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Validity of a Demand Curve Measure of Nicotine Reinforcement with Adolescent Smokers

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Abstract

High or inelastic demand for drugs is central to many laboratory and theoretical models of drug abuse, but it has not been widely measured with human substance abusers. The authors used a simulated cigarette purchase task to generate a demand curve measure of nicotine reinforcement in a sample of 138 adolescent smokers. Participants reported the number of cigarettes they would purchase and smoke in a hypothetical day across a range of prices, and their responses were well-described by a regression equation that has been used to construct demand curves in drug self-administration studies. Several demand curve measures were generated, including breakpoint, intensity, elasticity, P_{max}, and O_{max}. Although simulated cigarette smoking was price sensitive, smoking levels were high (8+ cigarettes/day) at prices up to 50¢ per cigarette, and the majority of the sample reported that they would purchase at least 1 cigarette at prices as high as $2.50 per cigarette. Higher scores on the demand indices O_{max} (maximum cigarette purchase expenditure), intensity (reported smoking level when cigarettes were free), and breakpoint (the first price to completely suppress consumption), and lower elasticity (sensitivity of cigarette consumption to increases in cost), were associated with greater levels of naturalistic smoking and nicotine dependence. Greater demand intensity was associated with lower motivation to change smoking. These results provide initial support for the validity of a self-report cigarette purchase task as a measure of economic demand for nicotine with adolescent smokers.

Keywords

tobacco; smoking; adolescents; behavioral economics; reinforcement; demand curve; nicotine dependence; motivation

1. Introduction

Behavioral economic theories of addiction view substance dependence as a state in which the reinforcing efficacy of drugs is high in comparison to the reinforcing efficacy of other activities that are available in an individual's environment (e.g., Loewenstein, 1999;

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Rachlin, 1997; Murphy et al., 2009). Within this behavioral economic framework, demand curves have been used to describe the reinforcement efficacy of a drug or a specific dose of a drug within a specific context (Bickel et al., 2000). Demand curves plot consumption of a drug across a range of response costs or “prices,” and have demonstrated utility in preclinical research aimed at assessing the abuse liability of drugs or response to an experimental manipulation (for a review, see Hursh & Silberberg, 2008).

Recently several investigators have developed cost-efficient measures of drug demand that do not involve actual drug consumption and therefore can be administered in clinical settings in which actual drug consumption is prohibited or inadvisable. Hypothetical drug purchase tasks are modeled after laboratory drug self-administration procedures, but use hypothetical choices between drug and monetary amounts that are analogous to the choices participants would make in a laboratory drug administration procedure (Griffiths et al., 1996; Jacobs & Bickel, 1999; Petry & Bickel, 1998). For example, the initial question may assess drug or alcohol purchases at zero cost per unit (e.g., a single cigarette or alcoholic beverage), with subsequent questions gradually increasing in price up to a level at which consumption is drastically suppressed (e.g., $5 for a cigarette). The reported purchases can then be used to generate an individual’s demand curve for the substance: a quantitative representation of their estimated consumption across a range of prices. Several reinforcement indices can be generated from demand curves, including demand intensity (number of cigarettes or drinks consumed when price = 0), O_{max} (maximum expenditure), P_{max} (the price at which demand become elastic), breakpoint (the price which completely suppresses consumption) and elasticity (the rate of decrease in consumption as a function of price).

Advantages of these tasks are their close resemblance to the laboratory tasks after which they are modeled and their ability to yield precise quantitative measures of participants’ choices (demand curves; Jacobs & Bickel, 1999). Simulation procedures have been widely used in experimental economics (Camerer, 1999), and in behavioral economic studies of addiction. For example, over 20 published studies provide strong support for the reliability, validity, and utility of the hypothetical delayed reward discounting (DRD) task with a variety of human populations (see Green & Myerson, 2004 for a review). Specifically, results suggest that although an individual’s absolute level of discounting may vary across real versus hypothetical discounting paradigms, the relative level of discounting across paradigms is similar, as are the relations with naturalistic drug use (Madden et al., 2004). Although only a few studies have examined hypothetical purchase tasks, one study found a high degree of correspondence between choices on a hypothetical alcohol purchase task and actual laboratory based demand for alcohol (MacKillop Amlung et al., 2010), and another study found that the reported consumption values and reinforcement metrics derived from a hypothetical alcohol purchase task demonstrated good to excellent test-retest reliability (Murphy et al., 2009).

