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Naturalistic assessment of demand for cigarettes, snus, and nicotine gum

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Abstract

Rationale—Behavioral economic measures of demand provide estimates of tobacco product abuse liability and may predict effects of policy-related price regulation on consumption of existing and emerging tobacco products.

Objective—In the present study, we examined demand for snus, a smokeless tobacco product, in comparison to both cigarettes and medicinal nicotine. We used both a naturalistic method in which participants purchased these products for use outside the laboratory, as well as laboratory-based self-administration procedures.

Methods—Cigarette smokers ($N = 42$) used an experimental income to purchase their usual brand of cigarettes and either snus or gum (only one product available per session) across a range of prices, while receiving all products they purchased from one randomly selected price. In a separate portion of the study, participants self-administered these products during laboratory-based, progressive ratio sessions.

Result—Demand elasticity (sensitivity of purchasing to price) was significantly greater for snus than cigarettes. Elasticity for gum was intermediate between snus and cigarettes but was not significantly different than either. Demand intensity (purchasing unconstrained by price) was significantly lower for gum compared to cigarettes, with no significant difference observed between snus and cigarettes. Results of the laboratory-based, progressive ratio sessions were generally discordant with measures of demand elasticity, with significantly higher “breakpoints” for cigarettes compared to gum and no significant differences between other study products. Moreover, breakpoints and product purchasing were generally uncorrelated across tasks.

Conclusions—Under naturalistic conditions, snus appears more sensitive to price manipulation than either cigarettes or nicotine gum in existing smokers.

Keywords

Cigarettes; Snus; Nicotine gum; Tobacco; Demand; Progressive ratio schedules

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Compliance with Ethical Standards

Conflict of interest The authors report no conflicts of interest.

Snus is a low-nitrosamine, smokeless tobacco product generally considered to be a less harmful alternative to cigarettes and other combustible tobacco (Fagerström and Schildt 2003; Foulds et al. 2003; Hatsukami et al. 2007; Henningfield and Fagerström 2001; Levy et al. 2004; Stepanov et al. 2008). Unlike other forms of smokeless tobacco, snus does not require spitting. Most varieties of snus available in the USA are sold in pre-packaged pouches that are placed under the lip during use. Some have advocated for snus as a means to reduce tobacco-related harm in smokers unable or unwilling to quit (Kozlowski 2007; Rodu et al. 2006). Such an approach may be valuable, as recent data indicate that use of snus in the USA is strongly associated with a desire to reduce cigarette consumption (Biener et al. 2014); moreover, snus produces therapeutic outcomes similar to medicinal nicotine gum in attempts at smoking cessation (Hatsukami et al. 2016; Kotlyar et al. 2011). However, despite the perception that snus is safer than cigarettes, snus poses greater health risks than medicinal nicotine (Hatsukami et al. 2016; Kotlyar et al. 2011) and its carcinogen and nicotine content appear unstable in an evolving marketplace (Stepanov et al. 2012a,b, 2015).

Although much is known about the effects of policy-related and experimental price regulation on consumption of cigarettes (e.g., Madden and Bickel 1999; Shahan et al. 1999), relatively little is known about the effects of price regulation on consumption of snus. This is particularly true in the USA, in which snus has only become widely available within the last decade (Biener et al. 2014). Research is needed to inform tobacco regulation, as willingness to initiate use of this product may be price-dependent. To this end, behavioral-economic assessments of *demand elasticity*, or sensitivity of consumption to changes in price, allow experimental evaluation of tobacco products' abuse liability (Hursh and Roma 2013). For example, smokers' consumption of cigarettes tends to be insensitive to increases in price (i.e., is "inelastic") across a broad range of prices (e.g., Few et al. 2012; Mackillop et al. 2008). This degree of sensitivity may be used as a baseline to judge the elasticity of novel tobacco products (e.g., snus) and their relative appeal. Importantly, these assessments allow between-product comparisons while controlling for differences in drug dose or potency likely to produce differences in the absolute quantities consumed (e.g., due to satiety; Hursh and Silberberg 2008; Hursh and Winger 1995). Independence of elasticity and dose is important in the present context, as nicotine content of snus varies considerably within and between brands (e.g., Stepanov et al. 2012a,b; Lunell and Lunell 2005). Moreover, potential differences in demand elasticity in consumption of snus compared to cigarettes would not otherwise be evident in estimates of the use of prevalence of snus available at a constant price (e.g., Biener et al. 2014).

