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Persistence and amplitude of cigarette demand in relation to quit intentions and attempts

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Abstract

INTRODUCTION—The cigarette purchase task (CPT) is a method that can be used to assess relative value of cigarettes. Based on cigarettes purchased across a price range, five derived metrics (Omax, Pmax, breakpoint, intensity, elasticity) can assess cigarette demand. A study with adolescent smokers found that these could be reduced to two latent factors: Persistence (price insensitivity) and Amplitude (volumetric consumption). We sought to replicate this structure with adult smokers, and examine how these variables relate to cessation efforts.

METHOD—Web-based survey conducted in 2014 among adult (18+) current daily cigarette smokers (N=1194). Participants completed the CPT, Fagerstrom Test for Nicotine Dependence (FTND), reported past-year quit attempts, and future quit intentions. We included published scales assessing perceived prevalence of smoking, social reactivity, smoker identity, and risk perception.

RESULTS—Our analysis supported two latent variables, Persistence and Amplitude, which correlated positively with FTND. Persistence correlated with several psychosocial factors, and was higher among those intending to quit very soon, but did not vary by number of past-year quit attempts. Amplitude differed across quit attempts and intention (p's <.001), and in multivariable models was significantly associated with lower 30-day quit intention [OR=0.76, p=.001].

CONCLUSIONS—Persistence and Amplitude factors characterized CPT data in adults, discriminated known groups (e.g., smokers by intentions to quit), and were positively associated with nicotine dependence. Factor scores also appear to relate to certain psychosocial factors, such as smoker identity and perceptions of risk. Future research should examine the predictive validity of these constructs.

COMPETING INTERESTS. The authors report no competing interests.

Introduction

Behavioral economists have developed objective behavioral tasks that assess the relative reinforcement value of commodities, termed demand (Bickel et al. 2011). Specific to substance use, purchase tasks quantify participants' drug consumption across varying levels of cost (Jacobs and Bickel 1999; MacKillop et al. 2008; Murphy and MacKillop 2006; Murphy et al. 2009; Murphy et al. 2011a). These responses contribute to multidimensional demand indices of consumption, expenditure, and price sensitivity (Mackillop et al. 2009). Elevated demand is associated with higher levels of dependence on alcohol and nicotine (MacKillop et al. 2010; Murphy et al. 2011a). Greater demand in purchase tasks appears to be associated with treatment failure for both alcohol (MacKillop and Murphy 2007; Murphy et al. 2015) and smoking (Mackillop et al. 2015). Others have extended the measure to assess demand for marijuana, and have provided evidence for predictive validity of purchase tasks on later marijuana use (Collins et al. 2014). Additionally, cigarette demand is increased through experimental manipulation of acute nicotine deprivation (MacKillop et al. 2012). Thus, demand may serve as an important motivational process that underlies cessation failure (Heckman 2014).

The cigarette purchase task (CPT) and its variants have been used to assess the impact of different smoking cessation interventions on demand for cigarettes (Mackillop et al. 2015; Madden and Kalman 2010; McClure et al. 2013; Schlienz et al. 2014), compare differences in cigarette dependence across mental health status (MacKillop and Tidey 2011), and to examine propensity to initiate or quit smoking (Murphy et al. 2011b). Five indices are typically derived from these measures (Murphy et al. 2011b): Breakpoint (the price where consumption goes to zero); Pmax (the price at which expenditure is maximized); Omax (maximum expenditure); Intensity (maximal consumption, typically at zero price); and Elasticity. Elasticity is typically modeled using an exponential equation, with consumption a declining function of increasing price (Hursh and Silberberg 2008). In general, demand has been associated with nicotine dependence, but observed inconsistency regarding the 5 indices calls into question which of these indices is most relevant. A parsimonious approach that reduces these indices into underlying latent factors may improve predictive utility. The five metrics are conceptually related, but two studies examining demand for cigarettes and alcohol have shown they can be reduced to two latent factors representing Persistence (i.e., maintaining consumption in the face of increasing price) and Amplitude (maximal level of use), with Omax loading on both factors (Bidwell et al. 2012; Mackillop et al. 2009). Persistence and Amplitude were shown to correlate positively with FTND, a measure of nicotine dependence, and inversely with motivation to quit smoking, but were not associated with longest abstinence from smoking (Bidwell et al. 2012). However, Persistence and Amplitude accounted for relatively low proportions of variance in FTND and motivation to quit, suggesting that other factors contribute substantially to smoking behaviors.

