Psychopharmacology (2009) 203:33–40
DOI 10.1007/s00213-008-1367-5

ORIGINAL INVESTIGATION

Latent structure of facets of alcohol reinforcement from a behavioral economic demand curve

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Received: 20 May 2008 / Accepted: 5 October 2008 / Published online: 17 October 2008
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Abstract

Rationale Behavioral economic demand curves are quantitative representations of the relationship between consumption of a drug and its cost. Demand curves provide a multidimensional assessment of reinforcement, but the relationships among the various indices of reinforcement have been largely unstudied.

Objectives The objective of the study is to use exploratory factor analysis to examine the underlying factor structure of the facets of alcohol reinforcement generated from an alcohol demand curve.

Materials and methods Participants were 267 weekly drinkers [76% female; age M=20.11 (SD=.1.51); drinks/week M=14.33 (SD=11.82)] who underwent a single group assessment session. Alcohol demand curves were generated via an alcohol purchase task, which assessed consumption at 14 levels of prices from \$0 to \$9. Five facets of demand were generated from the measure [intensity, elasticity, $P_{\max}$ (maximum inelastic price), $O_{\max}$ (maximum alcohol expenditure), and breakpoint], using both observed and derived calculations. Principal components analysis was used to examine the latent structure among the variables.

Results The results revealed a clear two-factor solution, which were interpreted as "Persistence," reflecting sensitivity to escalating price, and "Amplitude," reflecting the amount consumed and spent. The two factors were generally quantitatively distinct, although $O_{\max}$ loaded on both.

Conclusions These findings suggest that alcohol reinforcement as measured via a demand curve is binary in nature, with separate dimensions of price-sensitivity and volumetric consumption. If supported, these findings may contribute theoretically and experimentally to a reinforcement-based approach to alcohol use and misuse.

Keywords Alcohol · Demand curve · Reinforcement · Exploratory factor analysis

Introduction

Behavioral economic demand curves are quantitative representations of the relationship between consumption of a commodity and its price, and have been used in the field of psychopharmacology to study drug demand (for a review, see Hursh et al. 2005). Demand curves have most commonly been used to assess the relative reinforcing efficacy of an array of compounds (e.g., Ko et al. 2002; Mattox and Carroll 1996; Winger et al. 2006), but can also be used to examine interactions among multiple drugs (Spiga et al. 2005; Winger et al. 2006, 2007), influences of drug supply (Greenwald and Hursh 2006), and drug/money preferences under concurrent reinforcement schedules (Johnson and Bickel 2006; Madden

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and Bickel 1999). In the same way that a demand curve can be used to quantify a drug's relative reinforcing efficacy, the approach can also be used to characterize individual differences in the reinforcing efficacy of a drug (Greenwald and Hursh 2006; MacKillop et al. 2008; MacKillop and Murphy 2007; Murphy and MacKillop 2006). For example, Greenwald and Hursh (2006) recently found that opiate-dependent individuals with a history of cocaine use exhibited greater demand for hydromorphone than those who did not. Similarly, in a clinical application, MacKillop and Murphy (2007) found that variation in alcohol demand significantly predicted treatment outcome in alcohol abusers following a brief intervention.

Consistent with the law of demand (i.e., an inverse relationship between consumption of any commodity and its price), demand curves prototypically reveal decelerating consumption as a function of escalating price. In addition, demand curves are accompanied by associated expenditure curves that prototypically conform to an inverted U-shaped curve. A significant strength of a demand curve approach is that it provides a multidimensional quantitative assessment of reinforcing efficacy and motivation (Hursh et al. 2005). Across the demand and expenditure curves, five different facets of demand can be quantified: elasticity of demand (i.e., slope of the demand curve), $P_{\max}$, (i.e., maximum inelastic price), $O_{\max}$ (i.e., maximum output, or expenditure, across intervals of price), intensity of demand (i.e., consumption at minimal cost), and breakpoint (i.e., price at which consumption is reduced to zero). These facets are thought to reflect distinct aspects of demand (Bickel et al. 2000) and are depicted in Fig. 1 in prototypical demand and expenditure curves. Moreover, it has been argued that a behavioral economic demand curve approach may serve as an organizing framework for understanding drug reinforcement and reconciling inconsistent findings across studies using putatively equivalent measures of reinforcement (Bickel et al. 2000).