Although some prior studies have examined demand for snus in a behavioral-economic context, the generality of these findings remains unclear. Most relevant to the present study, O'Connor et al. (2014) used hypothetical purchase tasks (see Roma et al. 2015) to examine demand for cigarettes, snus, medicinal nicotine lozenges, and dissolvable tobacco, in which an internet-based sample of cigarette smokers reported the quantity of products they would purchase across a range of prices. Although these authors' research aims regarded the effects of product-specific advertisements on demand, they generally observed greater demand elasticity (lower abuse liability) for snus and nicotine lozenges compared to cigarettes. One factor that may limit this finding's generality is that a large proportion of participants

(almost half) reported having never tried smokeless tobacco or medicinal nicotine (including the specific products available in the study). Therefore, due to the hypothetical nature of the purchase tasks, these participants' demand data were not informed by direct experience. Although these authors reported no differences in demand between those who had and had not reported prior use of smokeless tobacco, the majority of participants who reported prior use likely did not specifically have direct experience with snus, as recent data indicate that only a relatively small proportion of smokers in the USA have ever tried this product (Biener et al. 2014). Moreover, additional data indicate that prior use of smokeless tobacco predicts acceptance of a free trial novel tobacco products, including snus; in turn, willingness to try snus turn is associated with greater snus demand assessed through an experimental auction (Rousu et al. 2015).

In the present study, we examined demand for cigarettes and snus by using methods that ensure prior exposure to study products. For purposes of comparison, we also examined demand for medicinal nicotine gum. Initially, cigarette smokers attended laboratory sessions in which they self-administered cigarettes and either snus or nicotine gum across increasing behavioral response requirements (plunger pulls). The purpose of these *progressive ratio assessments* (see Stafford et al. 1998) was twofold, as they both provided participants with a controlled environment in which to sample study products and provided a supplementary measure of reinforcing efficacy to be compared to subsequent demand measures. Next, by using a method of demand assessment recently developed in our lab (Koffarnus et al. 2015b; Wilson et al. 2016), participants obtained real-world supplies of study products to use outside the laboratory. At each of four prices ($0.12, $0.25, $0.50, and $1.00), participants used an experimentally provided income to report the number of study products they would like to purchase for use over the following week. Following task completion, one price was selected randomly to be "real" and participants took home all study products purchased at that price. Unlike other methods of demand assessment in which participants self-administer a drug in a laboratory setting (e.g., Shahan et al. 2001), this face-valid, naturalistic approach allows purchasing and consumption to be subject to not only price but also real-world constraints (e.g., social reinforcement or punishment; smoking bans).

Method

Participants

Participants were recruited from Roanoke, VA, and surrounding areas by using flyers, the internet, and word-of-mouth referral. To be eligible, participants had to meet DSM-IV (American Psychiatric Association 1994) criteria for nicotine dependence: smoke at least 10 cigarettes per day; smoke every day for the last 30 days; exhale at least 14 ppm carbon monoxide (CO) at intake, as measured by a CO monitor (CoVita Smokerlyzer; Haddonfield, NJ); be at least 18 years of age; and be willing to use snus or nicotine gum. Participants were excluded if they were pregnant, were trying to quit smoking or taking medications that aid in smoking cessation (e.g., varenicline, bupropion), met DSM-IV dependence for any drug of abuse other than nicotine, reported unstable mental or physical health, or reported regular prior use of snus or nicotine gum. Regular use of snus or gum was an exclusion criterion to minimize pre-existing bias for these products.

After providing informed consent, participants were assigned to self-administer and purchase their usual brand of cigarettes and either Camel® Winterchill™ snus (approximately 9 mg nicotine per pouch; Stepanov et al. 2012b) or Nicorette® FreshMint™ polacrilex gum (4 mg per piece). At intake, participants completed the Fagerström Test for Cigarette Dependence (FTCD; Fagerström 2012; Heatherton et al. 1991) and reported the average number of cigarettes smoked per day over the last 30 days by using a timeline follow-back survey (Brown et al. 1998), as well as a number of other behavioral tasks and surveys not reported here for brevity.