This latent structure implies that Persistence and Amplitude should correlate with psychosocial factors associated with addiction. For smokers, some of these psychosocial characteristics may include social reactivity, smoking identity, and normative beliefs about smoking behaviors. Smokers, particularly adolescent smokers, have higher social reactivity (e.g., rebelliousness) (Klabbers et al. 2009), which may relate to impulsiveness and other

elements known to be associated with nicotine dependence. Those individuals who indicate a strong personal identity as smokers may be more protective of their consumption, and less likely to quit (Tombor et al. 2013). Similarly, those who perceive smoking as a normative behavior may also be resistant to change (Dohnke et al. 2011; Hitchman et al. 2014). And, finally, smokers who perceive fewer health risks associated with tobacco use are less likely to make quit attempts (Costello et al. 2012; Savoy et al. 2014). Home smoking restrictions are also shown to relate to smoking cessation, often serving as an intermediate step (Borland et al. 2006; Hyland et al. 2009; Mills et al. 2009). Voluntarily placing an environmental restriction on behavior might indicate greater ability to regulate use, which may translate as lower price sensitivity. Examining whether latent factors that may underlie demand measures are also related to these smoking-associated psychosocial variables, and whether the latent demand characteristics add value in multivariable models of quitting behavior, is worthwhile. There is a need to see if demand measures capture the same or unique variance compared to psychosocial variables, which could reduce the total number of measures needed, or alternatively, indicate that more comprehensive assessment batteries are required.

The current study sought to 1) replicate the Bidwell et al. (2012) findings of a two-factor latent structure for a CPT administered to a web-based sample of adult smokers, and 2) examine the relationship of Persistence and Amplitude of cigarette demand to quitting behavior, controlling for other behavioral indicators and self-reported measures of tobacco dependence and related psychosocial factors.

Methods

Survey

A web-based survey designed to explore factors related to perceptions of health warnings and claims in snus advertisements was conducted in May 2014. Participants (N=3001, aged 15+) were drawn from existing web panels (GMI/Lightspeed) via email invitation. GMI/Lightspeed is a marketing research firm with access to pre-enrolled panels who complete various consumer-oriented surveys, with defined sociodemographic characteristics (including smoking status). For our research, we set minimum targets on accrual for age (at least 500 under 18) and smoking status (at least 25% smokers). Panel membership involves a double opt-in process where interested persons complete an online registration form and activate their account by email reply. After reviewing the risks, benefits, compensation, and confidentiality involved in the study, participants provided informed consent. Participants were compensated with 60 GMI "marketpoints" for completing the survey (approx US $3). Data here focus only on adult (18+) current daily cigarette smokers from that sample (N=1194). Questionnaire measures included the FTND (Heatherton et al. 1991), quit attempts (*In the last year, how many times have you quit smoking for at least 24 hours?*), and intentions (*Are you seriously thinking of quitting smoking?* – Yes, in the next 30 days; Yes, in the next 6 months; No). We also included previously published scales assessing perceived prevalence of smoking, social reactivity (Klabbers et al. 2009), smoker identity (van den Putte et al. 2009), and perceived risk of smoking related diseases (Hatsukami et al. 2015). Five items assessing beliefs about health risks of using unfiltered, natural, light, ultralight, and full flavored cigarettes (each assessed on a 1–10 scale) was summed to create a cigarette

harm scale (Cronbach's alpha = 0.93). The study protocol was reviewed and approved by the Roswell Park Cancer Institute Institutional Review Board.

