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Comparing Participant Estimated Demand Intensity on the Cigarette Purchase Task to Consumption when Usual-Brand Cigarettes were Provided Free

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Abstract

Accumulating evidence suggests that the hypothetical Cigarette Purchase Task (CPT), especially its demand Intensity index (i.e., estimated cigarettes participants would smoke if free), is associated with individual differences in smoking risk. Nevertheless, few studies have examined the extent to which hypothetical CPT demand Intensity may differ from consumption when participants are provided with free cigarettes. That topic is the overarching focus of the present study. Participants were 745 adult smokers with co-morbid psychiatric conditions or socioeconomic disadvantage. CPT was administered for usual-brand cigarettes prior to providing participants with seven days of their usual-brand cigarettes free of cost and consumption was recorded daily via an Interactive Voice Response (IVR) System. Demand Intensity was correlated with IVR smoking rate ($r_s .670-.696$, $p < .001$) but estimates consistently exceeded IVR smoking rates by an average of 4.4 cigarettes per day ($p < .001$). Importantly, both measures were comparably sensitive to discerning well-established differences in smoking risk, including greater cigarettes per day among men versus women ($F(1,732)=18.74$, $p < 0.001$), those with versus without opioid-dependence ($F(1,732)=168.37$, $p < 0.001$), younger versus older adults

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Credit Author Statement

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($F(2,730)=32.93$, $p<0.001$), and those with lower versus greater educational attainment ($F(1,732)=38.26$, $p<0.001$). Overall, CPT demand Intensity appears to overestimate consumption rates relative to those observed when participants are provided with free cigarettes, but those deviations are systematic (i.e., consistent in magnitude and direction, F s all <1.63 ; p s >0.19 for all interactions with subgroups). This suggests that demand Intensity was sensitive to established group differences in smoking rate, supporting its utility as an important measure of addiction potential.

Keywords

Cigarette Purchase Task; Behavioral Economics; Interactive Voice Response System; Smoking; Addiction Potential

Introduction

Behavioral economics integrates the principles of psychology and micro-economics and has been applied widely to studying the use of various addictive substances, including cigarettes (e.g., Bickel et al., 2016; Vuchinich & Heather, 2003). The Cigarette Purchase Task (CPT) is a behavioral-economic simulation task in which participants estimate the number of cigarettes they would smoke across an increasing range of hypothetical monetary prices (Jacobs & Bickel, 1999; see recent review by Reed et al., 2020), and is an alternative to time- and labor-intensive laboratory drug self-administration arrangements (Bickel & Madden, 1999a, 1999b). CPT demand is characterized by five indices with demand Intensity (i.e., the number of cigarettes participants estimate smoking per day if cigarettes were free or very low cost) being the index most pertinent to the current report (see González-Roz et al., 2019; Zvorsky et al., 2019, for reviews).

There is accumulating evidence that the CPT is effective at discerning important individual differences in demand for cigarettes, including differences in substance-related correlates (e.g., dependence severity, heavy versus light users) and sociodemographic risk factors (e.g., gender differences, presence versus absence of comorbid psychiatric conditions; see González-Roz, Jackson, Murphy, Rohesnow, & MacKillop, 2019; Zvorsky et al., 2019, for reviews). Indeed, there is sufficient interest that the Consortium on Methods Evaluating Tobacco recommends inclusion of the CPT in studies focused on informing US Food and Drug Administration (FDA) regulations (Berman et al., 2018) and several of the FDA-supported Tobacco Centers of Regulatory Science use the CPT to guide their policy-informing research (Higgins et al., 2017a; Higgins et al., 2019; Smith et al., 2017; Perry et al., 2019). Two recent meta-analyses examining the relative sensitivity of the CPT indices to individual differences in smoking reported evidence consistent with demand Intensity being particularly sensitive to individual markers of smoking risk and other smoking outcomes (González-Roz et al., 2019; Zvorsky et al., 2019).

