2021

Examining Antepartum Quit Attempts Using A Latent Factor Model Of A Hypothetical Cigarette Purchase Task

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EXAMINING ANTEPARTUM QUIT ATTEMPTS USING A LATENT FACTOR MODEL OF A HYPOTHETICAL CIGARETTE PURCHASE TASK

A Thesis Presented

by

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to

The Faculty of the Graduate College

of

The University of Vermont

In Partial Fulfillment of the Requirements
for the Degree of Master of Arts
Specializing in Psychology

August, 2021

Defense Date: April 27, 2021
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Abstract

Previous research has validated the use of hypothetical purchase tasks to measure smoking demand among pregnant women. This study extends that research by (1) examining the factor loading pattern of a hypothetical cigarette purchase task (CPT) in a sample of pregnant women who smoke, and (2) comparing the ability of the latent factor solution to predict antepartum quit attempts relative to more conventional predictors. Participants were 665 pregnant women seeking enrollment in a smartphone-based smoking-cessation trial. Data were taken from an intake assessment that included the CPT, the Kirby delayed discounting task, sociodemographic and smoking-history questionnaires, and assessment of antepartum quit attempts. Bivariate analyses compared sociodemographic and smoking characteristics between women who reported zero versus $\geq$ one antepartum quit attempt. Confirmatory Factor Analysis using a Principal Component Analysis method was used to assess whether the five CPT indices (Intensity, Omax, Pmax, Breakpoint, Alpha) loaded onto two latent factors (Amplitude & Persistence). Finally, stepwise regression modeling was conducted to examine associations between CPT latent factors and antepartum quit attempts adjusting for other variables that were significant at the bivariate level. All associations with $p < 0.05$ were retained in final models. Factor analysis confirmed a two-factor solution to the CPT whereby Intensity of demand and Omax loaded on one factor (Amplitude), and all other indices onto another factor (Persistence). Significant predictors of antepartum quit attempts in the final adjusted regression model included CPD antepartum, time to first cigarette (TFC) antepartum, Persistence, and menthol use. As CPD and Amplitude were highly correlated, a second regression was conducted excluding CPD. The variables retained in that model were TFC antepartum, Amplitude, Persistence, and race/ethnicity. These results extend the two-factor solution of CPT indices to pregnant women. The latent factors Amplitude and Persistence are significantly and independently associated with antepartum quit attempts, although the significance of the association of Amplitude with quit attempts is conditional on the presence of CPD as a predictor. These results lend further support to the potential utility of the CPT for examining individual differences in attempting to quit smoking upon learning of pregnancy.

Keywords: behavioral economics, combustible tobacco product, dependence, psychology, psychiatry, prenatal exposure, pregnancy, risk for tobacco use

Acknowledgement and Dedication

This project was supported in part by the Center of Biomedical Research Excellence P20GM103644 award from the National Institute of General Medical Sciences, and Institutional Training Award T32DA007242 from the National Institute on Drug Abuse. Technical support was provided by Joan Skelly, MS, biostatistician for the Vermont Center on Behavior and Health at the University of Vermont; Norman Medina, Research Assistant at the University of Vermont; and my co-mentors Drs. Allison Kurti and Stephen Higgins, faculty in the Departments of Psychiatry and Psychological Science, University of Vermont. This project is dedicated to my "Among Us" friends, Bailey Stahl, Mason Fugger, Amber Hunt, Hailee Milligan, London Wolski, Tyler and Kara Kurtz, Greg Garza, and Max Lockhart; my family, David, Andrew, and Nancy Evemy; and to my fiancé, Audra Balsley.

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Introduction

Cigarette smoking is the leading cause of preventable death in the United States, with 1 in 5 deaths attributable to smoking (US DHHS, 2014). In 2018, 13.7% of U.S. adults over the age of 18 reported smoking cigarettes, yet a clear and growing national health disparity has left vulnerable populations shouldering a disproportionate amount of the burden of smoking in the U.S. (Creamer et al. 2018; Schroeder, 2016). Included among these vulnerable populations are pregnant women, among whom the smoking rate has remained stable at approximately 13% over the last decade (Alshaarawy and Anthony, 2015; Kurti et al., 2017, Nighbor et al., 2020).

Smoking during pregnancy is associated with an increased risk for numerous serious adverse pregnancy and birth outcomes including ectopic pregnancy, placenta previa, intrauterine growth restriction, preterm birth, birth defects, sudden infant death syndrome, obesity, childhood behavioral problems, and later-in-life metabolic disorders (US DHHS 2014, Hackshaw et al. 2011; Baba et al., 2012; Barker 2004; Cohen et al., 2010; Dietz et al., 2010; Leslie, 2013; Rogers, 2009; US DHHS, 2014; Thompson et al., 2009). Smoking during pregnancy also has a tremendous economic toll. An average of approximately 370 million USD is spent annually on healthcare costs associated with adverse neonatal health consequences of smoking during pregnancy (Mohlman and Levy, 2016).

Of particular interest in research on smoking during pregnancy are individual differences associated with the likelihood of quitting. The present study examines predictors of making at least one quit attempt upon learning of pregnancy as a proxy measure of predicting late-pregnancy abstinence. A positive history of antepartum quit

attempts upon entering prenatal care is a significant predictor of achieving late pregnancy abstinence and can be reasonably conceptualized as an emerging form of eventual quitting (Kurti et al., 2016; Lopez et al., 2015; White et al., 2014). Better understanding the factors associated with making quit attempts has the potential to inform efforts to promote smoking cessation during pregnancy and to identify in early antepartum women most in need of interventions to promote smoking cessation (Higgins et al. 2017; Nighbor et al., 2019). Prior research has indicated that socioeconomic factors including poverty and lower educational attainment predict a lower likelihood of quitting smoking upon learning of pregnancy (White et al. 2014; US DHHS 2014). In addition to poverty and low educational attainment, a negative history of pre-pregnancy quit attempts (Higgins et al., 2017, Kurti et al. 2016; Lopez et al., 2015; White et al., 2014), younger age at smoking initiation (Higgins et al. 2017), greater number of cigarettes smoked per day (CPD) (Higgins et al., 2017; White et al., 2014) and a shorter latency to smoking upon awaking (Kurti et al., 2016) are conventional smoking characteristics that have been demonstrated to predict a lower likelihood of quitting.