Although preclinical laboratory demand curve analyses have typically evaluated the reinforcing efficacy of several drug types or doses (Winger et al., 2002), hypothetical drug purchase tasks can assess potentially meaningful *individual differences* in susceptibility to drug reinforcement. In this context, economic demand may reflect strength of desire for drugs (i.e., motivational salience of drugs), and may vary across individuals, or within an individual over time or across contexts. The demand metrics may thus have clinical utility (MacKillop, Miranda et al., 2010); individual differences in consumption and expenditures on a simulated drug purchase task might capture important variability in the extent to which individuals value a substance. Although it is possible to obtain self reports of actual drug use and expenditures in the natural environment, which have been shown to predict substance use outcomes (e.g., Roddy & Greenwald, 2009; Tucker et al., 2009), advantages of simulation tasks include the ability to control for contextual influences on consumption through the use of a standard scenario and to model aspects of consumption that would be difficult to capture using naturalistic patterns of drug use and expenditures (Jacobs & Bickel, 1999). MacKillop and Murphy (2007) found that heavy drinkers who reported greater alcohol consumption and expenditures on a hypothetical alcohol purchase task were less likely to reduce their consumption in response to a brief motivational intervention. This study provided support for the validity and clinical utility of purchase tasks as a measure of strength of substance-related reinforcement.

The present study evaluated the initial construct validity of a Cigarette Purchase Task (CPT) among adolescent smokers. The CPT is a self-report measure of hypothetical cigarette purchases as a function of escalating prices. Estimated consumption at escalating prices can be modeled as a smoking demand curve from which various indices of smoking reinforcement can be derived. Jacobs and Bickel (1999) initially examined the validity of a CPT in a sample of nicotine- and heroin-dependent adults. They found that as price increased, self-reported consumption decreased, associated expenditures exhibited the characteristic inverted U-shaped curve (i.e., expenditures were low when price was low, increased at moderate prices, then decreased at very high prices), and that the data conformed with a quantitative model used in previous drug administration studies (Hursh & Silberberg, 2008). MacKillop et al. (2008) provided further support for the validity of the CPT in a small pilot study of 33 adult smokers. They found that the CPT exhibited strong convergent and divergent validity; most indices were significantly positively associated with nicotine-related variables (i.e., cigarettes/day, nicotine dependence), with the strongest relationships demonstrated between baseline smoking rate and dependence and intensity of demand and O_{max}.

The aim of the current study was to replicate and extend these findings with a sample of adolescent smokers. First, we were interested in characterizing the impact of cigarette price on adolescent smoking. Although epidemiological data attest to the price sensitivity of adolescent smoking initiation, smoking level, and smoking cessation (Chaloupka, 2003; Powell et al., 2005), the CPT allows for a more thorough investigation of reported demand for cigarettes across a wide range of prices, and also for the exploration of individual difference variables associated with price sensitivity, than is possible with epidemiological data on cigarette demand. Specifically, we investigated the ability of the CPT to generate prototypic demand curve data and the relationships between CPT variables and baseline smoking rate and nicotine dependence level. We also sought to examine the relationship between demand and motivation to change smoking. In this case, we hypothesized that the CPT demand measures would be negatively related to motivation to change smoking. Individuals for whom smoking is a more potent reinforcer will express less interest in reducing their smoking.

2. Method

2.1. Recruitment

Participants were recruited using newspaper, radio, and public transportation advertisements, and with flyers and presentations in public and private high schools in Rhode Island and Massachusetts. Interested students called the research lab to complete a confidential screening interview. To be eligible, participants had to: 1) be current smokers; 2) report smoking at least once in the prior two weeks; 3) be enrolled in high school (grades 9–12); and 4) read and understand English. Students were ineligible if they reported other (non-cigarette) tobacco use on more than 4 days in the prior month. Eligible students were invited to participate and scheduled for a private appointment with a research assistant, which took place after school either at the research laboratory, or at a community setting such as a school or library.

Data for this study were taken from a larger study that compared adolescent smokers to a matched sample of nonsmokers on various indices. Participants were paid $25 for completing each of two assessment sessions. Current data were collected in the first of the two sessions and exclude responses from nonsmokers. All study procedures were approved by the university Institutional Review Board. Informed consent was obtained prior to research participation. Participants younger than 18 provided assent and were required to have parental consent.

