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Further Validation of a Cigarette Purchase Task for Assessing the Relative Reinforcing Efficacy of Nicotine in College Smokers

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The authors sought to further validate a cigarette purchase task (CPT), a self-report analogue of a progressive-ratio operant schedule, for the assessment of the relative reinforcing efficacy (RRE) of nicotine in smokers. The measure was assessed in terms of its correspondence to typically observed operant behavior, convergent validity, and divergent validity. Participants were 33 individuals (58% male, age $M = 19.30$ years) who smoked at least weekly ($M = 5.31$ cigarettes/day) and underwent a single assessment session. Data from the CPT exhibited the predicted inverse relationship between consumption and price, the predicted relationship between consumption and expenditure, and a heterogeneous pattern of interrelationships among the indices of reinforcement. In addition, 2 indices from the measure, intensity of demand and maximum expenditure for cigarettes, exhibited robust convergent and divergent validity. Although this is an incipient research area and the current study used a relatively small sample, these findings support the validity of a CPT as a time- and cost-efficient method for assessing nicotine reinforcement. Theoretical implications of the findings, limitations, and future directions are also discussed.

Keywords: behavioral economics, nicotine dependence, relative reinforcing efficacy, demand curve

Relative reinforcing efficacy (RRE) is a central concept in psychopharmacological research, referring to the behavior-strengthening or behavior-maintaining properties of a drug or a specific dose of a drug (Griffiths, Brady, & Bradford, 1979). Historically, RRE has been widely used for characterizing the abuse liability of drugs and for comparing drugs and drug doses, and it has been presumed to be a homogeneous construct (Griffiths et al., 1979; Katz, 1990). In recent human research, a drug's RRE has also been emphasized as a meaningful individual difference variable that uniquely predicts changes in substance use over time (MacKillop & Murphy, 2007; Murphy, Correia, Colby, & Vuchinich, 2005; Tucker, Vuchinich, Black, & Rippens, 2006; Tucker, Vuchinich, & Rippins, 2002).

However, challenges to the utility of the concept of RRE have also emerged. For example, the unitary nature of RRE has been contradicted by a number of reports in which putatively equivalent indices have not yielded consistent findings (e.g., Arnold & Roberts, 1997; Bickel & Madden, 1999; Griffiths, Findley, Brady, Dolan-Gutcher, & Robinson, 1975; Jacobs & Bickel, 1999; Johnson & Bickel, 2006; Johanson & Schuster, 1975; Richardson & Roberts, 1996). Similarly, Stafford, LeSage, and Glowa (1998) have reviewed evidence indicating that RRE is not static, but is substantially modified by pharmacological variables (e.g., previous drug exposure), tonic organismic variables (e.g., gender), and phasic contextual variables (e.g., hunger). As a result of these findings, Bickel, Marsch, and Carroll (2000) have persuasively argued that RRE is actually a multidimensional construct, comprising related, but nonetheless distinct, facets of reinforcement that are best understood functionally within the framework of behavioral economic demand curve analysis.

Given the active ongoing discussion about the nature and utility of the concept of RRE, an important collateral con-

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cern is the use of valid methods for assessing RRE. Typically, RRE is assessed using operant self-administration methods, such as fixed-ratio or progressive-ratio schedules, or forced-choice paradigms (Bickel et al., 2000). These methods directly assess observed behavior, but they are limited by the need for subjects to be exposed to a wide range of drug self-administration conditions over multiple sessions and also depend on costly and highly specialized equipment (Jacobs & Bickel, 1999). In addition to requiring multiple sessions, such methods are also relatively time-consuming within a session, potentially limiting their sensitivity to short-term dynamic changes in motivation (e.g., Madden & Zwaan, 2001; Zwaan, Stanfield, & Madden, 2000). Finally, self-administration methods may be ethically problematic if used in treatment-seeking samples (Jacobs & Bickel, 1999). For example, examination of the relationship between the RRE of nicotine and smoking cessation treatment response using traditional behavioral measures would require repeated nicotine self-administration sessions with individuals attempting to quit. For each of these reasons, there has been relatively little translation of basic methods for assessing RRE into clinical or applied research (MacKillop & Murphy, 2007).