In the spirit of the U.S. National Institute of Mental Health's Research Domain Criteria (RDoC) initiative (National Institute of Mental Health, 2019), which recommends characterizing psychiatric disorders in terms of underpinning psychological/biological processes rather than symptoms, our group has been examining individual differences in potential motivational processes underpinning quitting smoking during pregnancy with particular focus on the relative reinforcing effects of smoking (Higgins et al., 2017; Higgins et al., 2020; Nighbor et al., 2019). We focus on the reinforcement process because of the broad scientific consensus that chronic smoking is largely attributable to the reinforcing

effects of nicotine (Prochaska & Benowitz, 2019; US DHHS, 1988). In that effort, we assessed the relative reinforcing value of smoking using the Cigarette Purchase Task (CPT), a behavioral-economic task that asks smokers to estimate hypothetical cigarette consumption rate and expenditure under escalating price constraints (Jacobs & Bickel, 1999). A unique feature of this procedure is that it allows investigators to assess the relative reinforcing effects of smoking without participants having to smoke, which is valuable when dealing with highly vulnerable populations such as pregnant women (Higgins et al., 2017). Furthermore, in a study comparing CPT self-reported cigarette consumption to actual consumption, researchers found that demand Intensity was sensitive to individual differences in smoking rate was statistically similar to those using actual consumption, (Nighbor et al., 2020). In the seminal study on the CPT with pregnant women, individual and aggregate demand varied as an orderly function of price and also fared somewhat better than conventional predictors in multivariate models predicting antepartum quit attempts (Higgins et al., 2017).

The overarching goal of the present study is to systematically extend this literature examining cigarette demand among pregnant women. As noted above, the CPT and other hypothetical purchase tasks are used to examine demand metrics of consumption, expenditure, and price sensitivity for substances of abuse in an ethical and efficient manner and are highly associated with actual reinforcer consumption recorded in laboratory settings (Jacobs and Bickel, 1999; Johnson and Bickel, 2006; Mackillop et al. 2009). The procedure has been validated in many different populations of smokers and settings (Gonzalez-Roz et al., 2020; Reed et al., 2020; Zvorsky et al., 2019). The CPT used in the prior and present study with pregnant women characterizes demand into five

multidimensional indices. These indices include the amount a person would smoke if the price per cigarette was free or at very low cost (Intensity or Q_0), the highest expenditure a participant will incur (O_{max}), the financial price associated with peak expenditure (P_{max}), the most an individual would pay per cigarette before quitting rather than incurring the cost (Breakpoint), and a measurement of the rate at which consumption changes as a function of increasing price (Elasticity or α).

Perhaps not surprisingly, the above indices of demand derived from a simulated CPT are correlated with one another (Jacobs and Bickle, 1999; Mackillop et al., 2008; Murphy and Mackillop, 2006; Murphy at al., 2011; Mackillop et al., 2015), generating interest in a more parsimonious and concise measure of demand. In present study, I will explore the latent-factor structure of the CPT indices via principal component analysis. Several latent-factor CPT studies in non-pregnant populations have identified that the Intensity index loads exclusively onto a latent factor termed Amplitude, or demand unconstrained by price, while the other indices load exclusively onto a latent factor termed Persistence, or overall sensitivity to price (Bidwell et al., 2012; Gonzalez-Roz et al., 2020; O'Connor et al., 2016, Higgins et al. 2020). While the latent-factor structure of the CPT has been investigated in other vulnerable populations of smokers (e.g., Higgins et al., 2020), this has not been previously investigated with pregnant women. Examining this question among pregnant women represents an important next step in the use of the CPT with them. Pregnant women represent a relatively unique population given the considerable risk that continuing to smoke poses for their fetus and the high degree of social stigma associated with smoking during pregnancy (Stone, 2015).

In addition to exploring the latent-factor structure of the CPT among pregnant women, I will also systematically extend earlier observations on CPT demand among pregnant women by conducting the proposed study in a national sample of smokers being screened for participation in a smartphone cessation intervention for pregnant women. Previous studies on this topic have been conducted exclusively among Vermont samples participating in clinic-based cessation trials (Higgins et al., 2017; Higgins et al., 2020; Nighbor et al., 2019). This smart-phone intervention recruits throughout the U.S. and predominantly by Facebook ads and thus includes a more geographically and sociodemographically diverse sample of women than in our Vermont, clinic-based samples. Studying diverse samples can be important as prior research has demonstrated, for example, that making at least one quit attempt upon learning of pregnancy is less common among Non-Hispanic White compared to Non-Hispanic Black but not Hispanic women (Evemy et al., 2020).

Study Aims

Aim 1: To examine the latent-factor structure of a hypothetical CPT in a national sample of pregnant women using a Principal Component Analysis.

Hypothesis 1: The two-factor solution will extend to CPT demand among pregnant women, with demand Intensity loading exclusively onto the Amplitude latent factor and all other indices loading onto the Persistence latent factor.

Aim 2: To characterize the relationship between the latent factors of Amplitude and Persistence to antepartum quit attempts relative to conventional predictors of antepartum quit attempts.

Hypothesis 2a: Amplitude and Persistence will be significantly associated with making at least one quit attempt upon learning of pregnancy.

Hypothesis 2b: Multivariate models will reveal that the latent-factors Amplitude and Persistence are both independent and significant predictors of antepartum quit attempts even after adjusting for more conventional predictors.

Methods

Participants

Women were recruited through either a Facebook advertisement deployed nationally or in Women, Infants, and Children (WIC) and obstetrical clinics in Vermont. Study inclusion criteria included proof of pregnancy (e.g., written confirmation from a healthcare provider), self-reported smoking at least one puff of a cigarette in the past 7 days, $\geq$ 18 years old, and owning a smartphone. Study exclusion criteria included being over 25 weeks pregnant, living with someone who is enrolled in the trial, residing in a group home, receiving opioid maintenance therapy, actively participating in another study involving financial incentives for behavior change, smoking marijuana more than once weekly and unwilling to quit for the duration of the study, medical or psychological conditions that could interfere with participation in the study, and currently taking antipsychotic medications.