Cigarette demand assessment

Participants completed an abbreviated CPT, with 12 possible price points ($0, $0.01, $0.05, $0.13, $0.25, $1, $2, $3, $4, $5, $6, $11) per cigarette of their usual brand. The CPT requires the participant to imagine they have no access to any other cigarettes, and to report how many cigarettes they would smoke over 24 hours if they were available at the various prices. Elasticity values were derived by fitting individual curves using Prism (Graphpad), using a modified exponential demand equation (Koffarnus et al. 2015): $Q = Q_0 * 10^{k(e^{-\alpha Q_0 C} - 1)}$. This is a modification to the Hursh and Silberburg (2008) exponential demand equation that does not require eliminating, or substituting for, consumption values of zero. A fixed value of k=1.032 was applied across analyses, determined as the difference between the log of mean consumption at the highest price ($11) and the log of mean consumption at the lowest modeled price ($0.01) (Koffarnus et al. 2015). Q0 was fitted as a free parameter. In 131 cases, participants reported the same level of consumption across the range of prices, which results in extremely low (1×10^{-19}) alpha values. As the reported levels were plausible given the price range, rather than drop these cases (Stein et al. 2015), we recoded alpha as 1×10^{-6}, such that they remained lower than the lowest modeled value (2.6×10^{-6}). The remaining demand indices were empirically derived from the observed CPT responses (BP = price at which consumption goes to 0; Pmax = price at maximum consumption; Omax = highest observed expenditure). For participants who did not achieve a breakpoint within the range of prices, BP was set to equal $35 (the next price that would have appeared sequentially in the MacKillop et al 2008 purchase task). Additionally, we derived new estimates of essential value, Omax and Pmax, proposed by Hursh (Hursh 2014a; b) based on the exponential demand equation, using an Excel calculator (Kaplan and Reed 2014). Consistent with prior work (O'Connor et al. 2014), we excluded cases where $R^2 < .30$ for the exponential demand model. Accounting for exclusions per the above criteria, the final analytic sample was N=1114.

Factor analysis

Principal components extraction, followed by Oblimin rotation with a specified two factor solution to replicate earlier findings was employed (Bidwell et al. 2012). A two-factor solution was confirmed by parallel analysis (O'Connor 2000). The entered variables were breakpoint, observed Pmax, observed Omax, observed intensity, and 1/elasticity (Model 1). The latter three variables were $\log_{10}$ transformed for analysis to meet normality assumptions. Factor scores were derived by the regression method, such that the scores on each have mean 0 and SD of 1. We then repeated this analysis using the Kaplan and Reed (2014) calculations of Omax, Pmax, and essential value (Model 2); these values were all $\log_{10}$ transformed for factor analysis. All analyses were conducted using SPSS 21.0 (IBM, Armonk, NY).

Dependence and Psychosocial relationships

Correlations and analysis of variance (with Dunnet post-hoc test) were used to assess relationships between demand measures and psychosocial variables putatively related to

smoking behavior and dependence. Multivariate simultaneous logistic regression was used to examine correlates of quit intentions and attempts. All analyses were conducted using SPSS 21.0 (IBM, Armonk, NY).

Results

The analytic sample was 54.5% female and 75.9% non-Hispanic white. Younger adults (18–34) comprised 42% of the sample, compared to 38% aged 35–49, and 20% aged 50 or greater. Considering quit attempts, 43% reported none in the past year, 33% reported 1 or 2 attempts, while 24% reported three or more. Nineteen percent of respondents reported an intention to quit within the next 30 days, while 42% reported an intention in the next 6 months.

Factor analysis

The factor analysis largely replicated the pattern matrix reported by Bidwell et al., 2012. Two factors were extracted -- Persistence and Amplitude. Factor loadings and mean scores are presented in Table 1. The extracted factors combined to explain 87% of variance. The factor patterns did not appear to differ dramatically when using the observed versus the modeled versions of Omax and Pmax, though there appeared to be more cross loading with the modeled parameters. Persistence (r=.89) and Amplitude (r=.96) scores under both models were strongly correlated. We use the Model 2-derived versions for subsequent analyses to reflect the most current recommended methods for estimating essential value, Omax, and Pmax.