One area that has not been extensively studied is the relationship among the various dimensions of demand. The different facets are thought to be functionally related, but nonetheless distinct because they reflect different topographical features of the demand and expenditure curves (Bickel et al. 2000). This has been supported by recent studies that have found prototypical demand curves but highly variable correlations among the facets of demand (Jacobs and Bickel 1999; Murphy and MacKillop 2006; MacKillop et al. 2008), ranging from negligible associations to statistically significant, high-magnitude associations. However, studies have not determined whether the five facets of a demand curve represent a smaller number of latent dimensions, or factors, a possibility that is also implied given the high correlations between some of the variables (e.g., Jacobs and Bickel 1999; Johnson and Bickel 2006). Identifying latent factors that underlie the facets of a demand curve may help to characterize both the commonality and uniqueness of these different dimensions, and may also provide insight into the nature of drug-related reinforcement and motivation assessed by a demand curve. Such latent factors could also potentially serve as novel-dependent variables and reduce the probability of multicollinearity among the different facets of a demand curve in experimental research.

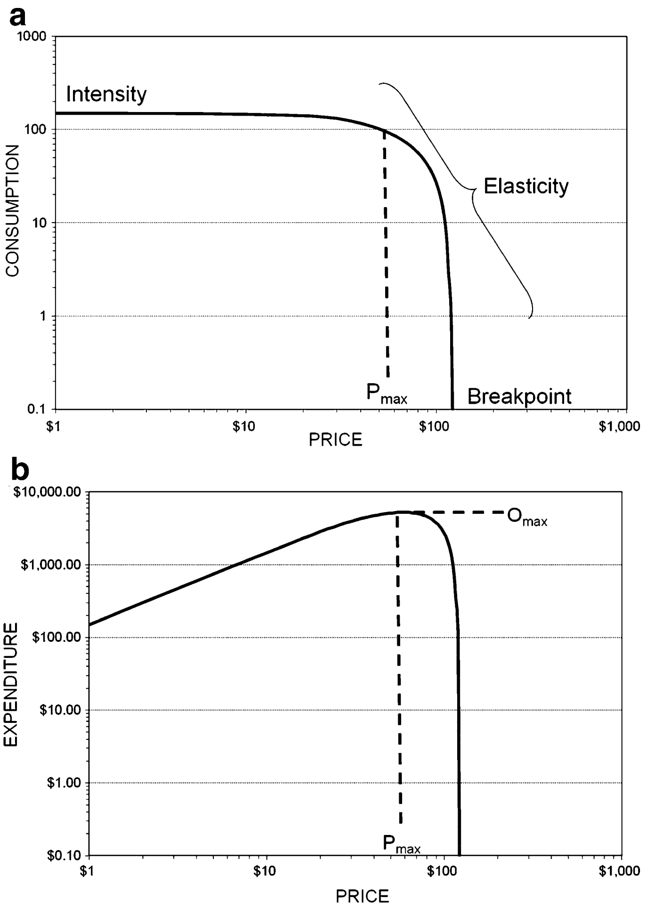

Fig. 1 Prototypical behavioral economic demand and expenditure curves. **a** provides the demand curve and the following associated facets of demand: intensity (i.e., consumption at minimal price), elasticity (i.e., slope of the demand curve), $P_{\max}$ (i.e., maximum inelastic price), Breakpoint (i.e., price at which consumption is reduced to zero). **b** The associated expenditure curve and $O_{\max}$ (i.e., maximum expenditure), with the accompanying $P_{\max}$, which is also the price at which $O_{\max}$ takes place. Note logarithmic units for proportionality and to accommodate large intervals; zero values are replaced with trivial nonzero values (0.1)