Participants who received information about the study at their WIC/OB office or via Facebook advertising were asked about both their pregnancy status and whether they were current cigarette smokers. Women who endorsed being pregnant, currently smoking cigarettes, and wanting more information about the study were sent a link to an online

survey using the web-based Research Electronic Data Capture (REDCap) tools hosted at the University of Vermont (Harris et al. 2009; Harris et al. 2019). REDCap is a secure, web-based software platform designed to support research by providing (1) an intuitive interface for validated data capture; (2) audit trails for tracking data manipulation and export procedures; (3) automated export procedures for seamless data downloads to common statistical packages; and (4) procedures for data integration and interoperability with external sources. In addition to self-report data collection, a REDCap algorithm was built into the survey such that those participants who met the initial pre-screen eligibility questions were automatically extended the opportunity to progress to a lengthier intake assessment that is described in greater detail below. Participants were not required to answer any questions that made them feel uncomfortable during any portion of the survey.

REDCap Intake Assessment

The REDCap intake survey included 306 questions and took approximately 30-45 minutes to complete. Survey data included self-reported smoking characteristics, sociodemographic information, the Fagerstrom Test for Nicotine Dependence (Heatherton and Kozlowski, 1991), the Kirby Delay-Discounting Task (Kirby et al. 1999), and a hypothetical Cigarette Purchase Task (CPT) all? detailed below (Jacobs & Bickel, 1999). Sociodemographic and smoking characteristics included self-reported measures of cigarettes smoked per day (CPD) and time to first cigarette upon waking both prior to and during their current pregnancy, race/ethnicity, age, educational attainment, employment status, age at first cigarette, marital status, employment status, and stress level on a 0-100 analog scale.

Cigarette Purchase Task

In this study, the CPT was a 19-item self-administered behavioral-economic measure adapted from Mackillop et al. (2008) used to simulate change in cigarette demand as a function of escalating prices. For each item, participants are asked to estimate how many cigarettes they would smoke in a 24-hour period if each cigarette cost X amount of money (Jacobs and Bickel, 1999). Price per pack of cigarettes relative to the corresponding price was also included. Preliminary instructions read, "Assume that: (1) The available cigarettes are your usual brand, (2) 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, and (3) you would smoke the cigarettes that you request within 24 hours; you cannot save or stockpile cigarettes for a later date."

Price increases per question proceeded as follows; (1) free (2) two cents (3) five cents (4) ten cents (5) twenty cents (6) thirty cents (7) forty cents (8) fifty cents (9) sixty cents (10) seventy cents (11) eighty cents (12) ninety cents (13) one dollar (14) two dollars (15) three dollars (16) four dollars (17) five dollars (18) ten dollars (19) twenty dollars. Scores were measured and compared using five indices of demand: (1) Intensity, or quantity of cigarettes consumed in a 24-hour period when cigarettes are free or at a very low cost; (2) O_{max} (peak expenditure); (3) P_{max} (financial price associated with O_{max}); (4) Breakpoint (price at which participants would quit smoking rather than incur the cost); and (5) Elasticity (α, overall sensitivity to a change in price of cigarettes).

Delay Discounting

The delay discounting measure administered as part of the study intake assessment was the 27-item self-administered Monetary Choice Questionnaire (MCQ-27; Kirby et al.,

1999). For each item, the participant is asked to choose between a smaller, immediate monetary reward and a larger, delayed monetary reward. The smaller, more immediate rewards ranged from 11-78 hypothetical dollars, and the larger rewards ranged from 22-85 hypothetical dollars with a 7-186-day delay. The derived discounting parameter (*k*) describes how steeply delay degraded value and was log transformed. The survey was scored with the 27-Item Monetary Choice Automated Scorer by Kaplan et al. (2016).

Data Analysis Plan

Prior to other data-analytic procedures, CPT data were first examined to identify those participants who provided unsystematic data that could not be used in subsequent data analyses. This involved visually inspecting all participants' CPT data for outliers. Subsequent outlier analyses were conducted using Grubbs' procedure in GraphPad Prism ® version 7.a for Mac (Graphpad Software, La Jolla California, USA, www.graphpaad.com) with alpha set to .05 to confirm outliers. Zero outliers were excluded from CPT analyses.

The degree of systematic responding for all remaining participants were examined using the procedure proposed by Johnson and Bickel (2008) and again by Stein et al. (2015) with the following direction limits for 'bounce' (B) or how consumption increases as price increases, 'trend' (ΔQ) or whether consumption is lower at the highest price than at the lowest price, and 'reversals from zero' or identifying nonzero consumption at a higher price than a price where the participant indicated zero consumption (Koffarnus and Kaplan, 2017), respectively: 0.025, 0.10, and 0 (Johnson and Bickel, 2008). Data identified as non-systematic according to the described criteria were excluded from further CPT analyses (N = 53, 8%).

Elasticity/α was derived from individual demand curves, which was fitted using GraphPad Prism ® for Mac (Graphpad Software, La Jolla California, USA, www.graphpad.com), via the Hursh and Silberberg (2008) exponential demand equation:

$$\log Q = \log Q_0 + k \cdot \left(e^{-\alpha(Q0 \cdot C)} - 1 \right)$$

Where Q is consumption at each price, Q_0 is consumption when cost is zero (converted to \$0.01 for curve fitting in log-log plot), k is the range of consumption in logarithmic units (calculated as the difference of the logarithms of the maximum and minimum consumption values plus .05), and α is the rate of change in elasticity across the demand curve. All other demand indices were empirically quantified from observed values. All demand indices were log10 transformed to correct for Skewness and Kurtosis.

Principle component analysis (PCA) with oblique rotation method, performing a non-orthogonal linear transformation on the factor solution, was used to determine whether the five conventional demand indices were accounted for by a specified two latent-factor solution (Bidwell et al., 2012). All five demand indices were entered into the model. O_{max}, P_{max}, and Breakpoint were log10 transformed, whereas Intensity and Elasticity were square root transformed for analyses. 1/ α of elasticity was used in the analysis to facilitate a more intuitive interpretation of the factor structure, with larger values indicating greater reinforcement. CPT demand indices that had loadings > .40 based on standardized regression coefficients were loaded on a particular factor (Stevens, 2002; Tabachnick and Fidell, 2001).