For these reasons, the development of time- and cost-efficient measures of RRE would be of substantial utility. One promising approach is the use of purchase tasks, or self- report measures of estimated substance consumption at a range of prices that are analogues of a behavioral progressive-ratio operant schedule (Hodos, 1961). In a preliminary study, Jacobs and Bickel (1999) examined cigarette and heroin purchase tasks in 17 nicotine- and heroin-dependent individuals to validate these measures in terms of whether the data were consistent with previous findings in studies examining observable behavior. Confirming the authors' predictions, self-reported consumption of both drugs decreased as a function of price, and the associated expenditure conformed to an inverted U-shaped curve (i.e., participants' implicit expenditure initially increased as price increased, but then reached a peak following which it decreased to zero). In addition, the data conformed to a quantitative model (Hursh, Raslear, Shurtleff, Bauman, & Simmons, 1988) used in previous studies examining RRE via observable behavior. Subsequently, Murphy and MacKillop (2006) validated an alcohol purchase task in a large sample of drinkers recruited from a university population, finding that self-reported consumption decreased as a function of increasing price, that expenditure exhibited an inverted U-shaped curve, and that multiple indices of reinforcement were significantly associated with alcohol use. Most recently, MacKillop and Murphy (2007) found that indices of RRE generated from an alcohol purchase task predicted treatment response to a brief intervention in heavy-drinking college students. These initial studies suggest that purchase tasks may be time- and cost-efficient methods for assessing RRE and may also have clinical utility.

Despite the promise of purchase tasks, only Jacobs and Bickel (1999) have studied a cigarette purchase task[1] (CPT) and the goal of the current study was to further validate this approach by replicating and extending their findings in several ways. In this study, we sought to replicate Jacobs and Bickel by examining the correspondence of the self-report data generated by a CPT to behavior typically observed under a progressive-ratio operant schedule by assessing the topography of responses, the adequacy of Hursh and colleagues' (1988) demand equation for the data generated, and the relationships among the variables generated. We predicted that consumption would decrease as a function of increasing price; that expenditure would conform to an inverted U-shaped curve; that Hursh et al.'s demand equation would provide a good fit to the data; and that the generated facets of RRE would exhibit moderate to high correlations but would not be collinear, instead reflecting multidimensionality.

In addition, we sought to extend the previous findings by examining the aforementioned hypotheses in a novel sample—college smokers—and also by examining the measure's convergent validity (i.e., capacity of a measure to correspond with putatively related variables; Nunnally & Bernstein, 1994) and divergent validity (i.e., capacity of a measure to detect relevant group differences; Nunnally & Bernstein, 1994). Specifically, we examined the measure's convergent validity by assessing the continuous relationships between the RRE indices and measures of smoking (i.e., nicotine dependence, cigarettes/day). We predicted that the facets of RRE would be positively associated with nicotine dependence and self-reported tobacco use, although we did not predict which ones would exhibit greater or lesser degrees of association. We examined the measure's divergent validity by conducting a median split of the sample on the basis of nicotine dependence and comparing those at lower and higher levels of dependence. We predicted higher RRE of nicotine in individuals who were more dependent on nicotine compared with those who were less dependent, although again we did not predict which specific indices would be most sensitive to between-groups differences. Finally, given the potential relevance of income to performance, we also examined the relationships between indices from the CPT and income for exploratory purposes.

[1] For clarification, the grammatical articles modifying *cigarette purchase task* (CPT) in this study differ based on whether they pertain to the general methodology or the specific measure. With regard to the general methodology in general, the article *a* CPT, not *the*, is used because the measure is based on a progressive-ratio operant schedule and such schedules provide a basic structure for assessing motivation but vary widely in their use on the basis of the experimental parameters (e.g., operant behavior, subject type, response requirement). Likewise, we consider the version used in this study to represent a basic assessment methodology but not necessarily to be the sole version. In contrast, the grammatical article *the* is used to refer to the specific measure used in the current study. That is to say, we examined the validity of *a* CPT to measure nicotine reinforcement using *the* CPT employed in the current study.

Method

Participants

Participants were drawn from a larger study on genetic factors underlying impulsive behavior (Eisenberg et al., 2007). Participants for that study were recruited from the Human Subjects Research Pool at the State University of New York at Binghamton and were included in the current study if they met an entry criterion of weekly self-reported cigarette smoking. Of the 195 participants in the larger study, 33 (58% male; age $M = 19.30$ years, $SD = 1.61$) met criteria for the current study. These individuals were relatively variable in their smoking habits ($M = 5.31$ cigarettes/day, $SD = 7.36$), with a range from 1 cigarette per week to 30 cigarettes per day. There was similar variability in nicotine dependence as measured by the Fagerstrom Test of Nicotine Dependence (described below), $M = 1.90$ ($SD = 2.02$, range = 0–6). These patterns are similar to those previously reported for college smokers (e.g., Colder, Lloyd-Richardson, & Flaherty, 2006). With regard to income, participants were assessed in terms of total household income and current bank account balance, hereafter referred to as *discretionary income*. Median household income was \$80,000 per year (interquartile range [IQR] = \$50,000–\$100,000), and median discretionary income was \$300 (IQR = \$27.50–\$1,355). In terms of race/ethnicity, the sample was relatively diverse: European (39%), Asian (27%), Latin American (12%), and mixed ethnicity (6%); 5 participants (15%) did not report race/ethnicity.

