Tobacco demand, delay discounting, and smoking topography among smokers with and without psychopathology

Samantha G. Farris[a,b,c], **Elizabeth R. Aston**[d], **Ana M. Abrantes**[a,c], and **Michael J. Zvolensky**[e,f]

[a]Alpert Medical School of Brown University, Department of Psychiatry and Human Behavior, 345 Blackstone Blvd., Providence, RI 02906 USA

[b]The Miriam Hospital, Centers for Behavioral and Preventative Medicine, 164 Summit St., Providence, RI 02906 USA

[c]Butler Hospital, 345 Blackstone Blvd, Providence, RI 02906 USA

[d]Brown University School of Public Health, Center for Alcohol and Addiction Studies, Box G-S121-5, Providence, RI 02912 USA

[e]University of Houston, Department of Psychology, 126 Fred J. Heyne Building, Houston, TX 77204 USA

[f]The University of Texas MD Anderson Cancer Center, Department of Behavioral Science, 1155 Pressler St., Houston, TX 77230 USA

Abstract

Introduction—Tobacco demand (i.e., relative value attributed to a given reinforcer) and delay discounting (i.e., relative preference for smaller immediate rewards over larger delayed rewards) are two behavioral economic processes that are linked to the progression of problematic substance use. These processes have not been studied among those with psychopathology, a vulnerable group of smokers. The current study examined differences in tobacco demand and delay discounting, and their association with smoking topography among smokers with (n=43) and without (n=64) past-year psychopathology.

Method—Adult daily smokers (n = 107, M_{age} = 43.5; SD = 9.7) participated in a study on "smoking behavior." Past-year psychological disorders were assessed via a clinician-administered

Correspondence: Samantha G. Farris, Ph.D., Alpert Medical School of Brown University, Department of Psychiatry and Human Behavior, 345 Blackstone Blvd, Butler Hospital, Providence, RI 02906., samantha_farris@brown.edu, Phone: 401-455-6219, Fax: 401-455-6685.

diagnostic assessment. All subjects participated in an *ad libitum* smoking trial and then completed an assessment of delay discounting (Monetary Choice Questionnaire) and tobacco demand (Cigarette Purchase Task) approximately 45–60 minutes post-smoking.

Results—Smokers with psychopathology, compared to those without, had significantly higher demand intensity and maximum expenditure on tobacco (O_{max}), but did not differ on other demand indices or delay discounting. Smokers with psychopathology had shorter average inter-puff intervals and shorter time to cigarette completion than smokers without psychopathology. Tobacco demand and delay discounting measures were significantly intercorrelated among smokers with psychopathology, but not those without. Both behavioral economic measures were associated with specific aspects of smoking topography in smokers with psychopathology.

Discussion—The association between tobacco demand and delay discounting is evident among smokers with psychopathology and both measures were most consistently related to smoking behavior.

Keywords

cigarette purchase task; delay discounting; smoking topography; relative value; comorbidity

1. Introduction

Despite reductions in the prevalence in smoking over the past fifty years (United States Department of Health and Human Services, 2014), approximately 36.5 million Americans still smoke which is about 15.1% of the US population (Centers for Disease Control and Prevention, 2016). However, the prevalence of smoking among individuals with a psychological disorder is significantly higher (36.1%) than the general population (Centers for Disease Control and Prevention, 2013; Lasser et al., 2000; McClave et al., 2010) and has remained relatively stable at this rate over recent years (Centers for Disease Control and Prevention, 2013). Increased scholarly efforts have focused on understanding factors contributing to the maintenance of smoking and stagnated cessation rates among this vulnerable sub-set of smokers.

One way to study smoking behavior among those with psychopathology is through a behavioral economics framework. Behavioral economics integrates principles from psychology and economics in an effort to analyze key processes involved in decision-making (Camerer, 1999). This framework has been applied to understand substance use behaviors through the "reinforcer pathology" model (Bickel et al., 2014, 2011). Reinforcer pathology comprises the dual effects of two fundamental processes related to the progression of problematic substance use: (a) persistently elevated value attributed to a given reinforcer and/or (b) the excessive preference for obtaining or consuming a given reinforcer immediately despite long-term consequences (Bickel et al., 2014, 2011). This theoretical model posits that individuals with substance use disorders, dependence, or problematic use may regularly attribute high value to a preferred substance while also exhibiting a desire to obtain and use it instantaneously. Two behavioral economic indices allow for objective evaluation of reinforcer pathology: substance demand and delay discounting (DD).