Bivariate analyses comparing participant sociodemographic, behavioral economic measures, and smoking characteristics using t-tests for continuous variables and chi-square

tests for categorical variables were used to determine which variables were associated with making at least one quit attempt upon learning of pregnancy. Those variables that were significantly associated with antepartum quit attempts at the bivariate level ($p < .05$) were included in the regression modeling detailed below.

Lastly, two backward elimination stepwise logistic regressions predicting antepartum quit attempts were conducted using participant characteristics that differed significantly in the bivariate analyses, including the CPT latent factors identified in the PCA. One model included all variables that were significantly associated with making at least one quit attempt upon learning of pregnancy. The second model included the same set of variables with the exception of CPD in the antepartum period. It was predicted that cigarettes per day in the stepwise regression would act as a measure which inherently collineates and accounts for variance potentially explained by other variables entered into the model. To avoid exclusion of these potentially relevant variables, a second analysis manually removed cigarettes per day from the stepwise regression model.

All analyses were conducted using SAS version 9.3 (SAS Institute, Cary, NC, USA) with significance set at $p < .05$.

Results

Participant Characteristics

Overall, the majority of women (90%) reported ≤12 years of education or a GED equivalency. Regarding race/ethnicity, approximately 75% of participants identified as Non-Hispanic White, with the remaining 25% distributed across Non-Hispanic Black

(15%), Hispanic (4%), or mixed or other race/ethnicities (7%). Nearly three quarters (73%) of participants recorded being single and 47% reported working for pay outside of the home. Additional covariates are included in the participant characteristics table below (Table 1).

Cigarette Purchase Task

Aggregate Demand Function and CPT Indices. The CPT aggregate demand function was well described by the modified exponential equation (Figure 1). The CPT indices showed that, on average, participants estimated that they would (a) smoke 16.21 cigarettes per day (CPD) if they were free (Intensity), (b) spend a maximum of $13.15 on cigarettes in a 24-hour period (O_{max}), (c) move from inelastic to elastic demand (i.e., where price has a substantial impact on demand) when price reached $2.29 per cigarette or $45.8 per pack ($P_{max}$), (d) forego smoking completely when price reached $2.94 per cigarette or $58.8 per pack (Breakpoint), with (e) an overall sensitivity to price of 0.037 (Elasticity).

Relative to participants who reported making at least one quit attempt upon learning of pregnancy, participants who made no antepartum quit attempts on average reported greater demand Intensity (Figure 3), a higher O_{max} (Figure 5), P_{max} (Figure 4), and Breakpoint (Figure 6), and less overall Elasticity (Figure 2).

Principal Component Analysis. The principal component analysis method with oblique rotation revealed the CPT indices O_{max}, P_{max}, Breakpoint, and Elasticity loaded on to one factor (Persistence) and Intensity of demand and O_{max} loaded on another factor (Amplitude). Preliminary correlation matrix identified several significant associations among the factors (Table 2). All five demand indices were included in the factor solution and contributed to the factor structure. Initial eigenvalues indicated that the Persistence,

which loaded Omax, Pmax, Elasticity, and Breakpoint, and Amplitude, which loaded Intensity, factors explained 65% and 22% of the variance in the model, respectively, and 87% of the variance overall. Omax had standardized regression coefficient loading patterns >.40 on both factors, and was formally loaded onto both Amplitude and Persistence (Table 3).

Bivariate Associations

Sociodemographic Variables. There was a positive association between race/ethnicity and making at least one quit attempt upon learning of pregnancy (X^2[3, 664] = 22.15, $p < .01$) where non-Hispanic black participants were more likely to have made a quit attempt than non-Hispanic white and Hispanic participants. Participants who reported antepartum quit attempts were also younger at the time that they completed their intake assessment than those who did not make a quit attempt (29.38$\pm$5.89 vs 30.79$\pm$5.76, t(643) = 2.93, $p < .01$).

Smoking History Variables. Making at least one quit attempt upon learning of pregnancy was positively associated with pre-pregnancy time to first cigarette > 5 minutes after waking (X^2[1,664] = 9.17, $p < .01$), and smoking <10 pre-pregnancy CPD (X^2[1, 664] = 10.61, $p < .01$), as well as during-pregnancy time to first cigarette > 5 minutes after waking (X^2[1, 664] = 26.28, $p < .01$), smoking <10 CPD (X^2[1, 661] = 72.97, $p < .01$), having made $\geq$1 pre-pregnancy quit attempts (X^2[1, 662] = 27.06, $p < .01$), and preference for smoking menthol cigarettes (X^2[1, 664] = 7.18, $p < .01$). Additionally, participants who reported making antepartum quit attempts were significantly older when they initiated smoking than those who did not make a quit attempt (16.46$\pm$3.67 vs. 15.48$\pm$3.00, t[662] = -3.51, $p < .01$).

CPT Latent Factors. Amplitude and Persistence were each significantly associated with antepartum quit attempts, with participants who made at least one quit attempt showing lower overall demand Amplitude (-0.15±1.07 vs. 0.28±.78, $t[610] = 5.25$, $p < .01$), and lower demand Persistence (-0.12±0.89 vs. 0.22+1.15, $t[610] = 4.16$, $p < .01$) than those who did not make any quit attempts.

Individual Logistic Regression Modeling

Sociodemographic Variables. In the current sample, Non-Hispanic Black women had 3.64 times greater odds of making at least one quit attempt when compared to Non-Hispanic White women (OR=3.64, 95% CI = 2.04-6.51). Additionally, non-Hispanic black participants had 3 times greater odds than Hispanic participants of making a quit attempt upon learning of pregnancy (OR=3, 95% CI = 1.16-7.75). No other significant differences by race/ethnicity were seen. In regard to participants' current age, for every 1-year increase in age, there was a 4% decrease in the odds (OR=0.96, 95% CI = 0.93-0.99) of making an antepartum quit attempt.

Smoking History Variables. Overall, women with greater nicotine dependence both before and during pregnancy were less likely to make antepartum quit attempts. More specifically, women who smoked ≥ 10 CPD pre-pregnancy had a 61% decrease in the odds (OR=0.39, 95% CI = 0.22-0.70) of making at least one antepartum quit attempt compared to those who smoked < 10 CPD. Similarly, women who smoked > 10 CPD during their current pregnancy had a 78% decrease in the odds (OR=0.22, 95% CI = 0.15-0.31) of making an antepartum quit attempt compared to those who smoked < 10 CPD.