Association of Persistence and Amplitude with dependence and smoking pattern

We saw no difference in either Persistence or Amplitude by sex, age, or race. Both Persistence ($r = .11$; $p<.001$) and Amplitude ($r = .29$; $p<.001$) correlated positively with FTND. (Note, Table 1 shows the correlations of each of the component items with FTND scores to facilitate comparisons to prior research). Table 2 outlines the relationships between Persistence and Amplitude with quitting and home policy measures. Those with no smoking restrictions showed the highest levels of Persistence and Amplitude compared to those with any restriction, with scores generally decreasing with increasing restriction. Persistence did not differ by number of past-year quit attempts (p=.972), but did differ significantly across levels of intention to quit in the future (p=.025). Persistence was highest among those intending to quit very soon, and lowest among those planning to quit in the next 6 months. Amplitude differed across both attempts (p=.006) and intention (p=.033). Those who had made three or more attempts in the past year had substantially lower Amplitude scores than those with fewer attempts. Amplitude was lowest among those with more immediate quit intentions, and highest among those with no intention to quit smoking.

Bivariate Associations of Persistence and Amplitude with psychosocial factors

Higher persistence was associated with lower scores on social reactivity ($r = -0.07$, p=.018) and health risks of cigarette types ($r = -0.09$, p=.002). Higher Persistence was positively associated with greater smoker identity ($r = 0.11$, $p<.001$) and perceived smoking prevalence ($r = 0.10$, p=.002). When sex, age, race, and FTND score were partialed out, we still see

significant correlations between Persistence and smoker identity (r_p=0.09, p=.002), perceived prevalence (r_p=0.07, p=.027), and cigarette risks (r_p=−0.09, p=.005). Amplitude was bivariately associated with lower perceived cigarette health risks (r = −0.10, p=.001), and this remained significant when adjusted for demographics and dependence (r_p = −0.09, p=.004).

Multivariable associations with quit intentions and attempts

Results are shown in Table 3. Relative to no intention to quit, increased Amplitude was significantly associated with lower intent to quit in the next 30 days [OR=0.76, p=.003], but was not associated with six month intention [OR = 0.91, p=.23]. Smoker identity and social reactivity were inversely related to 30-day intention, while perceived prevalence and cigarette health risks were all positively associated with 30-day intention. Indoor smoking policy did not seem to be associated with quit intentions. Smoker identity was strongly associated with 6-month intention to quit, with stronger identity associated with lower intention to quit (OR=0.49, p<.001). Perceived prevalence of smoking was positively associated with 6 month intention.

Neither Persistence nor Amplitude was associated with having made quit attempts (either 1–2 or 3+) adjusting for other factors. Smoker identity was inversely associated, while perceived prevalence was positively associated, with having made 1–2 or 3+ quit attempts. Smoker identity and social reactivity were associated with lower likelihood of having made 3 or more quit attempts.

Discussion

Overall, results of this study are highly consistent with previous reports finding two latent factors underlying demand measures derived from purchase tasks for cigarettes and alcohol (Bidwell et al. 2012; Mackillop et al. 2009). Factor scores discriminated on quit history and current intentions to quit, and were positively associated with nicotine dependence scores, providing evidence of concurrent validity. The correlation between FTND and Amplitude is stronger here than in analyses reported by Bidwell and colleagues, perhaps because the current sample included adult smokers whose smoking behavior was presumably more established. The factor model also holds whether we examined observed values for Pmax and Omax or values derived from the exponential demand equation (Hursh 2014a; Kaplan and Reed 2014), suggesting that the underlying concept is fundamentally sound.

Psychosocial variables are often not considered in the behavioral economics literature. The current study, attempting to integrate perspectives on nicotine dependence, examined the relationship of Persistence and Amplitude of cigarette demand to psychosocial measures associated with smoking. We found that Persistence in particular was associated with a number of measures, including social reactivity, smoker identity, and perceived risk. Though effects were small in magnitude, those who show greater Persistence self-identified more as smokers more strongly, perceived greater smoking prevalence in the population, were less apt to perceive cigarettes as dangerous, and perceived themselves at less at risk of developing smoking related diseases. However, when controlling for demographic factors and dependence, these relationships were attenuated, suggesting that they share common

