]

Aston ER, Metrik J, Amlung M, et al. Interrelationships between marijuana demand and discounting of delayed rewards: Convergence in behavioral economic methods. Drug Alcohol Depend. 2016b; 169:141–147. [PubMed: 27810657]

Aston ER, Metrik J, MacKillop J. Further validation of a marijuana purchase task. Drug Alcohol Depend. 2015; 152:32–38. [PubMed: 26002377]

Banks ML, Roma PG, Folk JE, et al. Effects of the delta-opioid agonist SNC80 on the abuse liability of methadone in rhesus monkeys: a behavioral economic analysis. Psychopharmacology (Berl). 2011; 216:431–439. [PubMed: 21369752]

Bickel WK, Jarmolowicz DP, Mueller ET, Gatchalian KM. The Behavioral Economics and Neuroeconomics of Reinforcer Pathologies: Implications for Etiology and Treatment of Addiction. Curr Psychiatry Rep. 2011; 13:406–415. [PubMed: 21732213]

Bickel WK, Marsch LA, Carroll ME. Deconstructing relative reinforcing efficacy and situating the measures of pharmacological reinforcement with behavioral economics: a theoretical proposal. Psychopharmacology (Berl). 2000; 153:44–56. [PubMed: 11255928]

Bidwell LC, MacKillop J, Murphy JG, et al. Latent factor structure of a behavioral economic cigarette demand curve in adolescent smokers. Addict Behav. 2012; 37:1257–1263. [PubMed: 22727784]

Budney AJ, Moore BA, Vandrey RG, Hughes JR. The time course and significance of cannabis withdrawal. J Abnorm Psychol. 2003; 112:393–402. [PubMed: 12943018]

Collins, RL., Vincent, PC., Earleywine, M., et al. The effects of perceived quality on demand for marijuana: Policy implications of a web-based behavioral economic experiment with young-adult marijuana users. NIH Campus; Bethesda, MD: 2016.

Collins RL, Vincent PC, Yu J, et al. A Behavioral Economic Approach to Assessing Demand for Marijuana. Exp Clin Psychopharmacol. 2014

Dennis ML, Funk R, Godley SH, et al. Cross-validation of the alcohol and cannabis use measures in the Global Appraisal of Individual Needs (GAIN) and Timeline Follow back (TLFB; Form 90) among adolescents in substance abuse treatment. Addict Abingdon Engl. 2004; 99(Suppl 2):120–128.

First, M., Spitzer, R., Gibbon, M., Williams, J. Structured Clinical Interview for DSM-IV-TR Axis I Disorders, Research Version, Non-Patient Edition. (SCID-I/NP). Biometrics Research; New York: 2002.

Goldberg, LR., Velicer, WF. Principles of exploratory factor analysis. In: Strack, S., editor. Differentiating normal and abnormal personality. Second. Springer; New York, NY: 2006. p. 209-237.

Horn JL. A rationale and test for the number of factors in factor analysis. Psychometrika. 1965; 30:179–185. [PubMed: 14306381]

Hursh SR. Behavioral economics. J Exp Anal Behav. 1984; 42:435–452. [PubMed: 16812401]

Hursh SR, Galuska CM, Winger G, Woods JH. The economics of drug abuse: a quantitative assessment of drug demand. Mol Interv. 2005; 5:20–28. [PubMed: 15731502]

Hursh, SR., Raslear, T., Bauman, R., Black, H. The Quantitative Analysis of Economic Behavior With Laboratory Animals. In: Grunert, KG., Olander, F., editors. Understanding Economic Behavior. Kluwer Academic; Dordrecht, Netherlands: 1989. p. 393-407.

Hursh SR, Roma PG. Behavioral economics and empirical public policy. J Exp Anal Behav. 2013; 99:98–124. [PubMed: 23344991]

Hursh SR, Silberberg A. Economic demand and essential value. Psychol Rev. 2008; 115:186–198. [PubMed: 18211190]

Hursh SR, Winger G. Normalized demand for drugs and other reinforcers. J Exp Anal Behav. 1995; 64:373–384. [PubMed: 8551194]

Jacobs EA, Bickel WK. Modeling drug consumption in the clinic using simulation procedures: demand for heroin and cigarettes in opioid-dependent outpatients. Exp Clin Psychopharmacol. 1999; 7:412–426. [PubMed: 10609976]

Johnson MW, Bickel WK. Replacing Relative Reinforcing Efficacy with Behavioral Economic Demand Curves. J Exp Anal Behav. 2006; 85:73–93. [PubMed: 16602377]

MacKillop J, Miranda R Jr, Monti PM, et al. Alcohol demand, delayed reward discounting, and craving in relation to drinking and alcohol use disorders. J Abnorm Psychol. 2010a; 119:106–114. [PubMed: 20141247]

MacKillop J, Murphy CM, Martin RA, et al. Predictive Validity of a Cigarette Purchase Task in a Randomized Controlled Trial of Contingent Vouchers for Smoking in Individuals With Substance Use Disorders. Nicotine Tob Res. 2016; 18:531–537. [PubMed: 26498173]

MacKillop J, Murphy JG. A behavioral economic measure of demand for alcohol predicts brief intervention outcomes. Drug Alcohol Depend. 2007; 89:227–233. [PubMed: 17289297]

MacKillop J, Murphy JG, Ray LA, et al. Further validation of a cigarette purchase task for assessing the relative reinforcing efficacy of nicotine in college smokers. Exp Clin Psychopharmacol. 2008; 16:57–65. [PubMed: 18266552]

MacKillop J, Murphy JG, Tidey JW, et al. Latent structure of facets of alcohol reinforcement from a behavioral economic demand curve. Psychopharmacology (Berl). 2009; 203:33–40. [PubMed: 18925387]

MacKillop J, O'Hagen S, Lisman SA, et al. Behavioral economic analysis of cue-elicited craving for alcohol. Addict Abingdon Engl. 2010b; 105:1599–1607.