Substance demand pertains to the perceived value of a given substance (Hursh et al., 2005). Cigarette purchase tasks (CPT) are one way to assess demand for tobacco via examination of hypothetical tobacco consumption at a range of prices (MacKillop et al., 2008). These tasks capture related, yet distinct, aspects of tobacco demand including: intensity (amount of tobacco consumed at zero cost), P_{max} (price at maximum expenditure for tobacco), O_{max} (peak expenditure for tobacco), breakpoint (cost whereby tobacco consumption is suppressed to zero), and elasticity of demand (the degree to which consumption decreases with increasing price). Tobacco demand indices appear to be moderately correlated with tobacco dependence and smoking frequency (MacKillop et al., 2008; Murphy et al., 2011), increase in response to acute nicotine deprivation and cue-induced craving (MacKillop et al., 2012), and are associated with lower motivation for smoking cessation (Murphy et al., 2011). Limited work has examined the impact of psychopathology on tobacco demand. Initial studies indicate that elevated depression symptoms and emotional disorders are associated with higher tobacco demand indices, especially under stress (Dahne et al., 2017a) or nicotine-deprived states (Farris et al., 2017). Other work has found that smokers with schizophrenia had higher intensity of demand, relative to healthy controls, when completing a hypothetical CPT under satiated states (MacKillop and Tidey, 2011). Thus, available data, albeit limited, indicates that smokers with various forms of psychopathology may have volumetric differences (e.g., heavy use) in demand.

DD refers to the propensity to discount future rewards over immediate rewards (MacKillop et al., 2011). For example, when asked to choose between a larger, delayed amount of money (e.g., $100 in 6 months) and an immediate smaller amount of money (e.g., $75 today), the rate at which a participant switches from preferring the smaller-sooner reward to a larger-later reward can be plotted as a function of delay (i.e., discount function), with *steeper* DD reflecting greater impulsive behavior. The undervaluation of future rewards (steeper DD) is a key characteristic of problematic health behaviors (Amlung et al., 2017, 2016), including cigarette smoking (Amlung et al., 2017). Additionally, steeper DD has been observed in various psychological disorders, including those characterized by impulsivity (hypomania/mania, attention deficit-hyperactivity disorder), disorders of cognitive or executive dysfunction (e.g., schizophrenia), disorders involving future-focused uncertainty/ fear (e.g., posttraumatic stress disorder, anxiety disorders, borderline personality disorder; Cáceda et al., 2014; Story et al., 2016). Despite the clear documented link between psychological disorders and DD, limited work has examined the nature of DD among smokers with psychological disorders. Self-reported depression has been found to be related to steeper delay discounting in treatment-seeking pregnant female smokers (Yoon et al., 2007) and adolescents (Imhoff et al., 2014), but not in all cases (Weidberg et al., 2015a). In smokers with schizophrenia, DD was not significantly different from healthy controls (MacKillop and Tidey, 2011), although discounting rate appears to be steeper among current and former smokers with schizophrenia relative to never smokers with schizophrenia (Wing et al., 2012). Thus, some data indicate that psychopathology influences DD in smokers.

In the current study, we examined the nature of tobacco demand and DD in smokers with various forms of psychopathology (internalizing and externalizing disorders) versus those without. Despite heterogeneity in disorders, common underlying factors (e.g., high levels of emotional distress, poor coping with negative distress states, difficulties with emotion

regulation) promote and maintain both internalizing and externalizing disorders (e.g., substance use, eating disorders, anxiety disorders, mood disorders; Mennin et al., 2007; Tice et al., 2001). Thus, we aimed to explore these associations among smokers with various forms of psychopathology. Specifically, among non-treatment seeking daily smokers, we examined differences in demand and DD among smokers with and without past-year psychopathology, following approximately 60 minutes of smoking deprivation. This assessment window allowed for the onset of tobacco craving, which can occur within 30 minutes of not smoking (Hendricks et al., 2006). Based on the existing literature, it was hypothesized that smokers with psychopathology would exhibit elevated demand and steeper DD. Additionally, we explored the associations between demand and DD as a function of psychopathology status and their association with smoking topography, a behavioral index of smoking reinforcement.

2. Material and Methods

2.1 Participants

Non-treatment seeking adult daily smokers were recruited for an experimental study on "smoking behavior" (Farris and Zvolensky, 2016). Community-recruited individuals who were between 18–65 years of age, reported smoking 10 or more cigarettes per day for at least one year, and smoked within the first 30 minutes of waking in the morning, were invited for a baseline assessment to determine eligibility for the experimental study (Farris and Zvolensky, 2016). Participants were excluded from participation during an initial telephone screen if they reported frequent drinking (9 standard drinks/week), illicit drug use (3 days/week), unstable medical conditions, or current psychotic symptoms. The current study is a secondary analysis of data from participants who completed the baseline assessment (n = 126), regardless of eligibility for the experimental phase of the study.