Apparatus and materials

Throughout the study, participants completed sessions in ventilated smoking booths (1.8 × 1.8 × 2.74 m) equipped with a desktop computer and a console featuring three response plungers (Med Associates, St. Albans, VT) requiring approximately 20 N to operate. Plungers were aligned horizontally, equidistant from one another along the front of the console.

In order to measure cigarette puff volume, the computer interfaced with a pressure sensor (Rayfield Equipment, Waitsfield, VT) attached to a cigarette holder via approximately 90 cm of polyvinyl tubing. Puff-induced pressure changes were processed by an A/D card (PCI-DAS08, using Instacal software; Measurement Computing Corp., Norton, MA).

Progressive ratio sessions

At intake and throughout the experiment, cigarette puff volume was standardized at approximately 70 mL (Johnson et al. 2004; Johnson and Bickel 2003). Participants were trained to light a cigarette without inhaling, place it in a cigarette holder connected to the pressure sensor, and then inhale from the cigarette while estimated puff volume was displayed in real time on a computer screen. Upon reaching 60 mL, the displayed puff volume turned from white to red, which signaled the approximate time participants should stop inhaling in order to reach approximately 70 mL. In contrast, participants were instructed to keep snus or nicotine gum in their mouths for 10 min (timed on the computer screen). To standardize use of nicotine gum, participants were instructed to chew the gum every 2 s to keep time with a computer-generated, metronomic tone (Digard et al. 2013).

Following intake, participants completed two, 3-h progressive ratio (PR) sessions in which either cigarette puffs or their assigned alternative product (snus or gum) could be earned by pulling a response plunger. Participants were informed which product was available prior to each session.

Only one product was available per session, and participants completed sessions for each product in a counterbalanced order. Prior to each PR session, participants provided breath samples to ensure approximately 6-h smoking deprivation (i.e., a CO level less than or equal to half of that at intake) and negative blood alcohol levels. If either of these criteria were not met, the session was rescheduled for another day.

Participants could self-administer the available products across response requirements that increased within session: 10, 100, 1000, 1800, 3200, 5600, and 10,000 plunger pulls. This

progression of PR values approximated a logarithmic scale, with some lower response requirements omitted to minimize within-session satiety and to increase the likelihood of reaching breakpoints before the 3-h session elapsed. The maximum response requirement completed during the session served as each participant's "breakpoint," where higher breakpoints reflect greater reinforcing efficacy. After participants completed each response requirement, they received a single unit of the available product (a standardized 70-mL cigarette puff or a single piece of gum or pouch of snus). Participants were required to wait a pre-determined amount of time (13 min for cigarettes, 3 min for snus or gum) after each self-administration before beginning the next highest response requirement.

Purchase sessions

Following PR sessions, participants returned to the laboratory to complete two purchase sessions (one for cigarettes and one for snus or gum; order counterbalanced), each separated by 7 days. In these sessions, participants were provided with an experimental income based on their real-world cigarette expenditure, obtained by multiplying mean cigarettes per week at intake for each participant by $0.25 (the approximate unit price of cigarettes in the Roanoke, VA area). Participants were informed that they could use this income to purchase available tobacco products and that they could keep any unspent income at the end of the purchase session. At each session, participants completed a computerized task to report the number of products they would like to purchase at each of four prices ($0.12, $0.25, $0.50, $1.00 per unit) to use over the following 7 days, with the amount of each purchase deducted from their income displayed on the computer monitor. At the end of each session, participants randomly drew one of these prices from a bowl and received the products purchased at this price as well any unspent income.

Participants were asked to refrain from using non-study products over the following 7 days. However, purchasing of non-study products was not penalized to encourage honest reporting. Seven days following each purchase session, participants returned to the laboratory to either complete the next purchase session or a follow-up session. Upon returning, participants completed the timeline follow-back survey to report all study and non-study products used the preceding week and were allowed to return unused study products for a refund.

Data analysis

All analyses were conducted by using GraphPad Prism (v. 6.05; La Jolla, CA, USA). Demographic data were compared between the snus and gum groups by using either *t* tests (age, education, cigarettes per day, and FTCD scores) or Fisher's exact tests (gender and race).