The CPT has been demonstrated to be a valid method of studying cigarette demand (Farris et al., 2017; Higgins et al., 2017b; Madden & Kalman, 2010) with high test-retest reliability (Few, Acker, Murphy, & MacKillop, 2012) and significant associations with smoking in naturalistic settings (Zvorsky et al., 2019). Nevertheless, there has been relatively little

experimental research examining correspondence between CPT hypothetical demand and consumption rates when participants are provided with product outside of the lab, and whether any deviations between the two are systematic in nature. We know of only two studies on this topic (Smith et al., 2017; Wilson et al., 2016). Wilson et al. (2016) reported that although CPT demand for participant usual-brand cigarettes under hypothetical conditions was significantly correlated with demand under real-reward CPT conditions, the hypothetical task overestimated demand inelasticity (overall insensitivity of demand to changes in price). Similarly, Smith et al. (2017) compared demand Intensity on the CPT examining demand for research cigarettes varying in nicotine content with the number of free research cigarettes participants smoked daily during a one-week observation period. Smith et al. reported that the two measures were correlated ($r=0.68$; 95% confidence interval=0.64–0.72) but did not quantify the extent to which demand Intensity differed from actual consumption. In sum, these two studies demonstrated empirically that assessments of cigarette demand using the hypothetical CPT do indeed correspond significantly with consumption when product is provided, but also documented deviation between the two methods.

Considering the evidence that hypothetical CPT demand Intensity is associated with important markers of individual differences in smoking risk (González-Roz et al., 2019; Zvorsky et al., 2019), further investigation of how demand Intensity and actual consumption differ is warranted. Towards that end, the purpose of the present study is to (a) examine the extent to which hypothetical CPT demand Intensity differs from actual reported CPD when participants are provided with free cigarettes to consume under naturalistic conditions, and (b) to characterize and quantify whether deviations between the two methods are systematic (i.e., consistent in direction or pattern), an essential prerequisite when examining the reliability and validity of demand Intensity.

Methods

Study Sample

Participants were from a multisite study (University of Vermont (UVM), Brown University, Johns Hopkins University School of Medicine (JHU)) including 745 adult daily smokers from three vulnerable populations (258 with affective disorders recruited from UVM and Brown, 249 with opioid-dependence and 238 socioeconomically disadvantaged women of reproductive age, both recruited from UVM and JHU). All participants provided written informed consent to participate in a randomized, controlled trial examining the effects of exposure to reduced nicotine content cigarettes on smoking rate and nicotine dependence severity. The institutional review boards at each site approved the study. The present study uses data from the trial one-week baseline assessments. As in previously published reports with these populations (Higgins et al., 2017a; Higgins et al., 2018), analyses were conducted collapsing across the three populations (see Table 1 for participant characteristics).

Study inclusion and exclusion criteria were consistent with a prior study on reduced nicotine content cigarettes in these same vulnerable populations (Higgins et al., 2017a). Briefly, all participants had to report daily smoking of five or more cigarettes per day for at least the past year with < 10 days use of other nicotine and tobacco products in the past month, no

current illicit drug use other than marijuana, and provide a CO sample > 8 ppm (CoVita, Haddonfield, NJ). Inclusion criteria specific to smokers with affective disorders were males and females ages 18–70 years, who met Mini International Neuropsychiatric Interview (Sheehan et al., 1999) criteria for current or past year major depressive disorder, dysthymic disorder, generalized anxiety disorder, post-traumatic stress disorder, obsessive compulsive disorder, phobia or panic disorder with or without agoraphobia. Inclusion criteria specific to opioid-dependent smokers were males and females ages 18–70 years currently receiving methadone or buprenorphine maintenance treatment for opioid-dependence. They had to be stable on their maintenance dose, defined as no dose change in the past 30 days and < 30% positive urine toxicology samples for illicit drug use in past month as confirmed by their provider. Specific inclusion criteria for women of reproductive age were ages 18–44 years with highest degree being high school or less.