2.2 Measures

2.2.1 Demographic Characteristics—Demographic characteristics were assessed via self-report. The *Financial Strain Questionnaire* (Pearlin et al., 1981), which was adapted from an economic strain measure, was used as a proxy for income. The FSQ, is an 8-item self-reported measure that assesses perceived difficulty affording clothes, leisure activities, car, furniture, and other necessities (i.e., medical care, housing). Items that are rated on a scale from 1 to 3 (e.g., "I have enough money", "I have somewhat enough money", "I don't have enough money"). Monetary status at the end of the month is also assessed using a similar scaling (1 = *some money left over*, 3 = *no money left over*). Items are summed to derive a total financial strain index, with higher scores indicating greater strain (possible range 8–24).

2.2.2 Smoking History—The *Smoking History Questionnaire* (SHQ; Brown et al., 2002), a 30-item self-report measure, was used to gather information about smoking history to establish pattern of cigarette use per eligibility criteria (e.g., daily use). A *Carbon Monoxide (CO) Analysis,* using the Vitalograph Breath Co carbon monoxide monitor, was conducted to measure the amount of CO (in parts per million [ppm]) in an expired breath sample. The *Timeline Follow-Back Interview* (Brown et al., 1998) is a calendar-based assessment of

substance use, which was used to document frequency, quantity, and patterns of tobacco use in the past 30 days. The *Fagerström Test for Cigarette Dependence* (Fagerström, 2012), a 6-item scale that assesses gradations in cigarette dependence, was used to assess the level of physiological dependence on tobacco (range 0–10, with higher scores reflecting higher levels of dependence). The FTCD has adequate internal consistency and is associated with biochemical indicators of smoking (Heatherton et al., 1991; Pomerleau et al., 1994)

2.2.3 Psychopathology Assessment—The *Structured Clinical Interview for DSM-IV Disorders-Non-Patient Version* (SCID-I/NP; (First et al., 2007), a clinician-administered semi-structured diagnostic assessment, was used to assess the presence of past-year psychopathology based on the DSM-IV-TR diagnostic guidelines. Diagnostic assessments were conducted by highly-trained post-baccalaureate research assistants. In the current study, all diagnostic assessments were audio-recorded and 100% of cases were supervised for diagnostic accuracy. A random 20% of recordings were subjected to blinded inter-rater reliability review by a doctoral-level clinical psychology graduate student. No cases of diagnostic disagreement were noted.

2.2.4 Tobacco Demand—The *Cigarette Purchase Task* (MacKillop et al., 2008) was used to assess the relative value of tobacco. The CPT is based on progressive-ratio operant schedules wherein participants self-report their cigarette consumption under various levels of price, and has been previously validated (MacKillop et al., 2008; Murphy et al., 2011). A state version of the CPT (Hitsman et al., 2008) was used in the current study. Participants were provided with the following task instructions: "*Imagine that you could smoke RIGHT NOW. The following questions ask how many cigarettes you would consume if they cost various amounts of money. Assume 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 at this time. You cannot save or stockpile cigarettes for a later date. Be sure to consider each price increment carefully.*" The CPT was completed approximately 60 minutes post-smoking, and was administered on the computer where each of the 22 questions/prices were presented one at a time, and read: "*How many cigarettes would you smoke RIGHT NOW if they were: Free [$0/pack], 1¢ each [20¢/pack], 5¢ each [$1/pack], 10¢ each [$2/pack], 20¢ each [$4/pack], 30¢ each [$6/pack], 40¢ each [$8/pack], 50¢ each [$10/pack], 60¢ each [$12/pack], 70¢ each [$14/pack], 80¢ each [$16/pack], 90¢ each [$18/pack], $1 each [$20/pack], $2 each [$40/pack], $3 each [$60/pack], $4 each [$80/pack], $5 each [$100/pack], $6 each [$120/pack], $7 each [$140/pack], $8 each [$160/pack], $9 each [$180/pack], $10 each [$200/pack]?*"

2.2.5 Delay Discounting—The Monetary Choice Questionnaire (Kirby et al., 1999) is a 27-item measure that yields three indices of DD for small, medium, and large-sized rewards. Participants must choose either a smaller, immediate reward (e.g., receive $15 today) or a larger, delayed reward (e.g., receive $35 in 13 days) for each item. To minimize burden while retaining discounting at multiple magnitudes, only the large ($75 – $85) and small ($25 – $35) magnitude items were used in analyses consistent with other studies (MacKillop and Tidey, 2011).