A number of statistical tools can be used for examining the latent structure of interrelationships among variables, including both exploratory and confirmatory factor analysis. One reason why these approaches have not been applied previously in this area is because they both require samples of moderate to large size (Tabachnick and Fidell 2001). Studies using demand curve analysis have historically used small samples because the most common method for generating demand curves is the use of a progressive-ratio operant self-administration schedule in the laboratory. This poses a number of challenges for large-scale data collection because subjects need to be exposed to a range of drug self-administration conditions over multiple sessions of relatively long duration (Jacobs and Bickel 1999). As a result, most studies using this approach in humans rely on small numbers of subjects (e.g., Johnson and Bickel 2006; Madden and Bickel 1999; Spiga et al. 2005). However, an alternative approach that has been recently investigated is the use of purchase tasks (e.g., Jacobs and Bickel 1999) or self-report analogues of progressive-ratio schedules. Purchase tasks assess estimated consumption of a drug across a range of prices and can be used to generate demand curves in relatively large samples because of the low burden of administration. Although purchase tasks assess hypothetical consumption, the indices of demand have been shown to closely correspond to actual substance use behavior, suggesting they validly reflect motivation for the substance (MacKillop et al. 2008; MacKillop and Murphy 2007; Murphy and MacKillop 2006). This is further supported by evidence that actual and hypothetical versions of other behavioral economic measures generate equivalent data (Kirby 1997; Kirby and Maracovic 1995; Johnson and Bickel 2002), presumably because these measures assess preferences for objectively defined, familiar commodities of relatively unambiguous levels of value to the individual.

The goal of the current study was to use exploratory factor analysis to examine the latent factor structure among facets of alcohol reinforcement from an alcohol demand curve. Demand data were collected from a relatively large sample of drinkers who completed an alcohol purchase task and a number of additional individual differences measures in an initial validation study of an alcohol purchase task (Murphy and MacKillop 2006). Given the absence of previous research in this area, we elected to use exploratory factor analysis to examine the latent interrelationships among the different facets. Because the different indices putatively reflect distinct topographical features of the demand curve (Bickel et al. 2000), we predicted that the factor structure would be multidimensional, but did not specifically predict the number of factors that would emerge. Finally, to further characterize the latent factors identified, we examined them in relation to self-reported alcohol use and alcohol-related problems.

Materials and methods

Subjects

Subjects were 267 Auburn University undergraduates (76% female; age M=20.11 [SD=0.1.51]) who reported drinking on a weekly basis. Mean weekly alcohol consumption was 14.33 (SD=11.82) drinks/week, with a mean of 1.70 (SD=1.44) heavy drinking episodes (4/5+ drinks in an episode for women/men; Wechsler et al. 2000) per week and a mean of 5.19 (SD=4.09) alcohol-related problems in the preceding month as measured by the Rutgers Alcohol Problems Index (RAPI; described below). Participants underwent a single group assessment session in an auditorium and were compensated with research credit in university courses.

Assessment measures

Daily Drinking Questionnaire Drinks per week and heavy drinking episodes were calculated via the Daily Drinking Questionnaire (DDQ; Collins et al. 1985), a seven-item measure of an individual's alcohol consumption during a typical week during the past month. The DDQ is a widely used measure of drinking that has been shown to have good psychometric properties (Kivlahan et al. 1990).

Rutgers Alcohol Problem Inventory Alcohol-related problems were assessed using the Rutgers Alcohol Problem Inventory (RAPI), which has demonstrated good reliability, internal consistency, and validity with young adults (White and Labouvie 1989). This version of the RAPI assessed the occurrence of 23 alcohol-related problems over the past 30 days. The scale range was from 0 to 23.