2.2. Participants

The final sample consisted of 138 adolescent smokers. Of these, 49% were female, 84.1% were White, and 9.4% reported Hispanic/Latino ethnicity. The average age of participants was 16.5 years (Standard deviation [*SD*] = 1.2). Table 1 provides information on demographic characteristics as well as the mean levels of weekly smoking and nicotine dependence in this sample. Participants reported smoking 5.97 cigarettes per day (SD = 5.99, Range = 0–38.07). Although all participants reported past-two week smoking on the screen, 2 participants reported no past two-week smoking when they completed the assessment session. However, they considered themselves current smokers and were included in the present analyses.

2.3. Measures

2.3.1 Demographics—Participants completed a brief demographics form which queried gender, date of birth, grade, and race/ethnicity. In addition, students were asked whether they qualified for free or reduced-price school lunch as a proxy measure of socioeconomic status (SES) (Scarinci et al., 2002). We created a 3 level income variable: highest income (private school students and students who attended public school with full pay lunch), middle income (students who attended public school and qualified for a reduced-price school lunch), and lowest income (students who attended public school and qualified for a free school lunch).

2.3.2. Timeline Follow back (TLFB)—The TLFB is a calendar-assisted retrospective recall of the number of cigarettes smoked each day; it has been validated for use with adolescents and its summary variables have been shown to have high stability over time (Lewis-Esquerre et al., 2005). Daily smoking over the prior two-week period was assessed.

2.3.3. Contemplation Ladder—The 10-point Contemplation Ladder provided a quasi-continuous index of motivation (readiness) to quit smoking. The assessment depicts a ladder with each rung associated with increasing levels of readiness to change, from 1 ("I enjoy smoking and have decided not to quit smoking for my lifetime. I have no interest in quitting.") to 10 ("I have quit smoking and I will never smoke again."). The Ladder has been shown to have good reliability and validity (Abrams & Biener, 1992; Biener & Abrams, 1991).

2.3.4. Modified Fagerstrom Tolerance Questionnaire (mFTQ)—The mFTQ is a 7-item measure of nicotine dependence that has been adapted from the original FTQ (Fagerstrom, 1978) for use with adolescent smokers. It has been shown to have good internal consistency, high test-retest reliability and strong concurrent validity (Prokhorov et al., 1996). Possible scores range from 0 to 9; the mean score in this sample fell within the "moderate dependence" range of the mFTQ (see Table 1).

2.3.5. Cigarette Purchase Task (CPT)—The CPT is a hypothetical cigarette task which generates several measures of nicotine reinforcement. The CPT was developed by MacKillop et al. (2008) who based their measure on an earlier CPT measure developed by Jacobs and Bickel (1999) and an alcohol purchase task developed by Murphy and MacKillop (2006). The CPT included in this study included 7 more price increments than the CPT used in MacKillop et al. (2008). The additional price increments provided a more fine grained analysis of the influence of price increases between the $1–$10 range. 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 26 prices in ascending order: zero (free), 1¢, 5¢, 13¢, 25¢, 35¢, 50¢, $1, $1.50, $2, $2.50, $3, $4, $5, $6, $7, $8, $9, $11, $35, $70, $140, $280, $560, $1120.

The CPT was used to generate five demand indices: 1) breakpoint (first price at which cigarette consumption is zero; 2) demand intensity (cigarette consumption at the lowest price), 3) O_{max} (output maximum, or maximum financial expenditure on cigarettes); 4) P_{max} (price maximum, or price at which expenditure is maximized); and 5) elasticity of demand (sensitivity of cigarette consumption to increases in cost). To generate an estimate of elasticity, demand curves were estimated by fitting each participant's reported consumption across the range of prices to Hursh and Silberberg's (2008) exponential demand curve equation: $\ln Q := \ln Q_0 + k\,(e^{-\alpha P} - 1)$, in which Q is the quantity consumed, k specifies the range of the dependent variable (cigarette consumption) in logarithmic units, and α specifies the rate of change in consumption with changes in price (elasticity). The value of k (3.5 in natural log units in the present study, based on the best fit with the sample mean consumption values) is constant across all curve fits. Individual differences in elasticity are thereby scaled with a single parameter (α) which is standardized and independent of reinforcer magnitude. Larger α values reflect greater price sensitivity (elasticity). Demand curves were fit according to the Hursh and Silberberg (2008) guidelines using the calculator provided on the Institute for Behavioral Resources website (www.ibrinc.org/ibr/centers/bec/BEC_demand.html). This nonlinear regression was used to generate an R^2 value, reflecting percentage of variance accounted for by the equation. Consistent with Jacobs and Bickel (1999), when fitting the demand curve data, the first zero consumption value (i.e., breakpoint) was replaced by an arbitrarily low but nonzero value of .001, which is necessary for the logarithmic transformations. We did not include subsequent 0 consumption values in our curve estimates.