Measures

Demographics. A measure of demographics was administered, which included items relating to age, sex, race/ethnicity, and income.

Fagerstrom Test of Nicotine Dependence (FTND). The FTND is a six-item, psychometrically validated questionnaire assessing quantitative and behavioral aspects of nicotine dependence (Heatherton, Kozlowski, Frecker, & Fagerstrom, 1991). The quantitative items include the number of cigarettes smoked per day and time to first cigarette. Behavioral items include the difficulty in refraining from smoking in forbidden places, resistance to giving up a particular cigarette, pattern of consumption, and whether the individual smokes when ill. Total scores on the FTND can range between 0 and 10.

Cigarette purchase task (CPT). The CPT used was based on Jacobs and Bickel's (1999) procedure and assessed a number of metrics of RRE. The instructional set was as follows:

> Imagine a TYPICAL DAY during which you smoke. The following questions ask how many cigarettes you would consume if they cost various amounts of money. The available cigarettes are your favorite brand. Assume that you have the same income/savings that you have now and NO ACCESS to any cigarettes or nicotine products other than those offered at these prices. In addition, assume that you would consume cigarettes that you request on that day; that is, you cannot save or stockpile cigarettes for a later date. Please respond to these questions honestly.

Participants were then asked to respond to the following question: How many cigarettes would you smoke if they were _____ each at the following 19 prices?: zero (free), 1¢, 5¢, 13¢, 25¢, 50¢, \$1, \$2, \$3, \$4, \$5, \$6, \$11, \$35, \$70, \$140, \$280, \$560, \$1,120. These prices were presented in the preceding order.

Cigarette purchase tasks generate an overall nicotine demand curve, reflecting the quantitative relationship between demand for cigarettes and escalating price, and generated five RRE indices: (a) breakpoint (i.e., the first price at which consumption is zero), (b) intensity of demand (i.e., consumption at the lowest price), (c) elasticity of demand (i.e., sensitivity of cigarette consumption to increases in cost), (d) O_{max} (maximum expenditure for cigarettes), and (e) P_{max} (i.e., price at which expenditure is maximized). For three of these measures—intensity, P_{max}, and O_{max}—purchase tasks can generate both observed and derived values (Murphy & MacKillop, 2006). Observed values were calculated by either directly examining responses on the CPT or arithmetically calculating values on the basis of responses; derived values were obtained using values generated by Hursh et al.'s (1988) demand equation and additional equations employing values generated by the demand equation (all equations are described below).

Procedure

All aspects of the study were approved by the Human Subjects Research Review Committee (Institutional Review Board) at the State University of New York at Binghamton and all participants provided a written informed consent. All were initially given explicit instructions, followed by a 1-hr computerized assessment battery including the FTND and CPT. Participants were tested in groups of 10 or fewer in university computer laboratories. All participants received research credit for their participation in the study.

Statistical Analyses

To examine the first goal of the study (correspondence to typical behavioral performance on a progressive-ratio schedule), we obtained calculations of the RRE indices using the following methods. Breakpoint was defined as the first increment of cost at which no cigarettes would be consumed. Intensity–Observed was defined as free access consumption (i.e., consumption at a cost of zero). O_{max}–Observed was defined as the peak expenditure for cigarettes. P_{max}–Observed was defined as the price associated with the peak maximum expenditure.

The derived demand metrics were generated by fitting the self-reported responses to Hursh et al.'s (1988) demand curve equation:

$$\text{Ln } C = \text{Ln } L + b\,(\text{Ln } P) - aP, \tag{1}$$

where C is predicted consumption at a unit price of P, L is the price intercept, and parameters b and a determine the slope and acceleration, respectively, of the resulting function. Nonlinear regression was used to fit Equation 1 to the data and generated an R^2 value, reflecting percentage of variance accounted for by the equation (i.e., the adequacy of the fit of the model to the data). Consistent with Jacobs and Bickel (1999), when fitting the data to Equation 1, breakpoint consumption was coded as an arbitrarily nonzero value of .01 to provide an *x*-axis intercept of the demand curve that was amenable to logarithmic transformation. Similarly, the initial price (i.e., free) was replaced by a value of one tenth of 1¢ (i.e., \$.001) to permit the use of the logarithmic transformation in Equation 1 (.01 was not used because it would overlap with the \$.01 price). Intensity–Derived was defined as the empirically generated price intercept, *L*. P_{max}–Derived was determined using the *a* and *b* parameters of Equation 1 in the following equation:

$$P_{max} = (1 + b)/a. \quad (2)$$

O_{max}–Derived was calculated by multiplying P_{max}–Derived by the predicted consumption at P_{max}, which was calculated by solving for consumption at P_{max} using Equation 1. The *a* and *b* parameters from Equation 1 were used to determine the elasticity of demand at each price using the following equation:

$$e = b - aP. \quad (3)$$

Overall elasticity of demand (hereafter simply referred to as *elasticity*) was generated by calculating the mean of the individual price elasticities (Jacobs & Bickel, 1999). Following the calculation of all variables, each was examined for its adequacy of distribution and outliers using observation of histogram distributions.

The second goal of the study (convergent validity) was examined using Pearson product–moment correlations between indices of RRE and participants' cigarettes/day and nicotine dependence as measured by the FTND. The third goal of the study (divergent validity) was examined by conducting a median split of nicotine dependence and comparing reinforcement indices of participants at lower and higher degrees of dependence using univariate analyses of variance (ANOVAs). Finally, the exploratory examination of the relationship between performance on the CPT and income was assessed using Pearson product–moment correlations.

For all analyses, we set critical *p* at .05; for ANOVA-based analyses, we used partial eta-squared (η_p^2) as a measure of effect size. All analyses were conducted using SPSS 14.0 (SPSS Inc., Chicago.).

Results

Preliminary Analyses

On the FTND, three participants skipped one item; therefore, an FTND total score was not calculated and those individuals were excluded from the divergent validity analyses. On the CPT, two participants provided fewer cases than parameters, reporting they would smoke only if cigarettes were free and rendering the demand equation nonviable for these individuals. All observed and derived variables were adequately normally distributed, with the exception of three outlying data points (one each on elasticity of demand, intensity of demand, observed and derived). These values were determined to be extreme but nonetheless legitimate data points and were therefore kept in the data set and recoded as 1 unit above the next highest value, as recommended by Tabachnick and Fidell (2001).

Response Topography and Relationship Among Reinforcement Indices

Data from the CPT topographically conformed to expectations, with self-reported consumption decreasing as a function of escalating price and implicit expenditure (i.e., attendant expenditure based on self-reported level of consumption) exhibiting an inverted U-shaped curve. These patterns are depicted in Figure 1. Hursh et al.'s (1988) demand equation provided a very good fit to the data: For individual demand curves, the equation typically accounted for more than 95% of the variance (median $R^2 = .96$, range = .91−.99), and accounting for a similar amount ($R^2 = .94$) for the overall demand curve using mean values. Pearson's product–moment correlations were calculated among indices of RRE and revealed a number of significant associations, presented in Table 1. Consistent with previous studies (Bickel & Madden, 1999; Jacobs & Bickel, 1999; Johnson & Bickel, 2006), breakpoint and P_{max} approached collinearity and, as anticipated and consistent with Murphy and MacKillop (2006), very high correlations were observed between the observed and derived versions of variables, *r*s = .70–.95, *p*s < .001. In general, however, the levels of associations among the different indices were variable and did not suggest a single underlying dimension.

Convergent and Divergent Validity

In terms of convergent validity, as predicted, several indices of RRE were associated with nicotine dependence and daily tobacco use (see Table 1). Both nicotine dependence and daily smoking were most closely associated with O_{max}, with high-magnitude associations for both observed and derived versions of the variable. Both smoking indices were also closely associated with intensity of demand, although only trend-level associations were evident for the derived values.

In terms of divergent validity, a median split by FTND (*Mdn* = 1.50) divided the sample into those scoring 0 or 1 on the FTND (*n* = 15; FTND *M* = 0.33, *SD* = .49), designated "minimal nicotine dependence," and those scoring 2 or above (*n* = 15; FTND *M* = 3.47, *SD* = .45), designated "mild-to-moderate nicotine dependence." Individuals who were mildly to moderately nicotine dependent exhibited significantly greater RRE compared with the minimally dependent participants in terms of intensity of demand and O_{max}, as shown in Table 2. Demand and expenditure curves for both groups are provided in Figure 2, as are the specific between-groups differences for Intensity–Observed and O_{max}–Observed.