Alcohol Purchase Task The Alcohol Purchase Task (APT) was based on Jacobs and Bickel's (1999) purchase task approach. The instructional set was: "Imagine that you and your friends are at a bar from 9 P.M. to 2 A.M. to see a band. The following questions ask how many drinks you would purchase at various prices. The available drinks are standard size beer (12 oz), wine (5 oz), shots of hard liquor (1.5 oz), or mixed drinks with one shot of liquor. Assume that you did not drink alcohol before you went to the bar and will not go out after." The prices used were zero (free), \$.25, \$.50, \$1, \$1.50, \$2, \$2.50, \$3, \$4, \$5, \$6, \$7, \$8, and \$9. Five facets of demand were generated from the APT: (1) elasticity of demand (i.e., sensitivity of alcohol consumption to increases in cost); (2) $P_{\max}$ (i.e., maximum inelastic price, where demand transitions from inelastic to elastic demand, and also the price at which response output is maximized); (3) $O_{\max}$ [i.e., maximum output (maximum expenditure)]; (4) intensity of demand (i.e., consumption at the lowest price); and (5) breakpoint, (i.e., the first price at which consumption is zero). For three of these measures—intensity, $P_{\max}$, and $O_{\max}$—an APT can generate both observed and derived values (Murphy and MacKillop 2006). Observed values reflect actual subject performance on the measure and were calculated by directly examining responses on the APT and performing arithmetic calculations of expenditure to determine $O_{\max}$. Derived values reflect estimates of the values based on quantitative modeling of the demand curve. Specifically, derived values were calculated using Hursh et al.'s (1988) demand curve equation: $\ln C = \ln L + b\ (\ln P) - aP$, where C=Consumption, L=Y-axis intercept, P Price, b=slope, and a=acceleration, with slope and acceleration being free parameters. This equation also generated an R^2 value, reflecting the percentage of variance the equation accounted for and the adequacy of the fit of the equation to the data. Derived intensity was defined as the consumption intercept (L); derived $P_{\max}$ was calculated using the equation: $P_{\max} = (1+b)/a$; and derived $O_{\max}$ was generated by calculating output at $P_{\max}$ using the demand curve equation. The a and b parameters from the demand curve equation were used to determine the elasticity of demand at each price as $e = b - aP$. Overall elasticity of demand for all prices was calculated by calculating the mean of the individual price elasticities (Jacobs and Bickel 1999). Further information on the calculation of the variables, correlations among the facets of demand, and descriptive statistics are provided in Murphy and MacKillop (2006).

Data analysis

To ensure normality, the data were initially examined for outliers. Univariate outliers were examined using standard scores (criterion Z=3.29), and multivariate outliers were examined by regressing all items onto a dummy variable and generating the Mahalanobis distance (critical χ^2 (df>100)= 149.45; $p<0.001$; Tabachnick and Fidell 2001), which reflects each subject's multivariate distance from the data centroid. 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. Although both PCA and principal axis (common) factor analysis examine the latent interrelationships among variables, PCA does so for the total variance, and principal axis does so within shared variance. We elected to use PCA based on the presumption that the facets of demand are distinct and that all variance among the items was of theoretical interest. In addition, characterizing the total variance among the indices, not only the shared variance, was preferable based on evidence of highly variable levels of association among the facets of demand (e.g., MacKillop et al. 2008). Factor structure was determined by examination of the scree plot for clear discontinuities between succeeding factors in the scree plot of Eigenvalues and an Eigenvalue of >1 (Goldberg and Velicer 2006). A factor loading of.30 on the pattern matrix was used as the criterion for determining if an item significantly loaded on a given factor (Tabachnick and Fidell 2001). Because the objective of the study was exploration of the latent structure of the variables, not identifying mutually exclusive factors (e.g., scale construction), facets of demand were permitted to load on multiple factors.

With regard to the observed and derived calculations of intensity, $O_{\max}$, and $P_{\max}$, each approach has advantages and disadvantages, and very high correlations between the values generated are evident [MacKillop et al. (2008), rs= 0.70–0.95; Murphy and MacKillop (2006): rs=0.54–0.93]. Therefore, to avoid identifying spurious latent variables because of these high correlations, two separate PCAs were conducted, one using observed values and one using derived values. No differences between the factor structures were predicted, but the relative convergence between the two solutions was considered of interest as an indicator of the robustness of the latent structure observed.

Finally, Pearson product-moment correlations (r) were used to examine the relations among the factors generated and three indices of alcohol-related behavior: drinks per week, weekly episodes of heavy drinking (5+/4+ for males and females, respectively; Wechsler et al. 2000), and negative consequences from alcohol in the last month.