Women who smoked their first cigarette > 5 minutes after waking pre-pregnancy had 1.64 times greater odds (OR=1.64, 95% CI = 1.19-2.26) of making at least one

antepartum quit attempt than women who smoked within 5 minutes upon waking. Similarly, women who reported smoking > 5 minutes after waking during pregnancy had 2.75-fold greater odds (OR=2.75, 95% CI = 1.85-4.09) of making at least one antepartum quit attempt than women who smoked their first cigarette within 5 minutes upon waking.

Women who reported making $\geq$ one quit attempt prior to learning of pregnancy had 2.57 times greater odds (OR=2.57, 95% CI = 1.79-3.70) of reporting antepartum quit attempts than women who reported no pre-pregnancy quit attempts. Women who reported smoking menthol cigarettes had 1.55-fold greater odds (95% CI = 1.12-2.13) of reporting at least one antepartum quit attempt than women smoking non-mentholated cigarettes. Finally, concerning age at smoking initiation, for every one-year increase in age, women had 1.09 times greater odds (95% CI = 1.04-1.15) of reporting an antepartum quit attempt.

CPT Latent Factors. For every one-unit increase in Amplitude, participants had a 48% decrease in the odds (OR=0.62, 95% CI = 0.51-0.75) of making an antepartum quit attempt. Stated differently, those participants who reported antepartum quit attempts also reported less overall consumption under minimal or no constraint on the CPT.

For every one-unit increase in Persistence, participants had a 34% decrease in the odds of making an antepartum quit attempt (OR=0.71, 95% CI = 0.60-0.84). Or, stated differently, participants who reported at least one antepartum quit attempt reported greater overall sensitivity to price.

Backward Elimination Logistic Regressions

Backward elimination logistic regression was conducted to identify independent predictors of antepartum quit attempts. CPD antepartum (OR=0.25, 95% CI = 0.17-0.37) (Wald χ^2 (1) = 47.58, $p < .01$), pre-pregnancy quit attempts (OR=2.77, 95% CI = 1.81-

4.23) (Wald χ^2 (1) = 22.23, p < .01), whether the participants preferred cigarette brand is mentholated (OR=1.50, 95% CI = 1.02-1.14) (Wald χ^2 (1) = 4.35, p < .05), age of smoking initiation (OR=1.08, 95% CI = 1.02-1.14) (Wald χ^2 (1) = 6.04, p < .05), and Persistence (OR=0.74, 95% CI = 0.74-0.90) (Wald χ^2 (1) = 9.27, p < .01) remained significant predictors of making at least one quit attempt upon learning of pregnancy (Table 5).

Because CPD and Amplitude are highly correlated (*ps*=<.01 in present study), we reran the model excluding CPD. With CPD antepartum excluded, race and ethnicity (OR=1.32, 95% CI = 1.03-1.68) (Wald χ^2 (1) = 4.98, p < .05), antepartum time to first cigarette (OR=1.91, 95% CI = 1.20-3.03) (Wald χ^2 (1) = 7.54, p < .01), pre-pregnancy quit attempts (OR =2.73, 95% CI = 1.80-4.12) (Wald χ^2 (1) = 22.59, p < .01), cigarette brand of choice containing menthol (OR=0.68, 95% CI = 1.01-2.14) (Wald χ^2 (1) = 4.03, p < .05), age at intake (OR=0.96, 95% CI = 0.93-0.99) (Wald χ^2 (1) = 7.00, p < .01), age at smoking initiation (OR=1.09, 95% CI = 1.03-1.15) (Wald χ^2 (1) = 7.80, p < .01), Amplitude (OR=0.73, 95% CI = 0.60-0.90) (Wald χ^2 (1) = 9.28, p < .01), and Persistence (OR=0.77, 95% CI = 0.64-0.93) (Wald χ^2 (1) = 7.02, p < .05) were all significant predictors of antepartum quit attempts (Table 4?).

Discussion

The present study was conducted with two primary aims: (1) to examine the factor loading pattern of a hypothetical CPT in a sample of pregnant women who smoke, and (2) to evaluate the extent to which the CPT latent factors were independent predictors of making a quit attempt upon learning of pregnancy when more conventional predictors were

also considered. Regarding the first aim, the present study revealed a factor loading pattern that is similar, if not identical, to research conducted with other vulnerable populations (e.g., economically disadvantaged women, Higgins et al., 2020; opioid dependent participants, Higgins et al., 2020; participants with affective disorders, González-Roz et al., 2020; adolescents, Bidwell et al., 2012). Consistent with those prior studies, all CPT indices loaded onto the hypothesized latent factors. That is, Intensity and O_{max} had standard regresssion coefficients >.40 for the Amplitude factor, and O_{max}, P_{max}, Elasticity, and Breakpoint loaded onto Persistence, thereby supporting the generality of the two-factor CPT solution across diverse participant populations including pregnant women. In the current sample, 87% of the variance in the 5 index CPT could be accounted for by these two factors. Regarding the second aim, the present study is the first to test the predictive validity of CPT latent factors in predicting quit attempts among pregnant women, thereby contributing new knowledge about the strength of associations between Amplitude, Persistence, and antepartum quit attempts after controlling for the influence of other sociodemographic and smoking characteristics.

Important to note is that whether Amplitude and Persistence predicted quit attempts varied as a function of whether CPD remained in the model. More specifically, when CPD was excluded, both Amplitude and Persistence significantly and independently predicted antepartum quit attempts, with Amplitude accounting for a larger proportion of variance than Persistence. In contrast, when CPD was permitted to remain in the regression model (Table 5), Amplitude was eliminated from the model entirely and Persistence remained a significant independent predictor. The elimination of Amplitude is inconsistent with findings from multivariate modeling in Higgins et al. (2017) where the CPT index

'Intensity', which is synonymous with Amplitude in the present study, was a slightly stronger independent predictor than CPD although the two were highly correlated. Results across these two studies demonstrate a strong, perhaps almost interchangeable relationship, between Amplitude and CPD among pregnant women. Future research examining associations between cigarette demand and smoking-related outcomes among pregnant women should be prepared for substantial multicollinearity between Amplitude and CPD and conduct their logistic regression modeling accordingly.