The demand metrics were examined for distribution normality and outliers. Following the recommendation of Tabachnick and Fidell (2001), outliers were defined as values more than three standard deviations above or below the mean and recoded as one unit greater than the highest non-outlier value. Outliers for intensity, breakpoint, and O_{max} were recoded in this manner. Intensity was square root transformed to correct for significant positive skewness and kurtosis. Breakpoint, P_{max}, and O_{max} were log transformed to correct for significant positive skewness and kurtosis. These transformations resulted in normal distributions for all demand metrics. Although relatively large correlations have been observed among the demand metrics in a previous study (MacKillop et al., 2008), each was used individually to clarify the specific relationships between individual measures of reinforcing value and the tobacco-related variables. No error correction was used because of the directional hypotheses and relatively small number of demand metrics. Because of its apparent relevance to a purchase task, cigarette demand was examined in relation to SES and where significant associations were evident, follow-up analyses covarying SES were conducted to examine independent relationships.

3. Results

3.1. The Impact of Cigarette Price on Reported Smoking and Expenditures

Figure 1 (Panel A) depicts the mean number of cigarettes that participants reported that they would smoke at 26 different prices, as well as the percentage of the sample that reported they would abstain at each price. As expected, cigarette smoking exhibited a decelerating trend in response to price increases; adolescents reported smoking 20 or more cigarettes at prices up to 5¢ per cigarette. When cigarette price was $1 (i.e., $20 per pack), mean reported consumption levels dropped to approximately 5 cigarettes per day, but only 14.5% of adolescents reported that they would abstain. Most adolescents reported that they would smoke 1–2 cigarettes per day, even at prices of $2.50 per cigarette. The sample abstinence rate first exceeded 50% at a price of $3 per cigarette (55% abstinent) and increased rapidly thereafter. However, 20% of adolescents reported that they would purchase at least one cigarette, even at a price of $7 per cigarette. Response output (expenditures) conformed to an inverted U-shaped function up to the point where the extremely large prices resulted in high mean expenditure values despite the fact that most participants had reached breakpoint (Panel B). The average peak expenditure for the sample was $5.33 and occurred at a price of $1.50 per cigarette. Demand became elastic thereafter as overall expenditures decreased (Panels C & D).

3.2. Descriptive Data and Adequacy of the Demand Curve Model

Figure 1 (Panels C and D) also depicts demand and expenditure curves plotted in conventional double logarithmic coordinates for proportionality. Hursh and Silberberg's (2008) demand curve equation provided a good fit to the sample mean cigarette consumption values (R^2 = .84) and an adequate fit for most participants' reported consumption data (median R^2 = .65, interquartile range = .59–.71; mean R^2 = .64, SE = .005). R^2 values were significantly correlated with smoking level (*r* = .19, *p* = .025) and breakpoint (*r* = .27, *p* = .002), indicating that the equation provided a relatively poor fit for lighter smokers who quickly reached breakpoint. Although no accepted criterion for adequacy of fit for Equation 1 exists, the model provided an adequate fit for 135 of 138 participants using a criterion that Reynolds and Shiffbauer (2004) suggested for curve fits obtained in a delayed reward discounting task ($R^2 \geq .30$). We did not use the alpha (elasticity) parameter estimates for the 3 participants with poor curve fit values. Descriptive data on cigarette smoking RRE metrics, naturalistic smoking, nicotine dependence, and motivation to change are presented in Table 1.