General Procedure

Sessions were conducted in ventilated observation rooms (at least 4.3×5.9× 7.3 ft) equipped with Acer Aspire ES1-111 series laptops with 11.6” monitors that were used for CPT assessments. Following the baseline assessment (described below), participants were given 150% of a weekly supply of their usual-brand cigarettes to simulate smoking rate without price constraint based on their mean reported cigarettes per day in a 30-day Timeline Followback assessment (Sobell & Sobell, 1996) calendar at study intake. Participants were asked to not share products and to return all used and unused packs of cigarettes.

All participants completed questionnaires assessing sociodemographics and the hypothetical CPT assessment (described below). Given the aim to understand the extent to which demand Intensity and actual cigarettes smoked per day when provided free varies across established risk factors for smoking, four were selected: gender, opioid-dependence, age, and educational attainment. Among daily smokers, women report smoking fewer cigarettes per day than men (Higgins et al., 2015; Kurti et al., 2016; Perkins, 2001; Shiffman & Paton, 1999). Opioid-dependent populations exhibit greater smoking rates than the general smoking population in naturalistic settings (Chun et al., 2009) and greater demand Intensity than not-opioid dependent populations (Higgins et al., 2017a; Nighbor et al., 2020), perhaps related at least in part to the effects of the opioid-maintenance medications on smoking rate (Chait & Griffiths, 1984). Generally, younger smokers report fewer CPD than do older smokers (Hall et al., 2011). Finally, lower educational attainment (e.g., having less than a college degree) is significantly associated with greater smoking rates (Coleman et al., 2019). Finally, given the multi-site nature of this study, we also examined whether any differences in smoking rate observed between the CPT and IVR procedures were consistent across sites.

Cigarette Purchase Task (CPT)

The CPT questionnaire asks participants to estimate how many cigarettes they would smoke in a 24-hr period across a series of escalating hypothetical prices. Participants were instructed to imagine that they are making these purchases in a context in which they have (a) the same income/savings as they do currently, (b) no access to any cigarettes or nicotine products other than those offered at these prices, (c) they would smoke the cigarettes purchased over the next 24 hours without any restrictions on opportunities to smoke, and (d)

saving or stockpiling cigarettes for a later date is not possible. The instructions and structure of this CPT is in line with best-practices of cigarette demand assessment (see review by Reed et al., 2020).

Interactive Voice Response (IVR) System

At the end of the first baseline visit, participants were trained to use the IVR system, which contacted participants daily and asked about their smoking behavior, including the total number of cigarettes the participant smoked in the previous 24-hour period (see also Donny et al., 2015; Hatsukami et al., 2018). Of the 745 participants, 727 of them (97.5%) provided at least one day of IVR data during the subsequent seven days, and 710 (95.3%) reported their smoking behavior on day 1. Participants were compensated for their responses through an adherence incentive program, which consisted of \$1 per call plus a \$10 bonus for seven consecutive calls. Participants used their own phones, except when they had unreliable telephone access, in which case they were provided a study cell phone. Only the first seven days of IVR assessments were analyzed for this study.

Data Analysis

CPT consumption estimates were checked for non-systematic cases using an established algorithm (i.e., Stein, Koffarnus, Snider, Quisenberry, & Bickel, 2015). Results from 11 of the 745 participants were omitted for unsystematic estimates (i.e., same consumption level estimated across prices, greater consumption at higher vs. lower prices, or a reversal from estimating zero consumption at one price to greater-than-zero consumption at higher prices). Participants' self-reported consumption at free price constituted the observed demand Intensity values used for subsequent analysis. In accordance with Tabachnick and Fidell's guidelines (2000) for addressing outliers, Intensity values higher than those likely to be consumed within 24 hours, or those > 3.29 standard deviations above the mean ($n=3$), were replaced by a value one unit greater than the greatest non-outlier value. IVR smoking rates were reported as cigarettes per 24-hour period for each of the 7 days assessed. Of the 745 participants, 97.5% provided at least one day of IVR data, and missing IVR data were not imputed (see Table 2 for n at each time point). All data were log-transformed to improve normality; thus, geometric means and standard errors are reported throughout. Spearman Rank-Order Correlation coefficients were computed to examine associations between demand Intensity and IVR smoking rates. Differences in reported smoking rates across the seven days of data collection were assessed using repeated measures analysis of variance including only the within-subjects effect of time. Finally, repeated measures analysis of variance was performed to address whether the degree of correspondence between demand Intensity and IVR smoking rate differed among various subgroups: gender (male versus female), opioid-status (opioid versus not-opioid dependent), age (18–24 years old, 25–49 years old, and 50 years old and older), educational attainment (High School versus >High School). We examined whether smoking rate differed by study site (UVM, Brown, Johns Hopkins) in considering whether site should be a covariate in analyses on socio-demographic subgroups. Smoking rate did not differ significantly by site ($F(2,731)=1.01$, $p=0.36$) and thus was not included as a covariate. These models examined smoking rate as a function of the source of the estimate (CPT or IVR) as a within-subjects effect, the subgroup of interest as the between-subjects effect, and the subgroup-by-source interaction. As we