Progressive ratio sessions—For the PR sessions, individual participants' PR breakpoints served as the dependent measure. Breakpoints were not normally distributed and were therefore square root transformed prior to analysis. Transformed breakpoints were compared by using one-way ANOVA, followed by sequential Bonferroni-corrected post hoc tests to compare between individual products.

Purchase sessions—Data from purchase sessions were subjected to preliminary analyses to detect possible instances in which price did not systematically affect purchasing; such data, if present, may require alternative analysis methods or, in some cases, may warrant exclusion. Using standardized criteria developed and tested in a previous paper (Stein et al. 2015), we identified five demand functions for snus and four for gum that were not systematically affected by price. Further analysis revealed that all such functions were identified as non-systematic due to an absence of purchasing at all prices. These "null" demand functions were retained in some subsequent analyses and excluded in others (see below). In addition, we used Fisher's exact tests to investigate whether the frequency of such null data differed between snus and gum. Moreover, because prior data indicate that adoption of snus is more common in males than females (Biener and Bogen 2009; Biener et al. 2014; Norberg et al. 2011), we used Fisher's exact tests to investigate whether the frequency of such null data differed by gender.

Group average demand functions for each product were then fitted by using a modified version of Hursh and Silberberg's (2008) exponential demand equation,

$$\log_{10}Q=\log_{10}Q_0+k(e^{-\alpha Q_0 P}-1), \quad (1)$$

where Q is consumption, P is price, k is span of consumption in $\log_{10}$ units, α is demand elasticity (sensitivity of consumption to increasing price), and Q_0 is demand intensity (consumption unconstrained by price). Although useful in describing demand data, Eq. 1 presents problems when participants do not purchase the available product at one or more prices. Because zero values cannot be log transformed, application of Eq. 1 to demand data requires either elimination of zeroes or replacement of zeroes with nominal values (e.g., 0.01, 0.1); both of these strategies, however, can drastically affect demand estimates depending on the number of obtained zero values or the precise nominal values used (see Koffarnus et al. 2015a). Because our obtained data contained a substantial number of these zero values (including, and in addition to, the null demand functions described above), we used the following validated formula modification (Koffarnus et al. 2015a; Yu et al. 2014):

$$Q=Q_0\times 10^{k(e^{-\alpha Q_0 P}-1)} \quad (2)$$

in which all parameters are identical to those in Eq. 1, but both sides of the equation have been raised to the power of 10. This modified Eq. 2 allows analysis of unaltered consumption values, including zeros.

Before final model fitting, we normalized quantities purchased by expressing purchases as $Q_{norm} = Q/Q_0$ and price as $P_{norm} = P\times Q_0$ (Hursh and Silberberg 2008). Values of k in all model fits were set to 1.40, which provided good fits to observed mean data (R^2 range 0.992–0.999). Model-derived values of Q_0 in initial model fitting were used to normalize data and, following normalization, were reduced to values of $Q_0 = 1$. Model-derived values of α and Q_0 (prior to normalization) served as the dependent measures of demand elasticity and intensity, respectively; we compared these values between products by using extra-sum-

of-squares *F* tests with sequential Bonferroni correction. These analyses were performed twice: once when including all participants (which produced a general estimate of demand for snus and nicotine gum) and once when excluding data from all participants who contributed the null demand functions described above (which restricted estimates of demand to those showing at least nominal valuation of snus or nicotine gum).

Correlations between progressive ratio breakpoints and purchasing—Finally, in order to investigate the degree of correspondence between PR breakpoints and product purchasing, we examined Spearman *rho* correlations between PR breakpoints and the quantity of products purchased at each price in the purchase sessions. We did not use model-derived demand estimates in this analysis because these measures in many cases were inestimable at the individual-subject level (see the null demand functions described earlier).

Results

Demographic characteristics

Forty-two individuals completed the study ($n = 22$ and 20 in the snus and gum groups, respectively). Table 1 provides demographic characteristics of each group. Results of chi-squared tests revealed no significant differences in gender or race between groups (in both cases, $p > 0.999$). Likewise, results of *t* tests revealed no significant differences between groups in age, education, cigarettes smoked per day, or FTCD score (in all cases, $p > 0.421$).