3.3. Relations among Nicotine Demand Metrics

Pearson's *r* was calculated among the nicotine demand metrics (Table 2). As anticipated, large magnitude positive associations were evident between the conceptually related metrics of breakpoint, P_{max}, O_{max}, and elasticity, which all reflect sensitivity of demand to increases in price. Demand intensity was highly correlated with O_{max}, moderately correlated with breakpoint, unrelated to P_{max}, and negatively related to elasticity. This pattern of relations is generally consistent with previous demand curve research with both alcohol and cigarette purchase tasks (MacKillop et al., 2008;Murphy et al., 2009).

3.4. Relations between Demand Metrics and Smoking Variables

Pearson's *r* was calculated for each of the demand metrics, daily smoking, nicotine dependence, and motivation to change smoking (Table 2). Demand intensity showed the predicted significant positive relations with TLFB reports of cigarettes per day and MFTQ measure of nicotine dependence, and the predicted negative relation with motivation to change. Adolescents who reported smoking more on the CPT reported less motivation to change. Intensity was the only demand or smoking metric to show an association with motivation; interestingly, neither TLFB cigarettes per day nor nicotine dependence were related to motivation to change. Breakpoint, O_{max}, and elasticity were significantly positively related to cigarettes per day and nicotine dependence. Thus, greater total cigarette expenditures, and lower price sensitivity was associated with greater daily smoking on the TLFB and greater nicotine dependence. P_{max} was also positively associated with nicotine dependence.

We conducted a series of partial correlations to determine whether the demand metrics which showed significant bivariate relations with nicotine dependence would remain significant after controlling for SES, which showed a significant positive association with elasticity (higher SES = greater price sensitivity) and significant negative associations with intensity and dependence (higher SES = fewer cigarettes purchased and less dependence) (see Table 2). After controlling for SES, breakpoint and P_{max} were no longer significantly associated with nicotine dependence. All of the other significant bivariate associations between reinforcement variables and smoking variables remained significant after accounting for SES (Table 3).

3.5. Nicotine Demand as a Function of Nicotine Dependence

To examine nicotine demand at different levels of nicotine dependence, the sample was divided into no (MFTQ = 0–2; n = 38) versus moderate (MFTQ = 3–5; n = 69) versus substantial (MFTQ = 6–9; n =29) nicotine dependence groups. Mean demand metric values for these nicotine dependence groups are shown in Table 4. We conducted a series of ANCOVAs to evaluate whether demand variables differed as a function of dependence level, after controlling for SES. Students with greater nicotine dependence reported significantly higher O_{max} values (p = .01). Pairwise contrast tests indicated that participants with substantial dependence reported significantly greater O_{max} values than participants with no dependence (p = .002) and participants with moderate dependence (p = .03). There was not a significant difference between individuals with no versus moderate dependence. There was a non-significant trend level effect for dependence level on breakpoint (p = .08). Pairwise contrast tests indicated that participants with substantial dependence reported higher breakpoint values than participants with moderate dependence (p = .026). No other pairwise contrasts were significant. Finally, there was a trend level effect for dependence level on intensity (p = .06). Pairwise contrast tests indicated that participants with substantial dependence reported higher intensity values than participants with no dependence (p = .027), but no significant differences between individuals with moderate dependence relative to the higher and lower dependence groups.

4. Discussion

The goal of the current study was to further validate the CPT as a time- and cost-efficient measure of the reinforcing efficacy of cigarettes in a sample of adolescent smokers. As predicted, the topographic features of the data were prototypic: self-reported cigarette demand was high at low prices and decreased as a function of increasing price, and associated expenditure generally conformed to an inverted U-shaped curve, paralleling findings using multi-session operant progressive ratio schedules in smokers (Bickel &

Madden, 1999; Johnson & Bickel, 2006; Madden et al., 2000; Madden & Bickel, 1999). Similarly, Hursh and Silberberg's (2008) quantitative model of demand provided a good fit to the aggregate data. Individual participant curve fits were highly variable; lighter smokers reached breakpoint fairly quickly which may have contributed to their lower curve fit values.

This study also supported the convergent and divergent validity of the CPT, with demand indices exhibiting significant associations with smoking rate and nicotine dependence, and trichotomous comparisons revealing meaningful differences for individuals at different levels of dependence. Of the demand indices, O_{max} (maximum expenditure), demand intensity (unconstrained consumption) and breakpoint (the first price to completely suppress consumption) were most clearly related to smoking and nicotine dependence. These findings are largely consistent with our predictions and in each case further support the utility of the CPT for assessing cigarette demand in adolescent smokers.