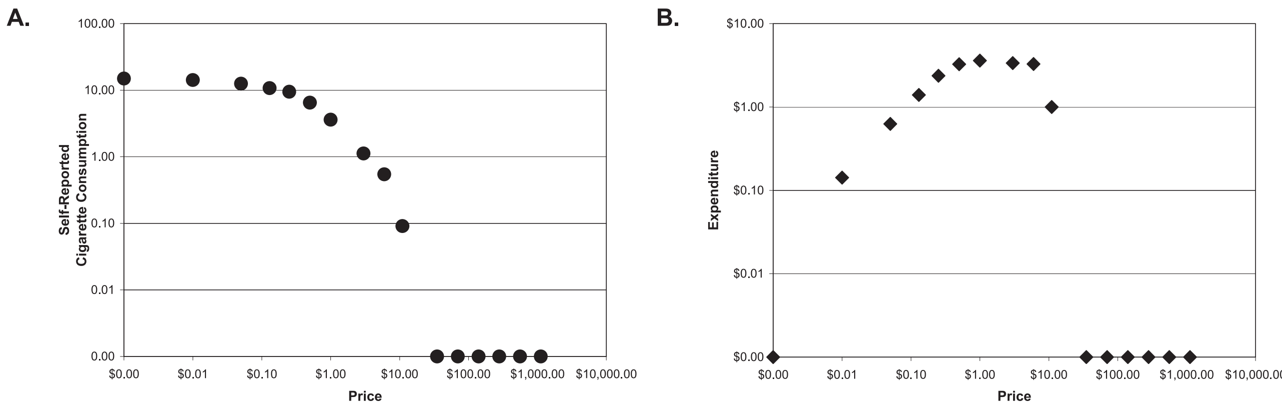

Figure 1. Cigarette demand and expenditure in smokers using a cigarette purchase task (CPT). Panel A depicts the cigarette demand curve, with the *x*-axis providing price in dollars ($) and the *y*-axis providing self-reported consumption in cigarettes. Conventional log-log coordinates are used for proportionality, with zero values replaced with trivial nonzero values (.001) for plotting on a logarithmic scale; values are shown to 2 decimal places. Panel B depicts the associated expenditure curve, with the *x*-axis providing price in dollars ($) and the *y*-axis providing expenditure in dollars ($). As above, log-log coordinates are used, with zero values replaced with trivial nonzero values (.001) for plotting on a logarithmic scale and values to 2 decimal places.

Finally, the indices of reinforcement were examined in reference to total income and disposable income, revealing low-magnitude nonsignificant associations ($ps = .12$ –.95).

Discussion

In the current study, we sought to further validate a CPT as a time- and cost-efficient measure of the RRE of nicotine, generating results that largely converge with previous studies using purchase tasks (Jacobs & Bickel, 1999; Murphy & MacKillop, 2006) and supporting the validity of the approach on three levels. First, the CPT data were both topographically and quantitatively consistent with what is typically observed in laboratory drug self-administration studies: Self-reported consumption decreased as a function of increasing price and was eventually suppressed to zero; expenditure initially increased, but peaked and then decreased eventually to zero, exhibiting an inverted U-shaped curve. Second, the measure exhibited strong convergent validity insofar as most indices were significantly positively associated with nicotine-related variables (i.e., cigarettes/day, nicotine dependence), most prominently for intensity of demand and O_{max}. Third, the measure exhibited strong divergent validity insofar as it captured differences in level of nicotine dependence, with the most sensitive indices again being intensity of demand and O_{max}. In addition, it was also of interest that participant income was not significantly associated with CPT performance. Taken together, these findings support the validity of a CPT as a time- and cost-efficient measure of the RRE of nicotine.

Beyond supporting the study's specific hypotheses, the relationship between the various facets of reinforcement generated by the CPT are also of interest. The relationships

Table 1
Correlations Among Facets of Relative Reinforcing Efficacy and With Nicotine Dependence and Average Cigarettes Smoked Per Day

Variable	E	BP	I-O	I-D	O-O	O-D	P-O	P-D	ND	C-D
Elasticity (E)	1.00									
Breakpoint (BP)	.50**	1.00								
Intensity-Observed (I-O)	−.05	.25	1.00							
Intensity-Derived (I-D)	−.53**	−.21	.70***	1.00						
O_{max}-Observed (O-O)	.23	.60***	.74**	.40*	1.00					
O_{max}-Derived (O-D)	.28	.69***	.75**	.35*	.95***	1.00				
P_{max}-Observed (P-O)	.57***	.86***	.35*	−.23	.65***	.69***	1.00			
P_{max}-Derived (P-D)	.54***	.99***	.17	−.26	.56***	.67***	.87***	1.00		
Nicotine dependence (ND)	.10	.34†	.48**	.31†	.42*	.66***	.24	.38*	1.00	
Cigarettes/day (CD)	.18	.41*	.65***	.32†	.70***	.76***	.42**	.35*	.75***	1.00

Note. Nicotine dependence (ND) was assessed using the Fagerstrom Test for Nicotine Dependence (FTND). Observed variables, $n = 33$; derived variables, $n = 31$; FTND $n = 30$.
† $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$. All tests were two-tailed tests.