Results

No univariate outliers were evident for breakpoint, elasticity, or intensity, although two outliers were evident for $O_{\max}$, and one was evident for $P_{\max}$. These outliers were examined and were determined to be legitimate values and of low magnitude discrepancy, and were retained as recommended by Tabachnick and Fidell (2001). No multivariate outliers were present. The data conformed to expectations topographically, with self-reported consumption initially inelastic and subsequently elastic, and associated expenditure exhibiting an inverted U-shaped curve. For descriptive purposes, mean alcohol consumption and expenditure at each price are presented in Fig. 2.

The scree plot from the PCA using observed values of intensity, $O_{\max}$, and $P_{\max}$ revealed variance discontinuities that suggested two latent factors. The first factor accounted for 60.89% of the variance, with an Eigenvalue of 3.04, and was primarily composed of three reinforcement indices: elasticity, $P_{\max}$, and breakpoint. The pattern matrix, providing the factor loading and reflecting the partial correlations between each variable and each rotated factor, is provided in Table 1. The second factor accounted for 23.90% of the variance, with an Eigenvalue of 1.20, and was primarily composed of intensity of demand. For both factors, $O_{\max}$ met the loading criterion, exhibiting a slightly larger loading on the second factor. The two factors were significantly correlated, r=0.25, $p<0.01$. Subsequent factors accounted for small proportions of variance with trivial Eigenvalues (all <0.5).

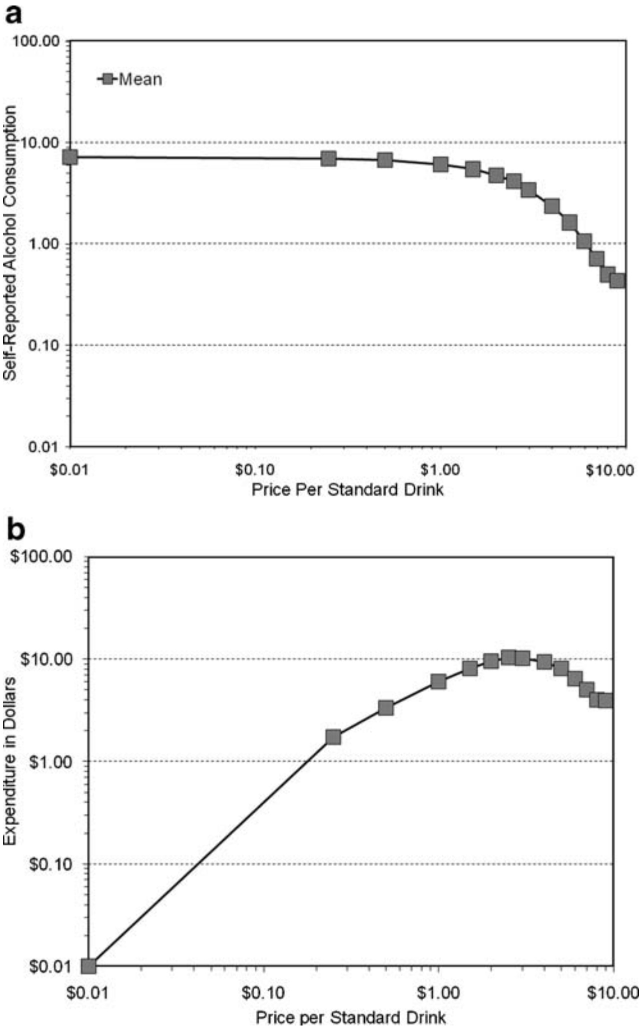

Fig. 2 Study sample mean alcohol demand and expenditure curves. **a** provides alcohol demand and **b** provides associated expenditure. Data are provided in conventional log–log units for proportionality. Zero price and consumption are replaced by 0.01 to permit logarithmic units

The scree plot of the total variance from the PCA using derived values of intensity, $O_{\max}$, and $P_{\max}$ also suggested a two-factor solution, which was further supported by the Eigenvalue magnitudes. Values and factor configurations were very similar to the analysis using observed values. The first factor accounted for 64.82% of the variance, with an Eigenvalue of 3.24, and was primarily composed of elasticity, $P_{\max}$, and breakpoint (Table 1). The second factor accounted for 24.98% of the variance, with an Eigenvalue of 1.25, and was primarily composed of intensity of demand (Table 1). Again, $O_{\max}$ met the loading criterion for both factors and was incorporated into both. In this case, however, $O_{\max}$ exhibited a larger loading on the first factor (Table 1). Like the PCA of observed values, the two factors were significantly moderately correlated, $r=0.20$, $p<0.01$. Subsequent factors accounted for small proportions of variance with trivial Eigenvalues. The observed and derived versions of each factor were significantly correlated with each other at high levels of association: Factor 1, $r=0.95$; Factor 2, $r=0.61$ ($ps<0.001$).