One novel goal of this study was to examine the relationship between demand for cigarettes and motivation to change smoking. In this case demand intensity was the only reinforcement or smoking variable that was significantly associated with motivation to change. As predicted, greater reported smoking when cigarettes were free (demand intensity) was inversely associated with motivation to change (reflecting resistance to change). Interestingly, contrary to what might be expected, neither baseline smoking rate nor nicotine dependence was related to motivation. Future research should explore the utility of the demand intensity index in predicting actual changes in smoking behavior following an intervention or quit attempt.

As with most behavioral economic studies, the role of SES in our findings warrants discussion (Green & Myerson, 2004). It is certainly plausible that SES would be associated with indices of tobacco demand, particularly those measures that are related to price sensitivity (elasticity, P_{max}, breakpoint) or maximum expenditure (O_{max}). Income might impose a constraint on smoking expenditures that might be partially independent of strength of desire for cigarettes. However, MacKillop et al. (2008) found no significant relationship between any indices of tobacco demand and income, and, in the current study, we found that SES was inversely correlated with demand intensity and positively correlated with demand elasticity. That is, higher SES (and presumably greater resources) was associated with higher price sensitivity, indicating that cigarettes were "inferior" rather than "normal" goods (DeGrandpre et al., 1993). With normal goods consumption and income are directly related (e.g., meals at fine restaurants); with inferior goods consumption and income are negatively related (e.g., meals at fast-food restaurants). Socio-economic status was also significantly inversely associated with nicotine dependence suggesting that higher SES individuals were generally less nicotine dependent. These results are consistent with numerous other studies indicating that lower SES is a risk factor for smoking initiation, escalation, and poor response to cessation programs (Ensminger et al., 2009; Graham, 2009; Hanson & Chen, 2007). The current results extend this literature on smoking and SES by indicating that lower SES individuals report greater reinforcement from cigarettes, both in terms of demand intensity and elasticity. Behavioral economic theory holds that drug reinforcement is influenced by the availability of alternatives (Carroll et al., 2009), and lower SES teens may overvalue nicotine related reinforcement in part because of the absence of alternative sources of reinforcement. It is important to note, however, that it is difficult to measure income in adolescence, and the proxy measure of family income used in this study (eligibility for free or reduced price school lunches) may have had limited sensitivity. Therefore, although our findings of a positive relation between income and elasticity are consistent with epidemiological research, future research should investigate this relation using a more sensitive measure of adolescent disposable income.

Beyond the specific findings, the data collected have a number of implications with regard to both adolescent smoking and the CPT, but should be interpreted in the context of a number of limitations to this area of research in general and to this study in particular. One pattern of findings of particular interest was the level of consumption reported by the adolescent smokers in this study. Specifically, compared to the levels of actual smoking, the levels of smoking reported on the CPT suggesting that their preferred level of consumption (when cigarettes were free) was about fourfold higher than they reported using in the natural environment. This might suggest that parental monitoring, costs, and other restrictions on under age tobacco consumption are effectively limiting teens' smoking behavior (Chaloupka, 2003; Powell et al., 2005). Given that most teens have some degree of restrictions on their day-to-day access to cigarettes, they may be inclined to "binge" in response to the free and low price smoking scenarios included in the CPT. This pattern of ad lib smoking measured on the CPT may provide important information about teens' level of smoking severity or likelihood of eventual cessation.

Also of interest were the absolute prices at which participants continued to report smoking; for example, the majority reported continuing to smoke if cigarettes cost $2.50 each. At first glance, this may be interpreted to suggest that most adolescent smokers would continue to smoke if cigarettes cost $50 per pack, but we regard this as unlikely. A limitation of this and previous CPTs studies is that the extrapolated cost of smoking purchases is not presented and is almost certainly rarely calculated by participants. As such, caution should be exercised in extrapolating to cost per pack reports and future versions of the CPT may benefit from including such a conversion. On the other hand, the single cigarette purchase format of this task may have some ecological validity with this adolescent sample (Landrine et al., 1998). Because most participants (80%) were under 18 years old and thus unable to legally purchase cigarettes, many of these teens may acquire cigarettes by purchasing them in small quantities either from peers, older friends of relatives, or through some urban convenience stores which sell individual cigarettes ("loosies") and are less likely to require identification as proof of age (Gratias et al., 2005; Klonoff et al., 1994). Future research should investigate the relations between teens' naturalistic methods for acquiring cigarettes and their reported demand on the CPT.