Table 2
Differences in the Relative Reinforcing Efficacy of Cigarettes Between Individuals With Minimal Nicotine Dependence (FTND = 0 or 1) and Individuals With Mild-to-Moderate Nicotine Dependence (FTND = 2-6)

Variable	Minimal dependence (n = 15)		Mild to moderate dependence (n = 15)			
	M	*SE*	*M*	*SE*	*F*	η_p^2
Elasticity	−477.78	109.40	−348.74	113.24	0.62	.02
Breakpoint	4.01	2.13	9.07	2.13	2.81	.09
Intensity-Observed	5.13	3.04	20.00	3.04	11.95***	.30
Intensity-Derived	13.99	7.17	35.32	7.42	4.28*	.14
O_{max}-Observed	2.74	1.60	8.98	1.60	7.59**	.21
O_{max}-Derived	2.12	1.50	9.34	1.52	11.70***	.30
P_{max}-Observed	1.77	0.67	2.75	0.67	1.06	.04
P_{max}-Derived	0.70	0.29	1.38	0.30	2.61	.09

Note. FTND = Fagerstrom Test for Nicotine Dependence. Means, standard errors, *F* ratios, effect sizes, and significance level are provided. Note that derived variables could not be generated for two individuals, so the degrees of freedom for analyses using observed values were 1, 28, and degrees of freedom for analyses using derived values were 1, 27.
$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .005$.