were interested in examining reliability across various subgroups without other characteristics potentially altering these relationships, all models included only the variables specific to that analysis, without additional covariates. Across all tests, statistical significance was defined as $p < .05$ (2-tailed).

Results

Correlations of demand Intensity to IVR Smoking Rate

Table 2 shows correlations between CPT demand Intensity and IVR-reported smoking rate on days 1–7. Overall, demand Intensity was significantly correlated (r s ranging from .670–.696, p s < .001) with each of the days of IVR smoking rate. Indeed, no significant differences or trend in IVR smoking rate were noted across the seven days ($F(6,4178) = 0.68$, $p = 0.66$).

Differences between Demand Intensity and IVR Smoking Rate

Estimated demand Intensity if cigarettes were free was greater than the IVR smoking rates reported daily when participants were actually provided with free cigarettes (Figure 1; $F(7,4904) = 17.54$, $p < 0.001$, all p s < 0.001 after Dunnett correction for multiple comparisons). Overall, demand Intensity averaged 4.3 cigarettes per day greater than IVR smoking rate, with mean differences between the two measures ranging from 3.8–5.3 cigarettes per day across the seven days (Figure 2).

Correspondence between Demand Intensity, IVR Smoking Rate, and Sociodemographic Factors

Given that there were no significant differences across the seven days of IVR reporting, the remaining analyses were limited to Day 1. Demand Intensity was greater than IVR smoking rates across each of the four sociodemographic subgroups examined (all F s > 79.08, all p s < 0.001), with no significant interactions (F s for all subgroup-by-source of estimates interactions < 1.84, all p s > 0.16). Because of the systematic nature of these differences, each measure was sensitive to sociodemographic differences in smoking rate. That is, men reported greater cigarettes per day than women when assessed by demand Intensity or IVR (Figure 3, top panel; $F(1,732) = 16.46$, $p < 0.001$), opioid-dependent participants reported greater smoking than those not-opioid dependent on both measures (Figure 3, middle-top panel; $F(1,732) = 155.47$, $p < 0.001$), participants age 25–49 and 50+ years reported greater smoking than those age 18–24 years on both measures (Figure 3, middle-bottom panel; $F(2,730) = 28.53$, $p < 0.001$), and lastly participants with High School education reported greater smoking than those with > High School education on both measures (Figure 3, bottom panel; $F(1,732) = 33.31$, $p < 0.001$).

Discussion

The findings from this study support the results of Smith et al. (2017) that CPT demand Intensity is significantly correlated with the number of cigarettes participants report smoking during a week in which they are provided with free cigarettes. However, the results of Wilson et al. (2016) also noted deviations of the CPT estimates from what participants did

under conditions in which they were provided cigarettes in the form of overestimated inelasticity. The present results demonstrate that demand Intensity overestimates IVR smoking rate by 3.9–5.4 cigarettes per day. Given that the CPT is anchored to individuals' experience buying cigarettes (Aston & Cassidy, 2019) and smokers rarely receive free cigarettes, perhaps it is not surprising that demand Intensity estimates would deviate from IVR smoking rates. Given more experience with freely provided product, demand Intensity may better approximate consumption. Still, if the CPT is to be used widely owing to its relative cost and time efficiency compared to procedures where participants are actually provided with products, such deviations need to be understood, which was the purpose for assessing whether any deviations between the two procedures obscured the ability of the CPT to discern well-established differences in sociodemographic characteristics and smoking risk.