It should be noted that the development of purchase tasks as useful measures of reinforcing value is relatively new and studies directly comparing estimated consumption on purchase tasks and actual consumption have not been conducted. Although a number of behavioral economic studies have repeatedly verified the relationship between hypothetical and actual performance on similar measures (Irwin et al., 1992; Kirby & Marakovic, 1995; Lagorio & Madden, 2005; Madden et al., 2003; Madden et al., 2004), this is the first study to use the CPT with adolescent smokers, so the extent to which their reported cigarette purchases on this task would correspond to actual purchases under varying prices is unknown. The results of the current study are consistent with previous studies that have supported the construct validity of hypothetical purchase tasks measures of reinforcement (Murphy et al., 2009; MacKillop & Murphy, 2007), but also suggest that the CPT might overestimate absolute consumption and expenditure levels. The inclusion of extremely high prices and the fact that participants' provided consumption estimates based on an ascending series of prices (rather than randomly presented price increments) may have contributed to the overestimate of cigarette demand observed in the present study. More generally, the inflated demand estimates generated by hypothetical purchase tasks may be analogous to research indicating that hypothetical delay discounting measures provide a valid measure of self-control/impulsivity (based on correlations with substance abuse and laboratory discounting measures), but tend to overestimate the absolute degree of discounting (Madden et al., 2004). Hypothetical demand curve measures may have greater translational value as individual difference measures of drug-related reinforcement than as predictors of actual consumption or expenditure levels.

A final aspect of the current study that is worthy of commentary is that with the exception of intensity, the demand metrics were not associated with motivation to quit smoking, which was contrary to our prediction. In any case, among the various dimensions of reinforcing value that a demand curve provides, it is important to identify which ones are the most relevant, an outcome that may vary by the criterion of interest. Although intensity of demand has been found to be among the most highly correlated with alcohol-related problems and symptoms of alcohol use disorders (Murphy & MacKillop, 2006; MacKillop et al., 2010), other indices of demand were found to be better predictors of treatment response for heavy alcohol use (MacKillop & Murphy, 2007). In general these results provide further evidence that reinforcement value is not a homogenous construct (Bickel et al., 2000; Johnson & Bickel, 2006; Madden et al., 2007), and that the different dimensions of reinforcement generated by demand curves may have unique associations with clinically relevant phenomena such as motivation and dependence.

In summary, the current study sought to advance the psychometric validation of a CPT approach to assess individual differences in economic demand for cigarettes. The approach was largely supported in terms of the demand curves generated, its convergent and divergent validity, and preliminary data on the relationship between demand and motivation to change. These findings should be interpreted conservatively in light of the ongoing development of this experimental methodology, but nonetheless contribute to what is known about motivation to smoke in adolescents, the multidimensional nature of the reinforcing value of cigarettes, and the potential applications of a purchase task approach.

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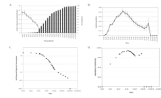

Figure 1.

Panel A depicts the mean number of cigarettes that participants reported that they would smoke at 26 different prices (left axis), as well as the percentage of the sample that reported they would abstain at each price (right axis). Error bars represent +/− 1 Standard Error of the Mean (SEM). As expected, cigarette smoking exhibited a decelerating trend in response to price increases. Abstinence rates were extremely low at prices up to $1 per cigarette. The sample abstinence rate first exceeded 50% at a price of $3 per cigarette (55% abstinent) and increased rapidly thereafter. Panel B depicts response output (mean cigarette expenditures, computed as reported cigarette consumption x cigarette price). Error bars represent +/− 1 SEM. Response output conformed to an inverted U-shaped function up to the point where the extremely large prices resulted in high mean expenditure values despite the fact that most participants had reached breakpoint. Panels C and D also depict demand and expenditure curves plotted in conventional double logarithmic coordinates for proportionality.