PR sessions

All participants completed at least one response requirement for cigarette puffs and their assigned study product (snus or nicotine gum). Figure 1 presents PR breakpoints for these products. We collapsed cigarette PR breakpoints across groups, as we observed no significant difference across groups, $t(40) = 1.189$, $p = 0.242$. Results of one-way ANOVA indicated a significant main effect of product on PR breakpoint, $F(2, 81) = 9.62$, $p < 0.001$. Post hoc tests revealed significantly lower breakpoints in gum compared to cigarettes ($p < 0.001$). However, only marginally significant differences were observed between cigarettes and snus ($p = 0.064$) and snus and gum ($p = 0.054$).

Purchase sessions

All participants purchased cigarettes at one or more prices. As mentioned previously, however, 5 of 22 participants never purchased snus and 4 of 20 participants never purchased gum at any price. The frequency of these null demand functions did not differ significantly between snus and gum (odds ratio = 0.85 [CI 0.19–3.74); $p > 0.999$). However, when we stratified these values by gender, null demand functions for snus were significantly more frequent in females compared to males (5/10 females vs. 0/12 males; odds ratio = 25.00 [CI 1.17–535.6]; $p = 0.010$). In contrast, no significant difference in the frequency of null data was observed for nicotine gum between males and females (1/10 females vs. 3/10 males; odds ratio = 0.26 [CI 0.02–3.07]; $p = 0.582$).

As with PR breakpoints, we observed no significant difference between the snus and gum groups in values of cigarette demand intensity, $F(1, 164) = 1.01$, $p = 0.317$, or elasticity, $F(1,$

164) = 0.01, $p = 0.941$; therefore, cigarette demand data were collapsed across group in all subsequent demand analyses. For each product, Fig. 2 depicts normalized demand functions for cigarettes, snus, and nicotine gum, as well as corresponding estimates of demand elasticity and intensity. The top panels depict these estimates when all data were included, whereas the bottom panels depict these estimates when excluding data from participants contributing null demand functions for snus or nicotine gum. Non-normalized quantities purchased appear in Table 2. Values of R^2 in the group models incorporating inter-subject variability in purchasing were 0.475 (cigarettes), 0.201 (snus), and 0.103 (gum) with all participants included; these values were 0.495 (cigarettes), 0.309 (snus), and 0.155 (gum) with null demand participants excluded.

Demand elasticity—When all data were included in the analysis (top panels of Fig. 2), we observed significantly greater elasticity for snus compared to cigarettes, $F(1, 254) = 37.87$, $p < 0.001$. However, we observed no significant difference in elasticity between gum and cigarettes, $F(1, 246) = 4.57$. $p = 0.070$, or snus and gum, $F(1, 166) = 2.18$, $p = 0.142$. When considering only data from participants who purchased snus or gum at least once (bottom panels of Fig. 2), we still observed significantly greater elasticity for snus compared to cigarettes, $F(1, 198) = 22.93$, $p < 0.001$, and again no significant difference between gum and cigarettes, $F(1, 194) = 1.71$. $p = 0.192$, or snus and gum, $F(1, 130) = 2.39$, $p = 0.248$.

Demand intensity—When all data were included in the analysis (top panels of Fig. 2), we observed significantly lower demand intensity for gum compared to cigarettes, $F(1, 246) = 37.13$, $p < 0.001$, but no significant differences in demand intensity between snus and cigarettes, $F(1, 254) = 3.09$, $p = 0.080$, or snus and gum, $F(1, 166) = 3.15$, $p = 0.156$. Likewise, when considering only data from participants who purchased snus or gum at least once (bottom panels of Fig. 2), we still observed lower demand intensity for gum compared to cigarettes, $F(1, 194) = 30.03$, $p < 0.001$, and no significant differences between snus and cigarettes, $F(1, 198) = 2.03$, $p = 0.156$, or snus and gum, $F(1, 130) = 4.75$, $p = 0.062$.

Correlation between PR breakpoints and purchasing

Table 3 presents Spearman rho correlations between PR breakpoints and the product quantities purchased at each price during purchase sessions. Rho coefficients were more frequently negative than positive (range −0.32 to 0.46). PR breakpoints for cigarettes were significantly correlated with cigarette purchasing at the $0.12 price (rho = 0.46, $p = 0.002$). However, no other coefficients reached statistical significance (all ps > 0.16, uncorrected).