The results were quite clear that this apparent overestimation of smoking rate by the CPT demand Intensity index was sufficiently systematic that it did not interfere with its sensitivity to these important individual differences in smoking risk. Demand Intensity scores were sensitive to differences in smoking rate associated with gender, opioid-dependence, age, and educational attainment in a manner that aligned closely with the differential patterns observed across these same characteristics using IVR reported smoking rates when cigarettes were provided free to these same participants. That is, consistent with the literature both assessment strategies demonstrated greater smoking rates among men versus women (e.g., Higgins et al., 2015; Kurti et al., 2016; Perkins, 2001; Shiffman & Paton, 1999), those with versus without opioid use disorder (Higgins et al., 2017a; Nighbor et al., 2020), younger versus older smokers (Hall et al., 2011), and those with lower versus greater educational attainment (Coleman et al., 2019; Higgins et al., 2009; Kurti et al., 2016). This sensitivity of demand Intensity to these well-established differences suggests that the tendency of the CPT to overestimate cigarette demand observed in the present study and Wilson et al. is sufficiently systematic to not substantially diminish its sensitivity to individual differences in smoking risk.

The current results also further underscore the practical utility of the CPT compared to more conventional methods where cigarettes are provided to participants, although both have their place depending on the nature of the scientific question (Griffiths, Troisi, Silverman, & Miumford, 1993; DeGrandpre, Bickel, Higgins, & Hughes, 1993; Bickel, Marsch, & Carroll, 2000). Importantly, the CPT allows for ethical, valid assessment of smoking without having participants actually smoke cigarettes as part of the study, which can be helpful with especially vulnerable populations such as pregnant women (see also Higgins et al., 2017b; Nighbor et al., 2019). Given the growing body of research using the CPT (González-Roz et al., 2019; Reed et al., 2020; Zvorsky et al., 2019) and the potential for the CPT to make contributions to informing policy (Berman et al., 2018; Higgins et al., 2017a; Higgins et al., 2019; Perry et al., 2019; Smith et al., 2017), the current results help to further validate the approach (see also Farris et al., 2017; Madden & Kalman, 2010).

At least two limitations of the current study merit mention. First, participants comprised a convenience rather than a nationally representative sample which could limit the generality of the findings to other smokers from these same vulnerable populations. Second, the IVR

estimates involved using participant self-report rather than direct observation of smoking. Thus, we cannot rule out that actual smoking rates may have deviated from reported rates, although it is worth noting that changes in smoking rate via the IVR have been accompanied by significant changes in biochemical measures of smoke and nicotine exposure (Donny et al., 2015; Hatsukami et al., 2018). These limitations notwithstanding, the current results provide new knowledge on the validity of the CPT and further highlight its sensitivity to individual differences in smoking risk, particularly the demand Intensity index (Zvorsky et al., 2019). Moreover, they provide researchers with detailed practical information on how CPT assessments of smoking may deviate from consumption patterns when participants are provided with product and, perhaps most importantly, reassurances that such deviations are systematic and do not preclude discerning important individual differences in smoking risk.

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Highlights

- Demand Intensity is participant estimated consumption of free cigarettes.
- We examined how demand Intensity differs from consumption of free cigarettes.
- Demand Intensity was higher than free cigarette consumption, but systematically so.
- Both measures were sensitive to established group differences in smoking rate.
- Findings support demand Intensity as important measure of addiction potential.

Figure 1.

Demand Intensity compared to each of the seven days of Interactive Voice Response System (IVR) smoking rate. Bars indicate one standard error of the mean.

Figure 2.
Mean differences between demand Intensity and each of the seven days of Interactive Voice Response System (IVR) smoking rate.

Figure 3. Correspondence between demand Intensity, Interactive Voice Response System (IVR) smoking rates, and sociodemographic risk factors.