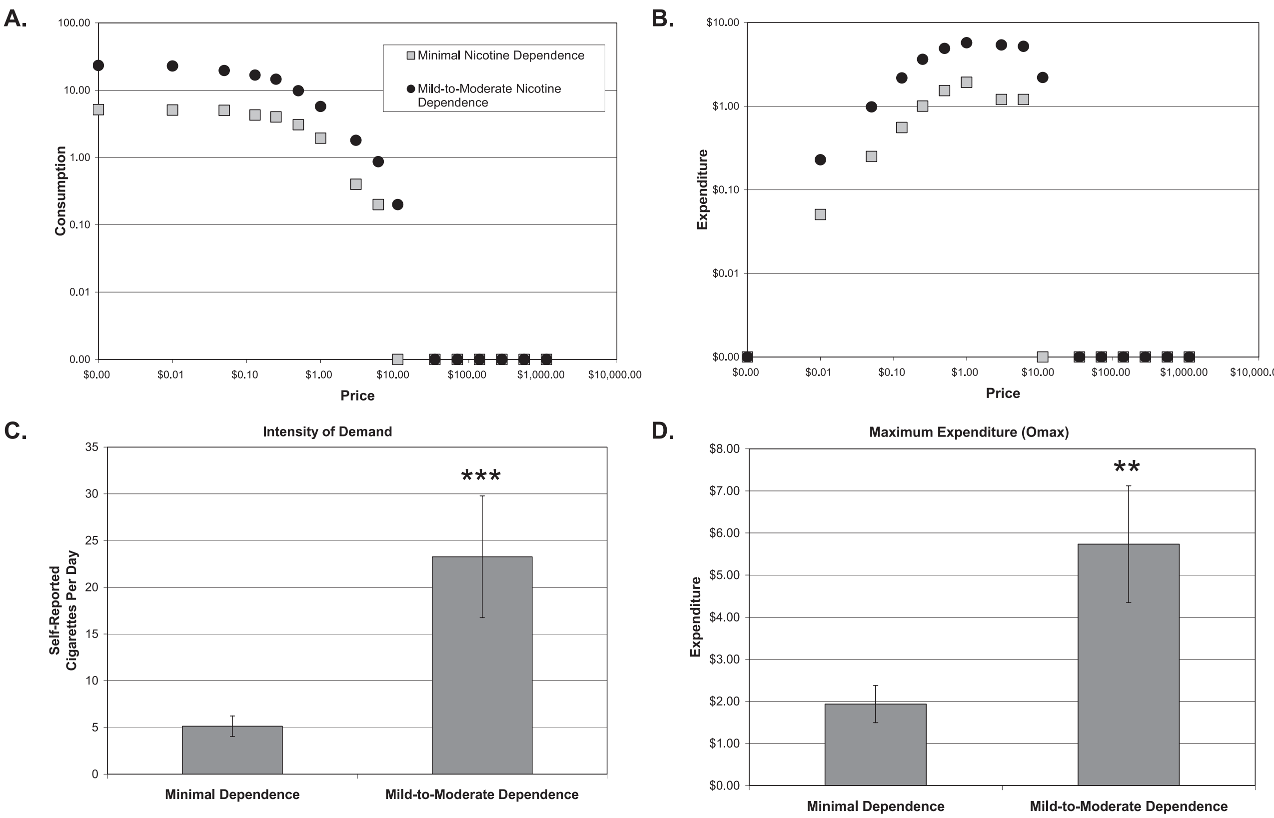

Figure 2. Cigarette demand and expenditure in minimally nicotine dependent smokers (n = 15) and mildly to moderately nicotine dependent smokers (n = 15) using a cigarette purchase task (CPT). Panel A depicts the cigarette demand curves, with the *x*-axis providing price in dollars ($) and the *y*-axis providing self-reported consumption in cigarettes on log-log coordinates, with zero values replaced with trivial nonzero values (.001). Panel B depicts the cigarette expenditure curves, with the *x*-axis providing price in dollars ($) and the *y*-axis providing expenditure in dollars ($) on log-log coordinates, with zero values replaced with trivial nonzero values (.001). Panel C depicts the means and standard errors of the two groups for observed intensity of demand; $^{***}p < .005$. Panel D depicts the means and standard errors of the two groups for observed maximum expenditure (O_{max}); $^{**}p < .01$.

observed among the different facets of RRE were often statistically significant and of moderate-to-high magnitude. This was particularly the case for P_{max} and breakpoint, which were essentially collinear, a finding that replicates three previous studies (Bickel & Madden, 1999; Jacobs & Bickel, 1999; Johnson & Bickel, 2006). Apart from that relationship, however, the pattern of associations among the other aspects of reinforcement was suggestive of multiple distinct facets, not a single underlying latent variable. Rather than being simply dissimilar, however, the relationships among variables could be systematically understood when considered in the context of their position on the demand curve. For example, negligible associations were observed between intensity of demand and breakpoint, reflecting the fact that the two characterize opposite ends of the demand curve (i.e., consumption at minimal response cost vs. the response cost that fully suppresses consumption). Equally, P_{max} was understandably significantly correlated with O_{max}, with the two reflecting different aspects of the demand curve's transition from inelastic to elastic demand.

This pattern of associations generally converges with a number of previous studies (Bickel & Madden, 1999; Jacobs & Bickel, 1999; Johnson & Bickel, 2006; MacKillop & Murphy, 2007; Murphy & MacKillop, 2006) and with Bickel et al.'s (2000) proposal that RRE is not a unitary construct, but is made up of heterogeneous phenomena that are functionally related to each other. Such findings pose a significant challenge to the concept of RRE and can be interpreted in two ways. If the construct of RRE does not consistently and systematically correspond to the putatively equivalent empirical variables that reflect it, it may simply be the case that RRE is, by definition, no longer a useful construct. From this perspective, Johnson and Bickel (2006) have recently argued for simply replacing the construct of RRE with a demand curve approach. Alternatively, it may be that RRE still has utility if it is revised to refer to a multidimensional construct that encompasses the multifarious relationships between operant behavior and outcome at different levels of response cost. However, in that case, it would still be incumbent on RRE to demonstrate greater explanatory power than simply characterizing those different measures as different facets of the demand curve. Although definitively addressing RRE as a construct is clearly beyond the scope of the current study, these data nonetheless converge with previous findings to clearly suggest that the construct is at least in need of revision.

Beyond theoretical implications, these findings also raise a methodological issue of relevance for future research—that of whether using observed or derived values is more appropriate. Observed values are calculated directly from participants' responses, whereas derived values are obtained from the demand curve generated by Equation 1. The advantage of observed variables is that they do not rely on any assumptions beyond the validity of participant reports, whereas the advantage of derived values is that they are not bound by the specific price increments used and thus the values from the extrapolated demand curve may have greater precision. To an extent, the issue could be considered moot, given that observed and derived values of a given variable were very highly correlated, with correlation coefficients ranging from .70 to .95. Similarly, there was no clear advantage or disadvantage to using observed versus derived variables in terms of convergent and divergent validity. However, because the two approaches generate different values and these small differences may nonetheless be meaningful, it seems imprudent at this point to suggest that observed and derived variables are interchangeable. As a provisional methodological recommendation, on the basis of parsimony, the observed values of intensity, O_{max}, and P_{max} appear to be more appropriate because they do not depend on the fit of the demand equation, which will vary among participants and generate parameter estimates that are increasingly inaccurate as variance accounted for by the equation decreases. It is important to note that this recommendation does not vitiate the importance of the demand equation, which is essential for assessing the adequacy of the data to the putative model and for calculating elasticity. In addition, although the observed and derived indices were very highly correlated in the current study, it is possible that the differential utility of one approach or the other would be more clear in certain contexts, for example, in reference to treatment-related variables (e.g., MacKillop & Murphy, 2007). Therefore, at this point, the recommendation to use observed values should not be considered definitive as this is clearly an area that needs further clarification in future studies.