Table 1

Descriptive Data regarding Demographic Variables, Smoking Variables, and the Cigarette Purchase Task (CPT) Demand Metrics (*N* =138).

Measure	Mean/%	SD	Median	Range
	Demographic Variables			
Gender				
Male	51%			
Female	49%			
Ethnicity				
Black	3.6%			
Latino	9.4%			
White	84.1%			
Other	2.9%			
Age	16.50	14.08	17	14–19
Socio Economic Status				
lowest	19.1%			
middle	7.3%			
highest	73.5%			
	Smoking Variables			
Motivation to Change	5.39	1.88	5	1–10
Cigarettes per Day	5.97	5.99	3.89	0–38.07
Nicotine Dependence	3.85	1.88	4	0–9
	CPT Demand Metrics			
Intensity	21.54	15.85	20	1–83
O_{max}	16.9	46.94	6.5	0–282
Elasticity	.023	.023	.013	.0001–.11
Breakpoint	8.87	22.54	3	0–142
P_{max}	10.95	47.15	1.5	0–282

Note: O_{max} = maximum output (expenditure); P_{max} = Price maximum

Socio economic status was coded as: highest income (private school students and students who attended public school with full pay lunch), middle income (students who attended public school and qualified for a reduced-price school lunch), and lowest income (students who attended public school and qualified for a free school lunch).

Table 2

Correlations among Reinforcement Metrics and Smoking Measures

Measure	Motivation To Change	Cigarettes/Day	Nicotine Dependence	Intensity	O_{max}	Elasticity	Breakpoint	P_{max}	SES
Motivation to Change	1								
Cigarettes/Day	−.02	1							
Nicotine Dependence	−.09	.70***	1						
Intensity	−.21*	.30***	.27***	1					
O_{max}	−.12	.34***	.31***	.41***	1				
Elasticity	.14	−.25**	−.24**	−.53***	−.74***	1			
Breakpoint	−.06	.21*	.17*	.22*	.81***	.64***	1		
P_{max}	−.07	.09	.17*	−.06	.73***	−.44*	.82***	1	
SES	−.12	−.15	−.20*	−.21*	−.15	.20*	−.12	−.01	1

Note: O_{max} = maximum output (expenditure); P_{max} = Price maximum; SES = socioeconomic status, 1 = lowest SES, 2 = middle SES, 3 = highest SES;

* $p \le .05$;

** $p \le .01$;

*** $p \le .001$

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Table 3

Partial Correlations among Reinforcement Metrics and Smoking Measures Controlling for Socioeconomic Status

Measure	Intensity	O_{max}	Elasticity	Breakpoint	P_{max}
Motivation to Change	−.24**	−.13	.15	−.09	−.03
Cigarettes/Day	.26**	.36***	−.24**	.18*	.12
Nicotine Dependence	.22**	.25**	−.20*	.13	.13

Note: O_{max} = maximum output (expenditure); P_{max} = Price maximum; SES = socioeconomic status, 1 = lowest SES, 2 = middle SES, 3 = highest SES, as indexed by school lunch status (full vs. reduced fee vs. free lunch) and full vs. reduced pay tuition status for adolescents attending private school;

* $p \leq .05$;

** $p \leq .01$;

*** $p \leq .001$

Table 4

Differences in the Relative Reinforcing Efficacy Metrics among Adolescents with No Nicotine Dependence (MFTQ = 0–2), Moderate Nicotine Dependence (MFTQ = 3–5) and Substantial Nicotine Dependence (MFTQ = 6–9).

	No Dependence (n = 38)		Moderate Dependence (n = 69)		Substantial Dependence (n = 29)		ANCOVA[1]	
Measure	**Mean**	***SE***	**Mean**	***SE***	**Mean**	***SE***	***F*(134)**	η^2
Intensity	17.03	2.36	22.97	2.03	25.45	2.48	2.81†	.04
O_{max}	7.21	1.25	16.33	5.67	32.09	13.11	4.82**	.07
Elasticity	.028	.004	.025	.006	.014	.003	2.10	.03
Breakpoint	6.95	2.10	8.11	2.88	13.89	5.46	2.54‡	.04
P_{max}	2.87	.95	11.25	5.75	21.57	13.35	1.29	.02

[1]Note: ANCOVAs included socioeconomic status as a covariate.

† p = .06;

‡ p = .08;

** p = .01