2.2.6 Smoking Topography—The *Clinical Research Support System* (CReSS; Plowshare Technologies, Borgwaldt KC, Inc., Virginia), specifically the portable CReSS pocket device, was used to assess puff topography. The device has a sterilized flow meter mouthpiece that is connected to a pressure transducer, which converts pressure into a digital signal that is sampled at 1,000Hz. CReSS computer software transforms the signal to a flow rate (mL/s), from which puff topography data are computed. The reliability and acceptability of use of the portable CReSS device is well documented (Blank et al., 2009; Perkins et al., 2012), and is recommended over direct observation (Blank et al., 2009). Puff topography data included: puff volume (amount of CO in mL of smoke inhaled), puff duration (time in seconds inhaled during puff), inter-puff interval (time in seconds between successive puffs), number of puffs, and total time spent smoking (minutes). Puff-level data were averaged to create mean scores.

2.3 Procedure

Participants were screened for potential eligibility by telephone, scheduled for an in-person appointment and instructed to bring their usual brand of cigarettes (at least 2 full cigarettes) to the laboratory. Upon arrival, participants provided a carbon monoxide (CO) analysis of expired breath to verify recency of smoking, completed a diagnostic clinical interview and a series of self-report assessments. Next, all participants completed an *ad libitum* smoking trial at a standardized point during the baseline assessment (approximately 90 minutes after arrival to the laboratory). Participants were told they could have a 'smoke break' during which they were oriented to the portable CReSS device and shown how to use it. The experimenter accompanied the participant outdoors, alongside the laboratory, and informed the participant that he/she would have the opportunity to smoke one cigarette using the device. The participant was told to smoke as usual, and was given as much time as desired. Next, the participants returned inside the laboratory and completed approximately 75 minutes of computerized self-report assessments, which were broken up by two scheduled snack/water breaks (no smoking or caffeine was permitted). The MCQ and CPT were completed at approximately 45 minutes and 60 minutes post-smoking (respectively); thus, all participants were in acute nicotine-deprivation. All participants were compensated $25 for completing the baseline assessment.

2.4 Data Analytic Procedures

Calculations of demand indices were obtained using the following methods. Price elasticity values were generated by fitting individual curves in GraphPad Prism using a exponential demand equation (Koffarnus et al., 2015), $Q = Q_0 \times 10^{k(e^{-\alpha Q_0 C}-1)}$, where Q = quantity consumed, Q_0 = derived intensity, k = a constant across individuals that denotes the range of the dependent variable (tobacco cigarettes), C = the cost of the commodity, and α = elasticity or the rate constant determining the rate of decline in consumption based on increases in price (i.e., essential value). This is a modification to a prior (Hursh and Silberberg, 2008) exponential demand equation that does not require eliminating or substituting for consumption values of zero. The appropriate k value was determined by subtracting the log_{10}-transformed average consumption at the highest price ($10.00) from the log_{10}-transformed average consumption at the lowest price used in curve fitting ($0.01). The k value used in analyses was 1.743. An R^2 value was generated to reflect percentage of

variance accounted for by the demand equation (i.e., the adequacy of the fit of the model to the data).

Data cleaning procedures were completed consistent with standard recommendations (Stein et al., 2015). Raw CPT data were examined for outliers using standard scores, with a criterion of $Z = 3.29$ to retain maximum data. A small number of outliers were detected (1.2%). The outliers were determined to be legitimate high-magnitude values and were recoded as one unit higher than the next lowest non-outlying value between subjects within a single price (Tabachnick and Fidell, 2000). Observed values for intensity, O_{max}, P_{max}, and breakpoint were estimated by directly examining CPT performance. Elasticity of demand was empirically derived using values generated from an exponentiated demand curve model.

Procedures outlined (Kirby, 2000) were used to infer values of the hyperbolic discount parameter (k) from a subject's choices between immediate and delayed rewards. Consistency values were generated for each subjects' k parameter to index the percentage of the participants' choices that did not contradict the discounting function. Only the small and large reward magnitude items were used in this study to maintain consistently with previous work (MacKillop and Tidey, 2011).