It is important to note that these findings should be interpreted with a number of considerations. This study is only the second to date validating a CPT, and both have been relatively small (current sample, $n = 33$; Jacobs & Bickel, 1999, $n = 17$). In addition, although the sample reported smoking patterns at similar levels to other college samples (e.g., Colder et al., 2006), they may not be representative of other samples of more nicotine-dependent smokers and caution should be exercised in generalizing these findings. Clearly, considerable further validation is required. Most obviously, future studies are necessary to examine the correspondence between self-reported performance on a CPT and actual behavioral performance to confirm it as a valid analogue. In addition, it will be important to examine the relationship between the CPT and other behavioral economic measures, especially the Multiple Choice Procedure (MCP; Griffiths et al., 1996). The MCP is also a self-report analogue of a progressive ratio schedule, using self-reported choices between a single unit of a substance and escalating amounts of money to identify a breakpoint. A CPT clearly differs from the MCP because it assesses both consumption and expenditure across a range of prices, thereby providing detailed account of price–consumption and price–expenditure relations. However, the measures overlap in the assessment of breakpoint and the relationship between CPT and MCP breakpoint estimates would be worth examining. Finally, as noted above, it will also be important to establish the validity of the approach in larger samples and in individuals with higher levels of dependence.

Limitations notwithstanding, these data nonetheless suggest that a CPT may have a number of experimental applications. For example, a CPT could be used concomitantly with other purchase tasks to characterize the RRE of nicotine compared with other psychoactive drugs and to predict preferences under different levels of cost. In clinical research, a CPT may also be useful as an individual difference variable and may predict important aspects of treatment response, as was recently found with an alcohol purchase task (MacKillop & Murphy, 2007). It is important to note that, although in the current study the CPT was essentially configured as a trait measure, it is also possible that it may be viable as a state measure for use in human laboratory studies. All of the preceding represent potential future directions, but also hinge on a more comprehensive validation of the approach.

Finally, these findings may have relevance for public policy on tobacco control via taxation and other price manipulations. The evidence that cigarette consumption was highly price sensitive in this sample supports the notion that increases in the cost of cigarettes will reduce consumption. However, a closer examination of the demand and expenditure curves also reveals that although consumption generally decreased as a function of price, participants typically accommodated this escalation, as reflected by increased commensurate expenditure, until cigarettes cost approximately $1 each (see Figure 1). This is the equivalent of $20 per pack and over 4 times the current average cost per pack in the United States ($4.49; Centers for Disease Control and Prevention, 2006). Thus, the current data suggest that although cigarette smoking is price sensitive, this is most dramatically the case at levels of price that are substantially higher than the actual costs of smoking in the current market. This dissociation may partially explain why, although price increases in tobacco costs via taxation generally increase motivation to quit smoking and actual cessation rates (e.g., Hanewinkel & Isensee, 2007), the majority of smokers do not quit and simply accommodate such increases in cost. In turn, these data suggest that for environmental price manipulations to yield high-magnitude decreases in smoking, substantially larger increases would be required. Moreover, because certain groups are differentially sensitive to such increases, such as younger smokers (e.g., Liang, Chaloupka, Nichter, & Clayton, 2003), it is plausible that reinforcement variables from a CPT could be related to price sensitivity in the natural environment. However, it should be noted that participants may not have been extrapolating the costs of individual cigarettes into the cost of packs of cigarettes and the aforementioned caveats with regard to the size of this sample and its representativeness should be applied also. For these reasons, we regard these interpretations as necessarily speculative.

In conclusion, this study sought to further validate a CPT as an efficient self-report measure of the RRE of nicotine and found support for the measure on a number of levels. In addition, the relationships observed among the indices of relative value converged with previous work that challenges the notion of RRE as a unitary construct. Although the study's sample was relatively small and validation of a CPT requires further research, it nonetheless appears to be a promising measure for use in experimental and clinical research.

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