Both factors for both PCAs typically exhibited significant or trend-level correlations with all four facets of reported alcohol use, but at varying magnitudes, as presented in Table 2. Factor 1 generally exhibited modest correlations with alcohol-related variables. Where significant associations were evident, they were typically of small-to-medium magnitude. Factor 2 generally exhibited significant moderate-to-high associations with the measures of alcohol use and problems. Correlations between alcohol-related variables and Factor 1 for derived values were consistently larger than for Factor 1 for observed variables. In contrast, correlations between alcohol-related variables and Factor 2 for observed values were consistently larger than for Factor 2 for derived variables. The difference in correlation magnitudes was directly tested using Hotelling–Williams *t* tests for each index of drinking in reference to each factor. In each case, the correlation between the measure of drinking and Factor 2 was significantly greater than the correlation between drinking and Factor 1($ps<0.05$–0.01). An exception to this was for problems resulting from drinking and the two derived factors, where the correlations were not significantly different from each other ($t\ [263]=-1.87$, $p>.05$).

Discussion

The goal of the current study was to examine the latent structure among facets of alcohol reinforcement from a behavioral economic demand curve. Exploratory factor analyses for observed and derived values both provided support for a two-factor solution, accounting for approximately 85% of the total observed variance and suggesting that there is substantial overlap among the five facets of the

Table 1 Pattern matrices for the principal components analyses of the indices of reinforcement generated from an alcohol purchase task

Index	Observed values		Derived values	
	Component		Component	
	Factor 1	Factor 2	Factor 1	Factor 2
Elasticity	0.95	−0.09	0.94	−0.24
Breakpoint	0.88	0.12	0.88	0.18
$P_{\max}$	0.90	−0.07	0.93	−0.24
$O_{\max}$	0.48	0.65	0.85	0.34
Intensity	−0.14	0.99	−0.02	0.99

Analyses were conducted separately for observed and derived values for $P_{\max}$, $O_{\max}$, and intensity of demand. A criterion of 0.30 was used to determine whether an index significantly loaded on a factor

Table 2 Correlations between the factors generated and alcohol use variables

Factor	Alcohol use variables			
	Drinks/week	Drinks per drinking day	Episodes of heavy drinking	Alcohol-related problems
Factor 1 (observed)	0.12****	0.11****	0.15*	0.06
Factor 1 (derived)	0.23***	0.16**	0.23***	0.14*
Factor 2 (observed)	0.69***	0.69***	0.61***	0.45***
Factor 2 (derived)	0.43***	43***	0.41***	0.28***

*$p<0.05$
** $p<0.01$
***$p<0.001$
****$p<0.0001$
Factors from both principal components analyses using observed and derived variables are provided. Correlation magnitude conventions are as follow: small $r=0.10$; medium $r=0.30$; large $r=0.50$ (Cohen 1988).

demand curve and that data reduction using factor scores or composite scores may be valuable. In both cases, the first factor was primarily composed of elasticity of demand, $P_{\max}$, breakpoint, and, to a lesser extent, $O_{\max}$. Similarly, in both PCAs, the second factor was primarily composed of intensity of demand and, to a lesser extent, $O_{\max}$. Correlations between the two factors were generally modest. Both factors were significantly correlated with weekly alcohol use and negative consequences from drinking, with higher magnitude correlations for the second factor.