The findings from the present study also revealed important information about sociodemographic and smoking characteristics associated with antepartum quit attempts, some of which complement while others contradict past research. For an example of consistent results, odds of antepartum quit attempts in the present sample were greater among women who initiated smoking at an older age, consistent with research conducted among U.S. national samples of pregnant women (Chen et al., 2006) and in a Vermont sample of pregnant women (Higgins et al., 2009). Similarly, the association between pre-pregnancy quit attempts and antepartum quit attempts in the present sample aligns closely with findings among the general population of smokers whereby more past quit attempts increases the likelihood of future cessation (Farkas et al., 1996; Hughes et al., 2014). Furthermore, the absence of prior quit attempts has been demonstrated to be a reliable independent risk factor for women failing to discontinue smoking during their pregnancy, whether trying to quit on their own or in the context of formal treatment as is smoking more than 10 CPD at the start of prenatal care (Kurti et al., 2016; Lopez et al., 2015; White et al., 2014; Higgins et al., 2017). For an example of results inconsistent with prior observations, menthol smokers in the current study had increased odds of antepartum quit

attempts relative to non-menthol smokers. This appears to contradict research indicating that menthol use is associated with reduced smoking cessation rates during pregnancy (Stroud et al., 2020). Alternatively, research conducted among the general population has suggested that while menthol cigarette smokers may be more likely to make quit attempts, they are less likely to successfully quit smoking (Levy et al., 2011, Keeler et al., 2017). Whether pregnant women who smoke menthol cigarettes are more likely to make antepartum quit attempts but less likely to achieve biochemically confirmed late-pregnancy smoking abstinence than their non-menthol smoking counterparts certainly merits additional examination.

Results of the current study also have implications for clinical practice as well as for treatment and tobacco regulatory policies intended to reduce maternal smoking during pregnancy. For example, results from the present study demonstrating strong associations between smoking rate and antepartum quit attempts suggest that one way for clinicians to quickly and accurately gauge a patient's nicotine dependence severity is to ask how many cigarettes she smokes per day, or how many cigarettes she would smoke in a 24-hour period if they were free. Patients' responses to these items alone may indicate whether they will require more intensive smoking-cessation counseling and/or referrals to smoking-cessation services. These study results also point to tobacco treatments and regulatory policies focused on reducing motivation to smoke. For example, one approach to reducing Amplitude (i.e., reducing the immediate reinforcing value of nicotine irrespective of price) is to provide alternative reinforcers contingent on smoking abstinence, as is done in contingency management interventions (Higgins et al., 2016, Higgins & Solomon, 2016; Higgins et al., 2014; Ondersma et al., 2012). Another potential approach to reducing

Amplitude is to deliver interventions such as Episodic Future Thinking (EFT), which is a mental simulation of future events aimed at reducing overall demand to use a substance. Human laboratory experiments have demonstrated that EFT reduces the Intensity index on the CPT among healthy adult smokers (Stein et al. 2016), although whether this generalizes to pregnant women remains to be examined. Finally, implementing policies at the national level that target all smokers may also reduce cigarette demand among pregnant women specifically. For instance, there is a growing research literature supporting a regulatory policy that would reduce the maximal nicotine content in cigarettes to very low or minimally addictive levels. Very low nicotine content cigarettes (VLNCs) have been demonstrated to reduce smoking rate and nicotine dependence severity among both the general population of US smokers (Kolzowski et al., 2001; Hatsukami et al., 2010; Donny et al., 2015) and vulnerable subpopulations (Higgins et al., 2017; Higgins et al., 2020b). Additionally, and most germane to the present study, there is evidence that VLNCs reduce cigarette demand among pregnant women who smoke (Heil et al., 2020).

The present results support efforts to reduce cigarette demand among this vulnerable population that are derived from both tobacco control and regulatory science. Given the significant adverse health impacts associated with smoking during pregnancy, it may be prudent to pursue multiple tobacco control and regulatory efforts to reduce smoking demand in this population simultaneously. Regarding tobacco control, providing widespread access to evidence-based treatments such as contingency management, which is more effective than other interventions at reducing smoking during pregnancy (Chamberlain et al., 2013; Lumley et al., 2009), would represent a significant positive contribution to improving maternal and child health. As noted above, tobacco regulatory

policies that reduce the nicotine content in marketed cigarettes are also likely to drive down cigarette demand among vulnerable populations including pregnant women (Heil et al., 2020; Higgins et al., 2017; Higgins et al., 2020b). The present study examining relationships between behavioral-economic measures of smoking demand and antepartum quit attempts has the potential to suggest important directions for future research, treatment, and policy by illuminating individual differences in motivational processes that underpin smoking and their relationship to attempting to quit smoking upon learning of a pregnancy. Continued dedication to efforts to reduce cigarette demand among pregnant women has considerable potential to improve maternal and child health and reduce health disparities.

The present study also has several limitations that merit mention. First, although the current study was conducted using a national clinical sample of pregnant women, whether the results generalize to a nationally representative sample of U.S. pregnant women is unclear. More specifically, the current sample was comprised of a higher proportion of non-Hispanic White women and women with $\geq$ 12 years educational attainment than pregnant samples in nationally representative surveys such as the Population Assessment of Tobacco and Health (PATH) study (Kurti et al., 2017b). This may be due to study recruitment methods that leveraged Facebook to reach these clinical participants. Indeed, a 2018 VCBH study using PATH data demonstrated that pregnant women with lower educational attainment were less likely to own a smartphone, send or receive texts, and download apps (Kurti et al., 2018). Of course, it is the case that the present sample was recruited exclusively based on interest in participating in a smoking-cessation trial, which is certain to be a select subset of pregnant women who smoke,

whereas the national survey samples are not recruited based on interest quitting smoking. As such it will be important for future research to examine the generality of the present research to non-clinical and socioeconomically and racially diverse samples. These limitations notwithstanding, the present study demonstrated significant and independent associations between latent CPT factors, as a two-factor loading pattern consisting of Amplitude and Persistence, and the odds of reporting antepartum quit attempts among a national sample of pregnant woman where there was an increased likelihood of making a quit attempt given lower self-report demand for cigarettes.