Table 1.**Participant Characteristics**

Characteristics	All (n= 745)	Participant Populations ^a		
		Affective Disorders (n = 258)	Opioid Dependent (n = 249)	Disadvantaged Women (n = 238)
Age (M ± SD)	35.68 ± 11.18	37.30 ± 13.33	38.53 ± 10.54	30.96 ± 7.03
Gender (% Female)	528 (70.87)	152 (58.91)	138 (55.42)	238 (100)
Race/Ethnicity				
Non-Latino White	605 (81.87)	215 (83.66)	202 (82.45)	188 (79.32)
Non-Latino Black	67 (9.07)	13 (5.06)	22 (8.98)	32 (13.50)
Latino	22 (2.98)	14 (5.45)	6 (2.45)	2 (0.84)
Non-Latino Other or >1 race	36 (4.87)	12 (4.67)	11 (4.49)	13 (5.49)
Non-Latino American	6 (0.81)	3 (1.17)	3 (1.22)	0 (0)
Indian/Alaskan Native				
Non-Latino Asian	2 (0.27)	0 (0)	0 (0)	2 (0.84)
Non-Latino Hawaiian	1 (0.14)	0 (0)	1 (0.41)	0 (0)
Education				
8th Grade or Less	16 (2.15)	2 (0.78)	12 (4.82)	2 (0.84)
Some High School	82 (11.01)	15 (0.81)	35 (4.06)	32 (13.45)
High School	292 (39.19)	71 (27.52)	117 (46.99)	104 (43.70)
Graduate/Equivalent				
Some college	255 (34.23)	92 (35.66)	64 (25.70)	99 (41.60)
2-Year Associate's Degree	36 (4.83)	25 (9.69)	10 (4.02)	1 (0.42)
College Graduate/4-Year Degree	48 (6.44)	38 (14.73)	10 (4.02)	0 (0)
Graduate or Professional Degree	16 (2.15)	15 (5.81)	1 (0.40)	0 (0)
Marital Status				
Married	107 (14.36)	34 (13.18)	26 (10.44)	47 (19.75)
Never married	442 (59.33)	152 (58.91)	155 (62.25)	135 (56.72)
Divorced or Separated	180 (24.16)	67 (25.97)	59 (23.69)	54 (22.69)
Widowed	16 (2.15)	5 (1.94)	9 (3.61)	2 (0.84)
Used marijuana in past 30 days	311 (42.1)	131 (51.4)	80 (32.5)	100 (42.2)
Cigarettes smoked per day (M ± SD)	17.78 ± 9.24	15.73 ± 8.41	22.61 ± 9.86	14.98 ± 7.26
Primary smoker of mentholated cigarettes	322 (44.60)	105 (42.51)	111 (46.06)	106 (45.30)
Age started smoking regularly (M ± SD)	16.13 ± 4.06	16.72 ± 4.31	15.67 ± 4.66	15.97 ± 2.90
Breath CO level (M ± SD)	17.90 ± 9.75	18.17 ± 10.66	19.55 ± 9.97	15.91 ± 8.04
Nicotine Metabolite Ratio (M ± SD)	0.47 ± 0.24	0.48 ± 0.25	0.48 ± 0.23	0.44 ± 0.24
Heaviness of Smoking Index (M ± SD)	3.48 ± 1.55	3.16 ± 1.60	4.22 ± 1.33	3.04 ± 1.44
Fagerström Test for Cigarette Dependence (M ± SD)	5.55 ± 2.37	5.22 ± 2.43	6.62 ± 2.03	4.79 ± 2.23

^aUnless otherwise indicated, data are expressed as number (percentage) of patients

Table 2.

Spearman Rank-Order Correlations of Cigarette Purchase Task demand Intensity with each of the seven days of Interactive Voice Response System Smoking Rate.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Intensity	.696	.691	.676	.684	.670	.681	.682
Significance (2-tailed)	$p < .001$	$p < .001$	$p < .001$	$p < .001$	$p < .001$	$p < .001$	$p < .001$
<i>N</i>	710	709	711	700	693	697	691