The results suggest an unambiguous and robust latent structure for these data that is captured by a two-factor solution. In terms of the content of the factors, Factor 1 appears to primarily represent three dimensions of the demand curve over the course of escalating price, with elasticity being the overall slope of the demand curve, $P_{\max}$ being the point of transition from inelastic to elastic demand, and breakpoint being the terminus of demand, where consumption is suppressed to zero. Albeit with a lower magnitude loading, $O_{\max}$ (maximum expenditure) also loaded on Factor 1. Taken together, these dimensions can be thought of as interrelated measures of sensitivity to escalating price on the X-axis. As such, we interpreted Factor 1 as "Persistence." In contrast, Factor 2 primarily reflected intensity of demand, or alcohol consumption under conditions of minimal cost, but also included $O_{\max}$. Together, both measures reflect volumetric aspects of motivation (i.e., changes on the Y-axes of drinks consumed and dollars spent). As such, we interpreted Factor 2 as "Amplitude." Simply put, when considered together, these two latent factors reflect how *far* the individual would go for alcohol in terms of cost (Factor 1: Persistence) and how *much* alcohol the individual would consume or spend (Factor 2: Amplitude).

It is interesting that most variables clearly loaded on one of the two factors, but $O_{\max}$ significantly loaded on both factors and did so to a lesser extent than the other variables. As an index of the maximum amount an individual will expend for a drug, $O_{\max}$ incorporates both a volumetric dimension (via number of drinks) and a price-sensitivity dimension (via price). Thus, $O_{\max}$ is at the intersection of price and consumption and, as such, uniquely captures elements of both dimensions. Previous studies have shown that $O_{\max}$ is among the most sensitive indices of demand in relation to alcohol and tobacco consumption (MacKillop et al. 2008; Murphy and MacKillop 2006). As such, instead of simply being a by-product of the other indices, $O_{\max}$ appears to be a particularly informative dimension of demand that captures both elements of volume and price sensitivity.

A second interesting aspect of the results was that Factor 2 (Amplitude) exhibited higher correlations with weekly alcohol use, heavy alcohol use, and problems with alcohol than Factor 1 (Persistence). This suggests that individual differences in alcohol use are more closely related to volumetric differences in demand than differences in price sensitivity. However, it is also possible that variation in Persistence and its underlying elements are related to other aspects of alcohol use that were not assessed in this study. For example, in using alcohol demand curves to predict drinks per week following treatment, MacKillop and Murphy (2007) found that intensity of demand provided the highest magnitude predictions of posttreatment drinks/week when considered alone, but after accounting for pretreatment drinking, it no longer did so. In contrast, the variables associated with Persistence showed unique relations with outcome that were independent of pretreatment drinking level. This suggests that although Persistence may not be as closely related to current alcohol use as measures of Amplitude, it may predict likelihood of changing an alcohol use pattern or other related variables, perhaps reflecting a more compulsive dimension of alcohol-seeking behavior. Likewise, the dimension of persistence may be more relevant among alcohol-dependent drinkers, whereas amplitude may be most salient among heavy drinkers.

Further comparison of these dimensions across levels of alcohol use and dependence status seems warranted.

Although previous studies have examined correlations among the various facets of demand curves, this is the first (to our knowledge) to directly examine the underlying factor structure among these facets. As such, these findings should be considered preliminary. In addition, there are a number of limitations to the current study that warrant discussion. Exploratory factor analysis is, by definition, an exploratory tool and cannot be used for definitive hypothesis testing. Further, although the findings in this study are relatively unambiguous, they speak only to the current dataset. As such, they cannot address whether demand for drugs other than alcohol would exhibit a similar factor structure or whether the factor structure would emerge in a clinical sample of individuals with alcohol dependence.

Another important consideration is that the data in this study were generated using a purchase task approach, not observable behavior on an operant task. Although several studies have supported the validity of purchase tasks (Jacobs and Bickel 1999; MacKillop and Murphy 2007; MacKillop et al. 2008; Murphy and MacKillop 2006), and there is evidence for near equivalence between real and estimated performance on other behavioral economic measures (Kirby 1997; Kirby and Maracovic 1995; Johnson and Bickel 2002), the correspondence between purchase task performance and operant task performance has not been examined. As such, it is not clear that the observed factor structure in this study would be evident in data from progressive-ratio operant schedules. In addition, the data generated from a purchase task are partially a function of the measure's instructional set, which did not prescribe a specific budget for alcohol and may have been variably applicable across subjects. It is also worth noting that income was not collected in this sample and could not be considered in the context of the observed findings. Recent studies have reported that indices of substance demand and income are uncorrelated (MacKillop et al. 2008), but relatively little research has been conducted in this area, and the relationship between income and alcohol demand could not be addressed in this study. These issues will need to be addressed in future research.