Discussion

The present study sought to compare demand elasticity for cigarettes, snus, and medicinal nicotine gum in cigarette smokers with little to no prior experience with these products. Purchasing of snus was significantly more elastic than cigarettes, regardless of whether participants who never purchased snus were included or excluded from analyses. In contrast, no significant differences in elasticity were observed in either analysis between cigarettes and gum or snus and gum. Approximately 21 % of participants never purchased snus or gum at any price, with such null demand data for snus significantly more frequent in females than

males. Finally, results of the laboratory-based, progressive ratio sessions were generally discordant with demand elasticity, with PR breakpoints uncorrelated with product purchasing and otherwise insensitive to differences observed in elasticity between cigarettes, snus, and gum.

Greater levels of demand elasticity in snus compared to cigarettes may be due to a number of factors, including differences in nicotine pharmacokinetics between products. Specifically, accumulation of plasma nicotine levels following self-administration of snus and gum is significantly slower than that observed for cigarettes (Digard et al. 2013; Schneider et al. 2004)—one factor that may limit the abuse liability of orally administered tobacco products (Henningfield and Keenan 1993). In addition, differences in sensory experience may also contribute to observed differences in elasticity between snus and cigarettes. Specifically, Biener et al. (2014) reported that of those in the USA who have tried but did not continue to use snus, approximately 70 % of females and 15 % of males report disliking its taste and approximately 81 % of females and 23 % of males report not liking how it feels in the mouth. Other prominent reasons for discontinuation of snus after sampling include the perception that using snus looked bad in public (58 % of females and 3 % of males) and nausea (17 % of females and 19 % of males; Biener et al. 2014). Regardless of the cause, the present data suggest that purchasing of snus is more sensitive than cigarettes and nicotine gum to price manipulation. Moreover, observed gender differences in the purchasing of snus agrees generally with prior experimental and survey data (Biener and Bogen 2009; Biener et al. 2014; Norberg et al. 2011), in which use of snus is more common among males than females; however, the present study is the first to our knowledge to demonstrate such differences in a behavioral-economic context.

Greater elasticity for snus compared to cigarettes in cigarette smokers in the present study corroborates findings reported by O'Connor et al. (2014), who used online hypothetical purchase tasks to examine demand for cigarettes, snus, medicinal nicotine lozenges, and dissolvable tobacco. Greater frequency of null demand for observed for snus compared to cigarettes is also consistent with the findings of O'Connor et al. (also see Rousu et al. 2014). Because we provided direct exposure to snus in the present study, reduced valuation of snus compared to cigarettes observed by O'Connor et al. was not likely due to neophobia or product inexperience. However, despite consistent conclusions about snus across studies, our conclusions about medicinal nicotine differ. Specifically, O'Connor et al. reported that elasticity for medicinal nicotine lozenges was intermediate between snus and cigarettes and significantly different than both. In contrast, demand elasticity for medicinal nicotine gum in the present study was statistically undifferentiated from both snus and cigarettes. Despite these null findings, however, we note that levels of elasticity for nicotine gum were generally intermediate to those for snus and cigarettes, which is at least ordinally consistent with prior data (O'Connor et al. 2014; Rousu et al. 2014) despite differences in the form of medicinal nicotine between studies. Although nicotine gum was not a primary focus of the present study and was included only as a comparator product, future work should compare demand for nicotine gum and cigarettes more thoroughly.

Results of the laboratory-based PR assessments in the present study were largely inconsistent with measures of demand elasticity. Specifically, purchasing of snus was more

elastic than cigarettes in the naturalistic assessment; however, in the PR assessment, only a marginally significant difference in breakpoint for cigarettes and snus was observed and PR breakpoints for gum were *higher* than for cigarettes. Moreover, we failed to observe robust, positive correlations in consumption between assessment types (see Table 3), with correlation coefficients more frequently negative than positive across prices and products. In contrast, between-product differences in PR breakpoints were highly consistent with differences in demand *intensity*—that is, both PR breakpoints and demand intensity were lower in nicotine gum compared to cigarettes and undifferentiated from snus. Here, we note that PR breakpoints, unlike measures of elasticity in the present study, confound sensitivity to fixed ratio price and differences in drug dose (which may differentially limit the absolute quantity of consumption across products). In contrast, by normalizing purchasing to levels of own-product demand intensity (which differed between cigarettes and gum in the present study), estimates of elasticity are able to isolate sensitivity to price from differences in raw consumption between products (Hursh and Winger 1995; Hursh and Silberberg 2008). This discrepancy between measures may account for why PR assessment yielded between-product differences more similar to demand intensity than elasticity.