Tables and Figures

Figure 1. Exponential demand curve, overall.

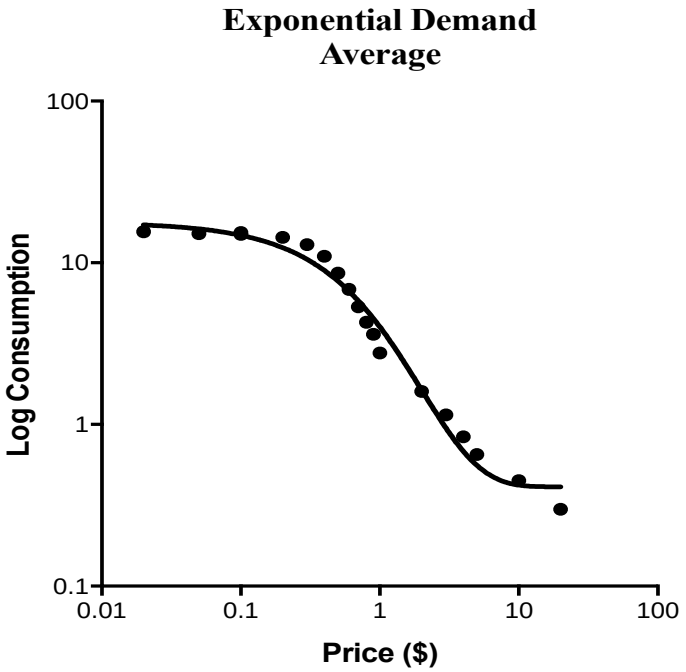

Figure 2. Mean comparisons of Elasticity of demand by number of quit attempts upon learning of pregnancy.

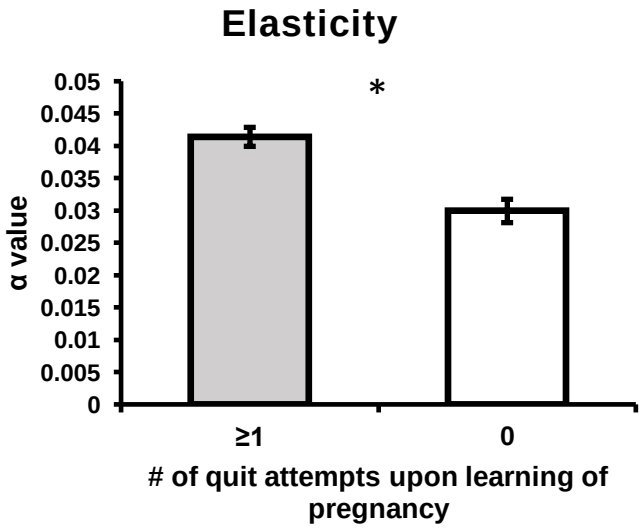

Figure 3. Mean comparisons of Intensity of demand by number of quit attempts upon learning of pregnancy.

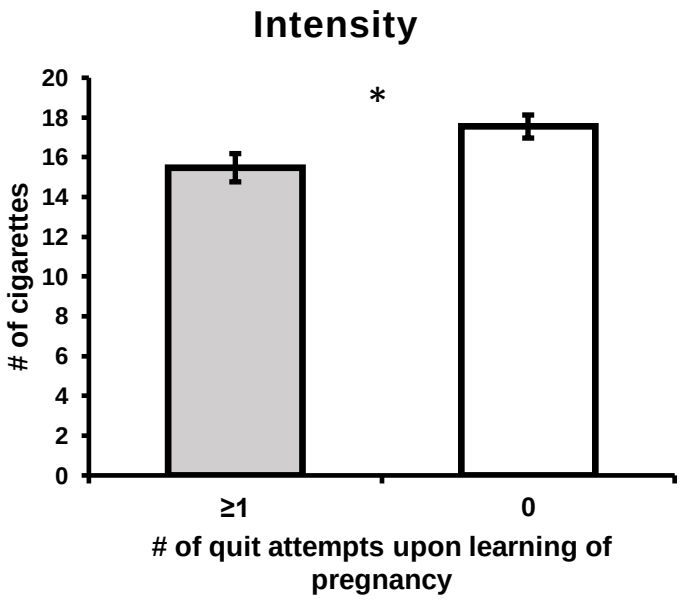

Figure 4. Mean comparisons of Pmax by number of quit attempts upon learning of pregnancy.

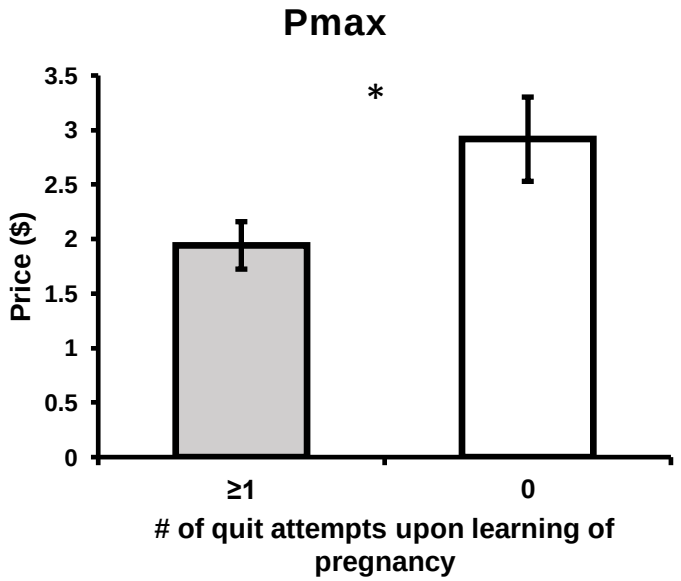

Figure 5. Mean comparisons of Omax by number of quit attempts upon learning of pregnancy.