Metrik J, Aston ER, Kahler CW, et al. Cue-elicited increases in incentive salience for marijuana: Craving, demand, and attentional bias. Drug Alcohol Depend. 2016

Metrik J, Aston ER, Kahler CW, et al. Marijuana's acute effects on cognitive bias for affective and marijuana cues. Exp Clin Psychopharmacol. 2015; 23:339–350. [PubMed: 26167716]

Metrik J, Rohsenow DJ, Monti PM, et al. Effectiveness of a marijuana expectancy manipulation: Piloting the balanced-placebo design for marijuana. Exp Clin Psychopharmacol. 2009; 17:217–225. [PubMed: 19653787]

Murphy JG, Dennhardt AA, Yurasek AM, et al. Behavioral economic predictors of brief alcohol intervention outcomes. J Consult Clin Psychol. 2015; 83:1033–1043. [PubMed: 26167945]

Murphy JG, MacKillop J. Relative reinforcing efficacy of alcohol among college student drinkers. Exp Clin Psychopharmacol. 2006; 14:219–227. [PubMed: 16756426]

Murphy JG, MacKillop J, Tidey JW, et al. Validity of a demand curve measure of nicotine reinforcement with adolescent smokers. Drug Alcohol Depend. 2011; 113:207–214. [PubMed: 20832200]

Murphy JG, Yurasek AM, Dennhardt AA, et al. Symptoms of depression and PTSD are associated with elevated alcohol demand. Drug Alcohol Depend. 2013; 127:129–136. [PubMed: 22809894]

O'Connor BP. SPSS and SAS programs for determining the number of components using parallel analysis and velicer's MAP test. Behav Res Methods Instrum Comput J Psychon Soc Inc. 2000; 32:396–402.

O'Connor RJ, Heckman BW, Adkison SE, et al. Persistence and amplitude of cigarette demand in relation to quit intentions and attempts. Psychopharmacology (Berl). 2016; 233:2365–2371. [PubMed: 27048156]

Schafer J, Brown SA. Marijuana and cocaine effect expectancies and drug use patternsa. J Consult Clin Psychol. 1991; 59:558–565. [PubMed: 1918560]

Skidmore JR, Murphy JG. The effect of drink price and next-day responsibilities on college student drinking: a behavioral economic analysis. Psychol Addict Behav J Soc Psychol Addict Behav. 2011; 25:57–68.

Skidmore JR, Murphy JG, Martens MP. Behavioral economic measures of alcohol reward value as problem severity indicators in college students. Exp Clin Psychopharmacol. 2014; 22:198–210. [PubMed: 24749779]

Stevens, JP. Applied Multivariate Statistics for the Social Sciences, Fourth Edition. 4. Psychology Press; Mahwah, NJ: 2001.

Tabachnick, BG., Fidell, LS. Using Multivariate Statistics. 4. Allyn & Bacon; Boston, MA: 2000.

Tiffany ST, Drobes DJ. The development and initial validation of a questionnaire on smoking urges. Br J Addict. 1991; 86:1467–1476. [PubMed: 1777741]

Velicer WF. Determining the number of components from the matrix of partial correlations. Psychometrika. 1976; 41:321–327.

Volkow ND, Baler RD, Compton WM, Weiss SRB. Adverse health effects of marijuana use. N Engl J Med. 2014; 370:2219–2227. [PubMed: 24897085]

Zwick WR, Velicer WF. Comparison of five rules for determining the number of components to retain. Psychol Bull. 1986; 99:432–442.

Table 1

Demographics and descriptive variables

	***n* (%)**
Employment	
Full-time	15 (15.2)
Part-time	53(53.5)
Unemployed in school	25 (25.3)
Homemaker	6 (6.1)
College Student Status	68 (68.7)
Past year DSM-IV cannabis dependence	15 (15.2)
	Mean (*SD*)
Age	21.4 (4.4)
Percent marijuana use days past 60 days	71.5 (21.7)
Times used marijuana on average day	2.0 (1.2)
Money spent on marijuana (past 30 days)	85.3 (71.7)

Note. Mean percent marijuana use days corresponds to approximately 5 days per week

Table 2

Factor loadings

Indices	Factor 1 *Persistence*	Factor 2 *Amplitude*
Intensity	.041	**.948**
O_{max}	**.778**	.356
P_{max}	**.928**	−.373
Breakpoint	**.964**	−.026
Elasticity (1/α)	**.835**	.310
Eigenvalue	3.29	1.14
% Variance	65.82%	22.72%

Note: Loadings of .400 and greater are printed in bold face.

Table 3

Correlations between MPT latent factors and marijuana variables

Marijuana Variables	**Persistence (Factor 1)**	**Amplitude (Factor 2)**
Marijuana Use		
Percent marijuana use days past 60 days	.129	.316 **
Marijuana craving severity	.184	.489 **
Number of cannabis dependence symptoms	.096	.241 *
Marijuana Cessation History		
Lifetime quit/reduction attempts	−.194 †	−.116
Marijuana Use Expectances		
Negative Expectancies	−.313 **	.001
Cognitive-Behavioral Impairment	−.347 **	−.098
Negative Effects	−.157	−.087
Craving/Physical Effects	−.152	.196 †
Positive Expectancies	−.035	.186
Social/Sexual Facilitation	−.032	.209 *
Relaxation/Tension Reduction	.101	.212 *
Perceptual/Cognitive Enhancement	−.155	.034

† $p < .054$;

* $p < .05$;

** $p < .01$