variance. Persistence, then, may be a behavioral reflection of attitudes and beliefs that relate to (or are a consequence of) nicotine dependence. It is equally possible, given the cross-sectional nature of these data, that dependence is a manifestation of persistent demand. Persistence had a nonlinear relationship with quit intention, with the lowest scores observed for those planning to quit in the next six months, relative to those with more immediate (30 day) or no intention. This may reflect an internal recognition of dependence -- those with a strong drive to continue smoking despite increased cost (i.e., greater Persistence) may also have a strong desire to quit (even if those quit attempts may be unsuccessful), while those with a less manifest drive may recognize a value in quitting, but defer that goal to a later time. Amplitude did show an independent relationship with short-term quit intention, with higher Amplitude scores associated with lower intention. Amplitude was also associated with lower likelihood of having made a high number of past-year quit attempts. This is consistent with other literature on the predictive validity of the Heaviness of Smoking index (which largely captures consumption) for smoking cessation (Borland et al. 2010; Kozlowski et al. 1994; Yong et al. 2014). An important next step is to examine prospectively whether demand has the same pattern: predicts quit outcomes over the short term (weeks) but has less predictive power over the longer term (months or years).

The data highlight smokers' struggles to balance a desire to quit against the reward value of smoking. This suggests the need to replace this reinforcing value if quitting is to be successful (e.g., alternative nicotine sources or rewards). A recent study shows that, in the context of contingency management, high indices of demand predicted smoking behavior when abstinence was not incentivized (Mackillop et al. 2015), suggesting that monetarily reinforced abstinence could overcome the reinforcement value of cigarettes. However, the current study indicates that addressing psychosocial factors such as smoker identity and misperceptions of risk may be as important to supporting cessation intentions and attempts. This provides further support for more comprehensive cessation interventions that address both dependence on nicotine (e.g., medication, alternative reinforcers) and conditions that hamper attempts to quit (e.g., cognitive behavioral therapy, public education). Future research should examine the predictive validity of these measures when assessed longitudinally–testing if demand metrics perform better as predictors of behavioral outcomes (i.e., quit attempt initiation, quit success), or as mediators between established predictors of behavioral outcomes. Similarly, further research on the interrelationship of measures of demand and psychosocial factors related to dependence could help elucidate targets for intervention. These findings support applications of the CPT in clinical as well as research settings as a tool for the assessment of smoker's valuation of cigarettes.

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Table 1

Mean values for the metrics derived from the demand curve and their associated latent factor loadings.

	Mean	Correlation with FTND	Model 1		Model 2	
			EV = 3.05 % Var =60.9	**EV = 1.11 % Var = 22.2**	**EV = 3.32 % Var = 66.4**	**EV = 1.07 % Var = 21.3**
	95% CI		**Persistence**	**Amplitude**	**Persistence**	**Amplitude**
Intensity	16.61 [a] (15.75, 17.51)	0.28 [c]	−.031	.988	−.005	.983
Breakpoint	18.6 (17.7, 19.4)	0.15 [c]	.897	−.051	.680	.200
Elasticity	0.0059 [b] (0.0049, 0.0073)	0.12 [c]	.809	−.010	---	---
Pmax	5.18 (4.93, 5.43)	0.10 [c]	.923	−.162	---	---
Omax	20.6 [a] (18.8, 22.7)	0.20 [c]	.825	.376	---	---
Essential value	1.60 [a] (1.31, 1.95)	0.10 [c]	---	---	.983	−.009
Pmax – Modeled	7.07 [a] (5.76, 8.68)	0.03	---	---	.956	−.257
Omax - Modeled	35.5 [a] (29.1, 43.3)	0.10 [c]	---	---	.983	−.009

EV = eigenvalue

[a] Back transformed from $\log_{10}$

[b] Back transformed from inverse of $\log_{10}$

[c] p <.001

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Table 2

Mean factor scores as a function of past-year quit attempts, quit intentions, and presence of home smoking restrictions.