All data were examined for distribution normality using histograms. All tobacco demand and MCQ variables were non-normally distributed. A square root transformation was used for intensity, $\log_{10}$ transformation was used for O_{max}, and cube root transformation was used for P_{max}, breakpoint, and elasticity. A square root transformation was used for k values (small, large) on the MCQ. Puff volume, duration, and inter-puff Interval were also non-normally distributed. Puff volume and duration were square-root transformed, and inter-puff interval was log-transformed and then cubic transformed. These transformations were successful in normalizing the data. All transformations improved the distribution substantially.

Primary analyses examined the demand curve indices, k values, and smoking topography by smokers with and without psychopathology. Analysis of covariance (ANCOVA) was used. Any between-group differences on demographic characteristics were entered as covarying factors, consistent with prior work (MacKillop and Tidey, 2011). Next, bivariate zero-order correlations were used to examine the associations between demand curve indices, k values, and smoking topography. The correlations were stratified by psychopathology status to examine the unique associations between indices as a function of psychopathology. Significance was defined as $\alpha < .05$ for descriptive analyses. Demand curve modeling was conducted using GraphPad Prism 7 and all other analyses were conducted using SPSS 23.0.

3. Results

Of the 126 cases, 11 showed evidence of inconsistent responding across prices on the CPT (i.e., had 3 reversals), and 4 cases exhibited constant demand, suggesting low effort during this task. Additionally, 6 cases had low consistency on the MCQ (k .778) and 2 cases were missing smoking topography data due to equipment malfunction. This results in 19 excluded cases from analyses. The modified exponential demand equation (Koffarnus et al., 2015)

provided an excellent fit to the CPT data (R^2 = .972) and a good fit to the individual data (median R^2 = .847, interquartile range = .763 – .904).

3.1 Sample Characteristics

Participants (n = 107; M_{age} = 43.5; SD = 9.7; 43.9% female) identified race as Black/ African-American (58.9%), white (33.6%), American Indian/Alaska Native (1.9%), Asian (0.9%), or other (4.7%), and 5.6% of participants identified ethnicity as Hispanic. Marital status was reported as: never married (49.5%), divorced/separated (34.5%), married/co-habitating (11.2%), and widowed (4.7%). Approximately half of the sample completed at least some college (57.0%). Employment status was reported as unemployed (39.3%), employed full time (25.2%), employed part time (23.4%), student (3.7%), disabled (7.5%), and retired (0.9%). On average, elevated financial strain was reported (M = 17.2, SD = 5.03).

Smokers with past-year psychopathology (n = 43; 40.2%) met criteria for the following disorders (range 1–4 diagnoses): posttraumatic stress disorder (30.2%), major depressive disorder (23.3%), specific phobia (20.9%), alcohol use disorder (16.3%), social anxiety disorder (16.3%), dysthymic disorder (11.6%), panic disorder with/without agoraphobia (9.3%), cannabis use disorder (9.3%), eating disorder (7.0%), generalized anxiety disorder (4.7%), bipolar disorder I (4.7%), bipolar disorder II (4.7%), obsessive-compulsive disorder (2.3%), psychotic disorder (2.3%), sedative use disorder (2.3%).

3.2 Group Differences

See Table 1 for comparison of demographic and smoking characteristics by smokers with and without psychopathology. Smokers with psychopathology reported significantly greater economic strain (per the FSQ), however did not differ in terms of other demographic characteristics. Regarding smoking behavior, there were no group differences in cigarettes/ day, level of tobacco dependence, or use of menthol cigarettes. However, smokers with psychopathology had significantly shorter inter-puff intervals and smoked more quickly, indicated by total time spent smoking, relative to smokers without psychopathology.

Untransformed indices of CPT and MCQ are presented in Table 2 by psychopathology status. Results indicated that, while covarying for economic strain (FSQ scores), there was a significant difference in demand intensity and O_{max}. Specifically, smokers with psychopathology had significantly higher consumption when price was unrestricted (intensity) and were willing to expend a significantly higher maximum amount of money for cigarettes (O_{max}). See Figure 1 for mean consumption and expenditure by psychopathology status on the CPT. There were no observed group differences in discounting of delayed rewards on the MCQ.

3.3 Exploratory Correlational Analyses

To characterize overlap among demand, delayed discounting, and smoking topography, a correlation matrix stratified by psychopathology status is presented in Table 3.