However, if the current results are affirmed, there are a number of potentially important implications, both theoretical and practical. From a theoretical standpoint, these findings suggest that drug reinforcement, as measured by a demand curve, fundamentally has two dimensions that largely reflect movement on the *X*- and *Y*-axes of the demand and expenditure curves, with Persistence pertaining to the *X*-axis and Amplitude pertaining to the two *Y*-axes. This is important because the assumption that relative reinforcing efficacy is homogenous, first articulated by Griffiths et al. (1979), has been contradicted by a number of studies revealing inconsistent findings on putatively equivalent measures of reinforcement (e.g., Arnold and Roberts 1997; Madden and Bickel 1999; Griffiths et al. 1975; Johnson and Bickel 2006; Johanson and Schuster 1975; Richardson and Roberts 1996). Thus, the current findings converge with the proposal by Bickel et al. (2000) that reinforcement may be better thought of as fundamentally heterogeneous in nature, composed of functionally related but separate dimensions.

These findings are also interesting theoretically because they converge with the theorized structure of operant behavior according to behavioral momentum theory (for a review, see Nevin and Grace 2000). According to this approach, operant behavior can be dissociated into two independent aspects, steady-state response rate and resistance to change. These two components are metaphorically equivalent to the velocity and mass of the object's momentum in Newtonian classical mechanics, hence the name of the theory. The approach emerged as a way to understand the lack of concordance between measures of response rate and measures of extinction. For example, in the context of alcohol consumption, the addition of an alternative non-drug reinforcer has been demonstrated to decrease the response rate of alcohol self-administration in rodents but to increase resistance to extinction (Shahan and Burke 2004), a finding which is consistent with studies using non-drug reinforcers (Nevin et al. 1990; Grimes and Shull 2001). This distinction is theorized to reflect response rate being a function of the response-reinforcer contingency and resistance to change being a function of the total rate of reinforcement available, contingent or noncontingent (Nevin and Grace 2000). In the context of the current findings, the factor structure observed strikingly converges with behavioral momentum's binary approach, with Factor 1 (Persistence) reflecting resistance to change and Factor 2 (Amplitude) reflecting response rate. Previously, important parallels and distinctions have been made between behavioral economics and behavioral momentum (Nevin 1995), and the current findings provide further evidence of the complementary nature of these two approaches.

From a practical standpoint, the current study provides initial findings with regard to the latent structure of the various facets of demand and provides an empirical basis for future tests of the interrelationships among facets of a demand curve using confirmatory factor analysis. Moreover, if this binary approach to reinforcement is affirmed, it would suggest that factor scores reflecting the amalgam of multiple facets may potentially serve as better dependent variables than individual facets of demand. In particular, consideration of both dimensions of demand may contribute to improved prediction of preferences for substances versus alternative rewards in the laboratory, where both the amount of substance available and its cost would presumably jointly affect decision making. Finally, from a clinical standpoint, Hursh et al. (2005) have argued that demand curve analysis may be useful for evaluating pharmacotherapies for treating substance dependence, and these findings suggest that clarifying which dimensions of reinforcement are affected by such therapies would be a useful contribution to understanding medication mechanisms. Likewise, these refined dimensions of motivation to use substances may be targeted in behavioral interventions. Even though generating factor scores may be a challenge to implement in studies using small sample sizes, these findings suggest that a binary approach at least be considered and evaluated to the extent possible. These implications, theoretical and practical, are all potentially significant, but will depend on a convergence of findings from future studies to affirm the current results.

Acknowledgements This research was partially supported by grants from the Alcohol Beverage Medical Research Foundation (ABMRF), the U.S. Department of Education, the National Institute on Alcohol Abuse and Alcoholism (AA 07850, AA 07459), and the National Institute on Drug Abuse (DA 022386). The authors gratefully acknowledge the editorial feedback of Lauren Wier, BA, on an earlier draft of this manuscript.

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