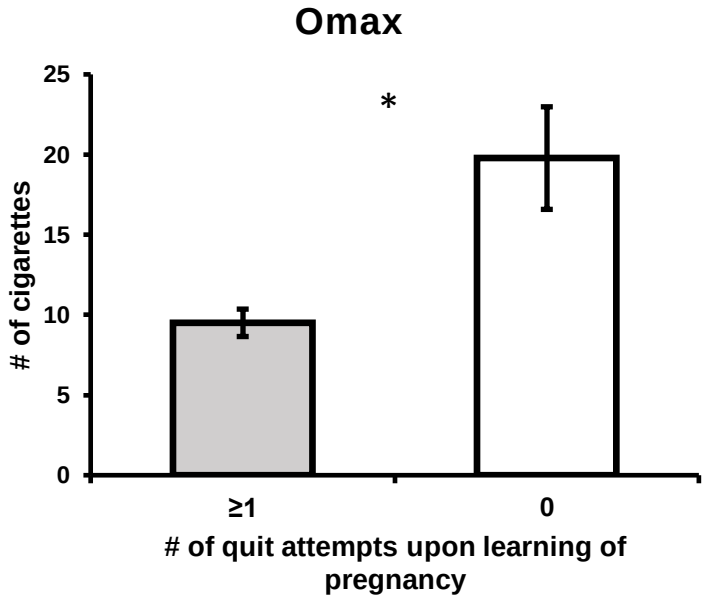

Figure 6. Mean comparisons of Breakpoint by number of quit attempts upon learning of pregnancy.

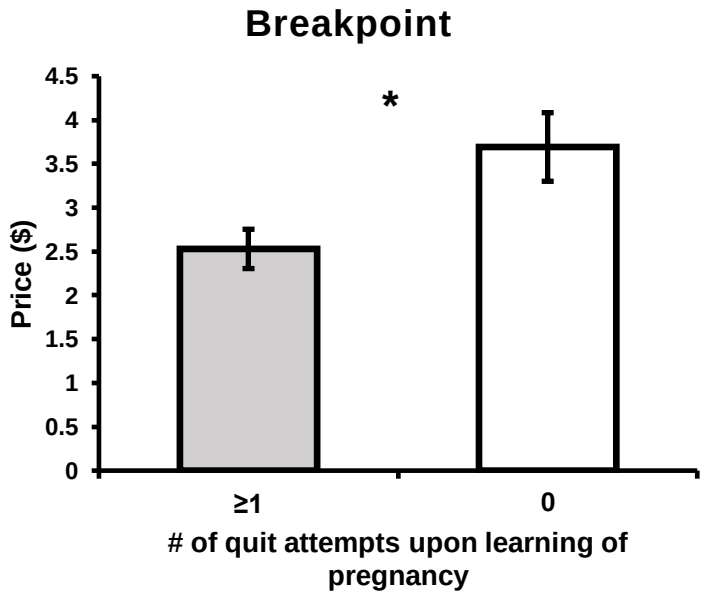

Table 1. Participant demographics and smoking history variables.

Demographics:		
Age at intake (years)		29.9 ± 5.9
Education		
	% < 12 years	10
	% = 12 years	55
	% > 12 years	35
% Married		27
% Private Insurance		29
Race and Ethnicity		
	% Non-Hispanic White	75
	% Non-Hispanic Black	14
	% Hispanic	4
	% Other	7
% Employed outside the home		47
Smoking History Variables:		
Age at smoking initiation (years)		16.1 ± 3.5
Cigarettes per day prior to pregnancy		
	% ≤ 10 per day	12
	% > 10 per day	88
Cigarettes per day during pregnancy		
	% ≤ 10 per day	44
	% > 10 per day	56
Time to first cigarette prior to pregnancy		
	% ≤ 5 minutes	41
	% > 5 minutes	59
Time to first cigarette during pregnancy		
	% ≤ 5 minutes	19
	% > 5 minutes	81
% Smoking menthol cigarettes		56

Table 2. Lower diagonal correlation matrix with Intensity (Q_0), Elasticity (α), Pmax, Omax, and Breakpoint (BP).

*Note: * indicates a significant correlation (p <.05). Coefficients refer to Spearman correlations.*

	α	**Q_0**	**P_{max}**	**O_{max}**	**BP**
α	—				
Q_0	-.335*	—			
P_{max}	-.094*	-.733*	—		
O_{max}	.527*	-.847*	.614*	—	
BP	.072	-.927*	.789*	.649*	—

Table 3. Mean index scores and rotated factor loadings.

Note: Variance describes amount of variance accounted for by a particular factor.

Index scores	**Mean**	**SD**	**Rotated latent factor loadings**	
			Amplitude Eigenvalue = 1.11 Variance = 22%	Persistence Eigenvalue = 3.27 Variance = 65%
α	.18	.08	.11	.80
Q_0	3.84	1.22	.98	-.02
P_{max}	-.11	.53	-.19	.98
O_{max}	.82	.43	.41	.79
BP	.11	.49	-.10	.96

Table 4. Backwards Elimination Stepwise Regression with cigarettes per day excluded.

Note: All variables were significantly associated with the making a quit attempt upon learning of pregnancy in a previous bivariate analysis.

Effect	Wald Chi-Square	OR [95% CI]	P-Value
Race/Ethnicity	4.98	1.13 [1.03-1.68]	<0.05
Time to first cigarette antepartum	7.54	1.91 [1.20-3.03]	<0.01
Quit attempts pre-pregnancy	22.59	2.73 [1.80-4.12]	<0.01
Menthol	4.03	1.47 [1.01-2.14]	<0.05
Age at intake	7.00	0.96 [0.93-0.99]	<0.01
Age at smoking initiation	7.79	1.09 [1.03-1.15]	<0.01
Amplitude	9.28	0.73 [0.59-0.89]	<0.01
Persistence	7.02	0.77 [0.64-0.93]	<0.01

Table 5. Backwards Elimination Stepwise Regression with cigarettes per day included.

Note: All variables were significantly associated with the making a quit attempt upon learning of pregnancy in a previous bivariate analysis.

Effect	Wald Chi-Square	OR [95% CI]	P-Value
Cigarettes per day antepartum	47.58	0.25 [0.17-0.37]	<0.01
Quit attempts pre-pregnancy	22.23	2.77 [1.81-4.23]	<0.01
Menthol	4.35	1.43 [1.02-2.18]	<0.05
Age at smoking initiation	6.04	1.08 [1.02-1.14]	<0.01
Persistence	9.27	0.74 [0.61-0.90]	<0.01

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