3.3.1 Smokers without Psychopathology—Among smokers without psychopathology (n=64), tobacco demand and DD indices were not significantly related. Demand intensity

was significantly negatively correlated with inter-puff interval ($r_{[62]} = -.25$, $p = .046$) and positively correlated with number of puffs at a trend level ($r = .24_{[62]}$, $p = .059$). Additionally, O_{max} was significantly positively correlated with number of puffs ($r_{[62]} = .26$, $p = .035$). After controlling for FTND scores, the correlations between demand intensity with inter-puff interval ($r_{[61]} = -.19$, $p = .137$) and number of puffs ($r_{[61]} = .20$, $p = .124$) were non-significant, and the correlation between O_{max} and number of puffs approached significance ($r_{[61]} = .23$, $p = .067$).

3.3.2 Smokers with Psychopathology—Among smokers with psychopathology (n=43), there were several observed significant associations between demand and DD indices. Specifically, O_{max}, P_{max}, and breakpoint were significantly positively correlated with large k, indicating steeper DD (large delayed rewards). After controlling for FTND, all correlations remained significant: O_{max} ($r_{[40]} = .35$, $p = .024$); P_{max} ($r_{[40]} = .37$, $p = .017$); and breakpoint ($r_{[40]} = .37$, $p = .017$). Additionally, P_{max} was positively correlated with small k, reflecting steeper discounting of small delayed rewards, which was significant at a trend level ($r_{[41]} = .28$, $p = .074$; $r_{[40]} = .28$, $p = .073$). Demand indices were significantly correlated with smoking topography indices. O_{max}, P_{max}, breakpoint were significantly negatively associated with inter-puff interval and elasticity was significantly positively associated with inter-puff interval. These correlations remained significant after controlling for FTND scores: O_{max} ($r_{[40]} = -.33$, $p = .031$); P_{max} ($r_{[40]} = -.33$, $p = .034$); breakpoint ($r_{[40]} = -.40$, $p = .009$); elasticity ($r_{[40]} = .34$, $p = .030$). O_{max}, P_{max}, breakpoint were also significantly negatively associated with time spent smoking and elasticity was significantly positively associated with time spent smoking. These associations remained significant after controlling for FTND scores: O_{max} ($r_{[40]} = -.34$, $p = .030$); P_{max} ($r_{[40]} = -.32$, $p = .042$); breakpoint ($r_{[40]} = -.39$, $p = .011$); and elasticity approached significance ($r_{[40]} = .30$, $p = .051$). In addition, small k was significantly negatively correlated with number of puffs ($r_{[41]} = -.37$, $p = .014$; $r_{[40]} = -.39$, $p = .010$).

4. Discussion

Among community-recruited daily smokers, two indices of tobacco demand were significantly higher among smokers with psychopathology versus those without: demand intensity (hypothetical tobacco consumption when price is unrestricted) and O_{max} (peak expenditure for tobacco). No group differences were evident in P_{max}, breakpoint, or elasticity. These findings provide unique evidence that smokers with psychopathology in nicotine-deprived states have greater *amplitude* of tobacco demand (i.e., value of greater amounts of tobacco) relative to smokers without psychopathology, but not *persistence* of demand (Bidwell et al., 2012; O'Connor et al., 2016), which compliments prior work in depression and serious mental illness that examine demand under stress-induced and nicotine-sated states (Dahne et al., 2017b; MacKillop and Tidey, 2011). Additionally, contrary to our hypothesis, DD did not significantly differ in smokers with and without psychopathology. Similar non-significant differences have been noted among smokers with and without with self-reported depression (Weidberg et al., 2015a) or schizophrenia (MacKillop and Tidey, 2011), although other studies have reported steeper DD in smokers with self-reported depression versus smokers without (Imhoff et al., 2014; Yoon et al.,

2007). Inconsistencies in this literature may be related to method variance (e.g., self-reported versus diagnostic assessment of psychopathology). More research in smokers is warranted to better understand how psychopathology may impact DD, given evidence of steeper (impulsive) DD in various forms of psychopathology (Cáceda et al., 2014; Story et al., 2016). Alternative forms of discounting (e.g., excessive probability discounting) should also be explored to better understand the nature of immediate tobacco preference despite known long-term consequences.

Significant associations between demand indices and DD were only evident in smokers with psychopathology. Specifically, in those with psychopathology, three demand indices (O_{max}, P_{max}, and breakpoint) were positively associated with greater impulsive DD (large rewards). Moreover, in smokers with psychopathology, demand indices (O_{max}, P_{max}, breakpoint, inelasticity) were negatively associated with smoking topography (inter-puff interval and time spent smoking) and DD (small rewards) was also negatively associated with puff count. These effects were significant after adjusting for level of tobacco dependence. In contrast, in smokers without psychopathology, demand intensity and O_{max} were significantly negatively inter-puff interval and puff count, respectively, although these effects were non-significant after adjusting for level of tobacco dependence. Moreover, DD was not associated with smoking topography. Overall, the patterning in findings suggest that among smokers with psychopathology: (a) higher demand and DD are significantly inter-related; (b) tobacco demand is associated with actual tobacco consumption, and (c) steeper DD (persistent preference for small-sooner reward) is associated with lower tobacco consumption, although finding warrants replication especially considering the non-significant associations between discounting of large delayed rewards.