		Persistence				Amplitude			
	N	**Mean**	**SD**	**F**	**p**	**Mean**	**SD**	**F**	**p**
Quit attempts (past year) [a]				0.028	.972			5.099	.006
0	478	.005	.972		Ref	.010	.848		Ref
1–2	363	−.010	.958		.969	.101	1.058		.333
3+	269	.006	1.103		1.000	−.154	1.143		.058
Quit intention [a]				3.687	.025			3.415	.033
No	429	.052	.982		Ref	.087	.950		Ref
6 mo	465	−.094	.873		.054	−.022	.954		.187
30 d	216	.098	1.249		.815	−.125	1.169		.022
Home smoking [a]				7.799	<.001			9.085	<.001
Allowed anywhere inside	439	.142	1.121		Ref	.151	1.057		Ref
Allowed some places inside	259	−.137	.875		.001	−.041	.990		.027
Not allowed inside	412	−.065	.917		.005	−.135	.922		<.001

[a] $F(2,1107)$

Individual row p-values from post-hoc comparisons using the Dunnett test, with the zero/none/anywhere group serving as the control, respectively.

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Table 3

Multivariate logistic regression models of correlates of past-year quit attempts (1–2 or 3+) and intentions to quit in the next 30 days or next 6 months (OR & 95% CI).

	Current Quit Intention						Past-Year Quit attempts					
	30d			6m			1 or 2			3 or more		
	OR	**LCL**	**UCL**	**OR**	**LCL**	**UCL**	**OR**	**LCL**	**UCL**	**OR**	**LCL**	**UCL**
FTND	**1.20**	1.09	1.32	1.06	0.99	1.14	1.01	0.94	1.08	1.00	0.92	1.08
Persistence	0.98	0.82	1.17	0.91	0.78	1.05	1.00	0.86	1.16	0.97	0.83	1.15
Amplitude	**0.76**	0.63	0.91	0.91	0.78	1.06	1.09	0.93	1.27	0.86	0.72	1.01
Social Reactivity	**0.90**	0.86	0.95	0.99	0.95	1.04	0.96	0.92	1.00	**0.92**	0.88	0.97
Smoker Identity	**0.77**	0.64	0.92	**0.49**	0.42	0.58	**0.77**	0.66	0.89	**0.84**	0.71	0.99
Perceived Smoking Prevalence	**1.02**	1.01	1.03	**1.01**	1.01	1.02	**1.02**	1.01	1.03	**1.03**	1.02	1.04
Perceived Health Risk	1.02	0.99	1.04	1.00	0.98	1.02	1.02	1.00	1.04	**1.03**	1.00	1.05
Perceived Cigarette Risk	**1.05**	1.02	1.07	1.01	0.99	1.03	1.00	0.99	1.02	1.01	0.98	1.03
Male	**1.86**	1.28	2.70	1.25	0.94	1.68	**1.51**	1.13	2.02	1.36	0.97	1.91
Female	REF			REF			REF			REF		
Age 18–34	**3.55**	1.90	6.64	1.28	0.85	1.91	1.43	0.95	2.16	**2.80**	1.71	4.60
Age 35–49	**2.11**	1.14	3.90	0.96	0.66	1.40	0.92	0.63	1.34	0.88	0.53	1.45
Age 50+	REF			REF			REF			REF		
Non-Hispanic White	**0.53**	0.35	0.80	**0.69**	0.48	0.98	0.90	0.63	1.29	**0.56**	0.39	0.82
Other Race/Ethnicity	REF			REF			REF			REF		
No Indoor Smoking Restriction	0.91	0.58	1.44	0.75	0.53	1.06	0.72	0.51	1.03	0.70	0.46	1.07
Some Indoor Restriction	1.18	0.70	1.98	1.39	0.95	2.04	1.12	0.76	1.66	1.45	0.94	2.26
No Smoking Indoors	REF			REF			REF			REF		

*Risk variables omitted from multivariate model as they showed no univariate association with quit attempts (p's >.50). Bolded values are statistically significant at p<.05. Referent for Current Quit Intentions was no intentions; Referent for Past-Year Quit Attempts was 0. UCL = upper 95% confidence limit; LCL = lower 95% confidence limit.