There are several limitations to address. First, all data were cross-sectional, therefore, it is unknown whether demand and DD causally contribute to smoking topography. Second, we assessed past-year psychopathology, and as a result, the lifetime disorders that naturally remitted or were successfully treated were not captured. Additionally, it is possible certain disorder-specific effects were undetectable based evaluation of psychological disorders as one group. It should be noted that internalizing disorders were more heavily represented than externalizing disorders in the sample, likely a result of the initial telephone screening procedures. Third, the sample size was small and consequently did not permit examination of demand and DD across specific psychological disorders, which may limit the specificity of the current findings based on the heterogeneity of disorders. It is possible that certain disorder-specific effects were undetectable in the current study based on the grouping of all psychological disorders into one group. Fourth, we excluded data from the CPT where participants displayed 3 reversals (n =11) and data from the MCQ where *k* consistency was .778 (n=6), potentially reflecting invalid responding. Reversals may have occurred from misunderstanding directions, limited cognitive functioning, or may be an artifact based on administration of the CPT and MCQ: items were presented one at a time rather than all at once.

Taken together, the reinforcer pathology model (Bickel et al., 2014) may be particularly relevant to the maintenance of smoking in those with psychopathology, especially in the context of nicotine-deprivation. Higher demand and steeper DD are related to poorer

substance use treatment outcomes (MacKillop and Kahler, 2009; MacKillop and Murphy, 2007), yet are malleable in treatment. For example, interventions that enhance future time orientation (Sheffer et al., 2016) and present-focused attention/mindfulness (Ashe et al., 2015) or provide contingent reinforcement (Weidberg et al., 2015b) appear to reduce DD. Additionally, brief motivational (Dennhardt et al., 2015) or personalized feedback interventions (Murphy et al., 2015) reduce the rewarding value of substances. Smokers with psychopathology may benefit from pre-cessation intervention that specifically targets (reduce) tobacco demand and DD, whereby increasing ability to manage withdrawal-induced urge and craving to tobacco that onset following a quit attempt. More work is needed to understand aspects of demand and DD, and their interplay in smokers with *specific* forms of psychopathology, to inform their influence on tobacco consumption, motivational factors for continued use, and cessation behavior.

Acknowledgments

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Highlights

- Smokers with psychopathology versus without had significantly higher tobacco demand

- There were no differences in delay discounting by psychopathology status

- Tobacco demand and DD were intercorrelated only in smokers with psychopathology

- The reinforcer pathology framework may apply to the psychopathology-smoking link
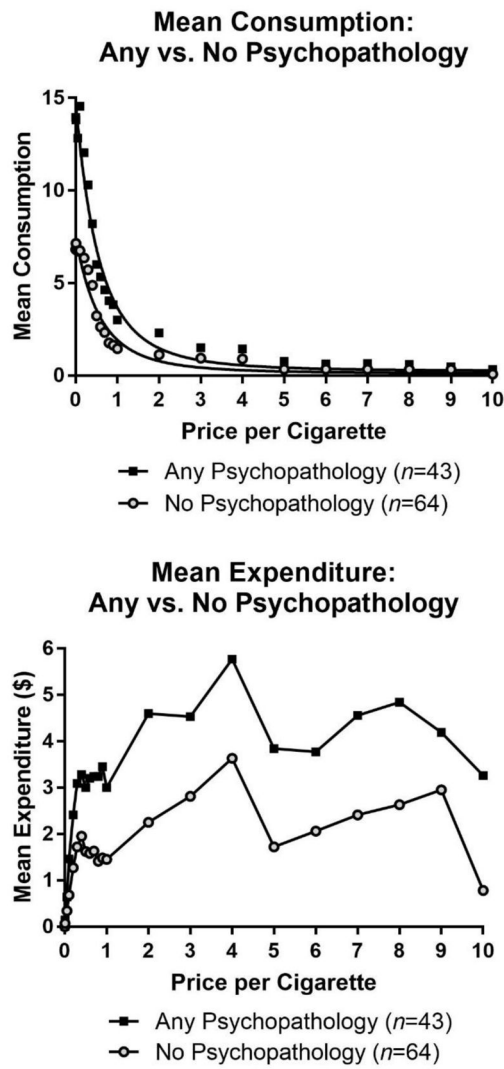
Figure 1.
Mean Consumption and Expenditure stratified by Psychopathology status

Table 1

Characteristics of smokers with and without psychopathology

	Any Psychopathology(n=43)	No Psychopathology(n=64)		
	M (SD)n (%)	M (SD)n (%)	t, x^2	p
Sex (female)	20 (46.5%)	57 (42.2%)	.195	.659
Age	42.42 (10.18)	44.27 (9.45)	0.96	.339
Race (black)	26 (60.5%)	37 (57.8%)	0.08	.785
Education (part college)	26 (60.5%)	35 (54.7%)	0.35	.554
Financial strain (FSQ)	18.65 (4.64)	16.23 (5.08)	−2.50	.014 [*]
Menthol Cig (yes)	27 (62.8%)	37 (57.8%)	0.27	.607
Cigs/day	15.06 (7.01)	14.84 (5.47)	−0.17	.863
Tobacco dependence (FTCD)	4.79 (1.57)	4.63 (1.45)	−0.56	.576
Puff Volume (mL)	65.54 (24.29)	63.18 (24.35)	−0.50	.620
Puff Duration (sec)	1.79 (0.69)	1.76 (0.60)	−0.037	.971
Inter-Puff Interval (sec)	11.55 (4.85)	14.33 (5.39)	2.73	.007 [**]
Time/Smoking (min:sec)	4:28 (1:30)	5:15 (1:17)	2.90	.005 [**]
Puff/number	20.53 (6.93)	20.42 (7.38)	−0.08	.937

[*] $p < .05$;

[**] $p < .01$

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Table 2

Behavioral economic measures by psychopathology status

| | Any Psychopathology(n=43) | | No Psychopathology(n=64) | | | |
	M	SEM	M	SEM	F	p
Intensity	13.73	2.02	6.96	1.64	6.80	.023 *
O_{max}	11.75	2.65	5.75	2.16	5.10	.026 *
P_{max}	2.22	0.41	1.50	0.33	1.44	.233
Breakpoint	2.71	0.46	2.30	0.38	1.02	.314
Elasticity	0.24	0.14	0.43	0.11	2.46	.120
Small k	0.07	0.01	0.09	0.01	1.32	.253
Large k	0.04	0.01	0.06	0.01	1.05	.309

*
$p < .05$;

**
$p < .01$;

non-transformed adjusted means are presented controlling for FSQ

Table 3

Correlations between behavioral economic measures and smoking topography by psychopathology status

	Intensity	O_{max}	P_{max}	Breakpoint	Elasticity	DD Small	DD large	Puff Volume	Puff Duration	IPI	Time Smoke	# of Puffs
Intensity	--	.589**	.119	.276†	-.431**	-.105	-.156	-.200	-.160	-.250*	-.032	.237†
O_{max}	.681**	--	.683**	.727**	-.715**	.035	-.004	-.149	-.175	-.205	-.002	.264*
P_{max}	.224†	.700**	--	.927**	-.584**	.061	.039	.021	.014	-.071	-.025	.079
Breakpoint	.306*	.746**	.777**	--	-.636**	.034	.009	.031	.076	.030	-.009	-.082
Elasticity	-.322**	-.769**	-.415**	-.535**	--	.029	-.005	.089	.152	.105	.070	-.127
DD Small k	.098	.157	.275†	.207	-.059	--	.757**	.077	-.089	-.015	-.114	.068
DD large k	.148	.351*	.364*	.368*	-.221	.754**	--	.022	-.040	.138	-.059	-.099
Puff Volume	.144	-.040	-.066	-.033	.083	-.115	-.020	--	.730**	.166	-.235†	-.399**
Puff Duration	-.045	-.246	-.061	-.099	.241	.227	.227	.594**	--	.167	-.244†	-.478**
IPI	.001	-.337*	-.326*	-.399**	.335*	.109	-.124	.254	.463**	--	.462**	-.706**
Time Smoke	.013	-.316*	-.316*	-.385*	.302*	-.040	-.166	.258†	.274†	.687**	--	.221†
# of Puffs	.002	.092	.071	.106	-.140	-.371*	-.192	-.079	-.431**	-.507**	.149	--

Note: Above diagonal = smokers without psychopathology; Below diagonal = smokers with psychopathology; bolded values reflect significant associations between CPT, MCQ, and Topography.

†
 $p < .10$

*
 $p < .05$;

**
 $p < .01$