Two additional factors may account for the discrepancies between PR breakpoints and demand elasticity. First, the laboratory environment in PR sessions featured no available nicotine substitutes for nicotine-deprived participants. This closed economy, compared to the open economy of the naturalistic context in which participants had continuous access to cigarettes, may have encouraged greater consumption of otherwise non-preferred products and therefore minimized between-product differences. Second, participants received explicit instruction on how to use snus and gum during the PR assessment. The purpose of this instruction, including the duration of each self-administration, was in part to accommodate the constraints of the laboratory environment (e.g., to minimize satiety over the course of a finite session length). In contrast, participants received no explicit guidance on use of these products outside the laboratory. Thus, topography of use in the naturalistic assessment was likely more heterogeneous, and similar to naturally occurring topography, than in the PR assessment. This difference, in turn, may have been responsible for discrepant findings and point to an instance in which laboratory constraints may obscure naturally occurring variables that influence tobacco consumption. In general, divergent findings across methods highlight the need for naturalistic methods of demand assessment that emulate the prevailing environmental conditions in which tobacco is typically purchased and used. Future research, however, will more systematically compare demand measures obtained from operant self-administration and purchase tasks.

The finding that snus is more sensitive than cigarettes to price manipulation may prove important in future policy efforts to regulate tobacco consumption. For example, if the promotion of snus proves a viable method of tobacco harm reduction, then the present findings suggest that the price of snus should be kept relatively low in order to effectively compete with cigarettes. Conversely, if snus either fails to prove an adequate substitute for cigarettes or facilitates adoption of tobacco use in those who would not otherwise smoke cigarettes, then the present findings suggest that consumption would be highly responsive to price regulation in order to reduce use. What is needed in future research, however, is a more dynamic approach to demand assessment. In the present study, only one product was

available for purchase at a time. In future studies, assessment of cross-price elasticity of demand (Hursh 1980, 1984), in which two or more products are available simultaneously, is necessary to accurately capture the complex interactions between product type and price and more closely approximate the real-world marketplace in which participants have access to a variety of tobacco products at different prices. Along these lines, Quisenberry et al. (2015) and O'Connor et al. (2014; discussed previously) used separate assessments of cross-price elasticity and reported that price-constant alternative tobacco products (including snus and medicinal nicotine) served as modest substitutes for cigarettes. Additional work should be designed to examine these substitutive relations following direct product exposure, as well as the conditions that may moderate these effects (e.g., smoking education, advertising, or demographic variables).

Limitations

Two limitations of the present study deserve note. First, the generality of our conclusions are restricted to the population we recruited—smokers who do not regularly use snus or nicotine gum. Whether demand for these products would be greater in dual users of cigarettes and one of these alternative products awaits further investigation. A comprehensive research approach to inform public policy should consider all population types to anticipate any untoward effects of price regulation. Second, our conclusions are also restricted to the specific varieties of snus and nicotine gum used in this study (Camel® Winterchill™ snus and Nicorette® FreshMint™). The complex, evolving marketplace for snus and medicinal nicotine features heterogeneity in nicotine content, flavor, and quality (Digard et al. 2013; Stepanov et al. 2012a,b, 2015), which poses research challenges and may limit general conclusions. However, mint flavors of smokeless tobacco and medicinal nicotine appear the most popular among clinical trial participants (Meier et al. 2016); thus, the flavors used in the present study were those shown in prior work to be widely preferred. Nonetheless, future work should investigate alternative varieties of snus and nicotine gum.

Conclusions

Under naturalistic conditions, the present data suggest that snus is more sensitive to price manipulation than cigarettes in existing smokers. In contrast, nicotine gum and cigarettes are approximately equally sensitive to price manipulation, despite differences in the absolute quantities purchased. Future research should systematically examine different varieties of snus and nicotine gum and assess demand for these and other alternative tobacco products under more dynamic conditions (e.g., assessments of cross-price elasticity).

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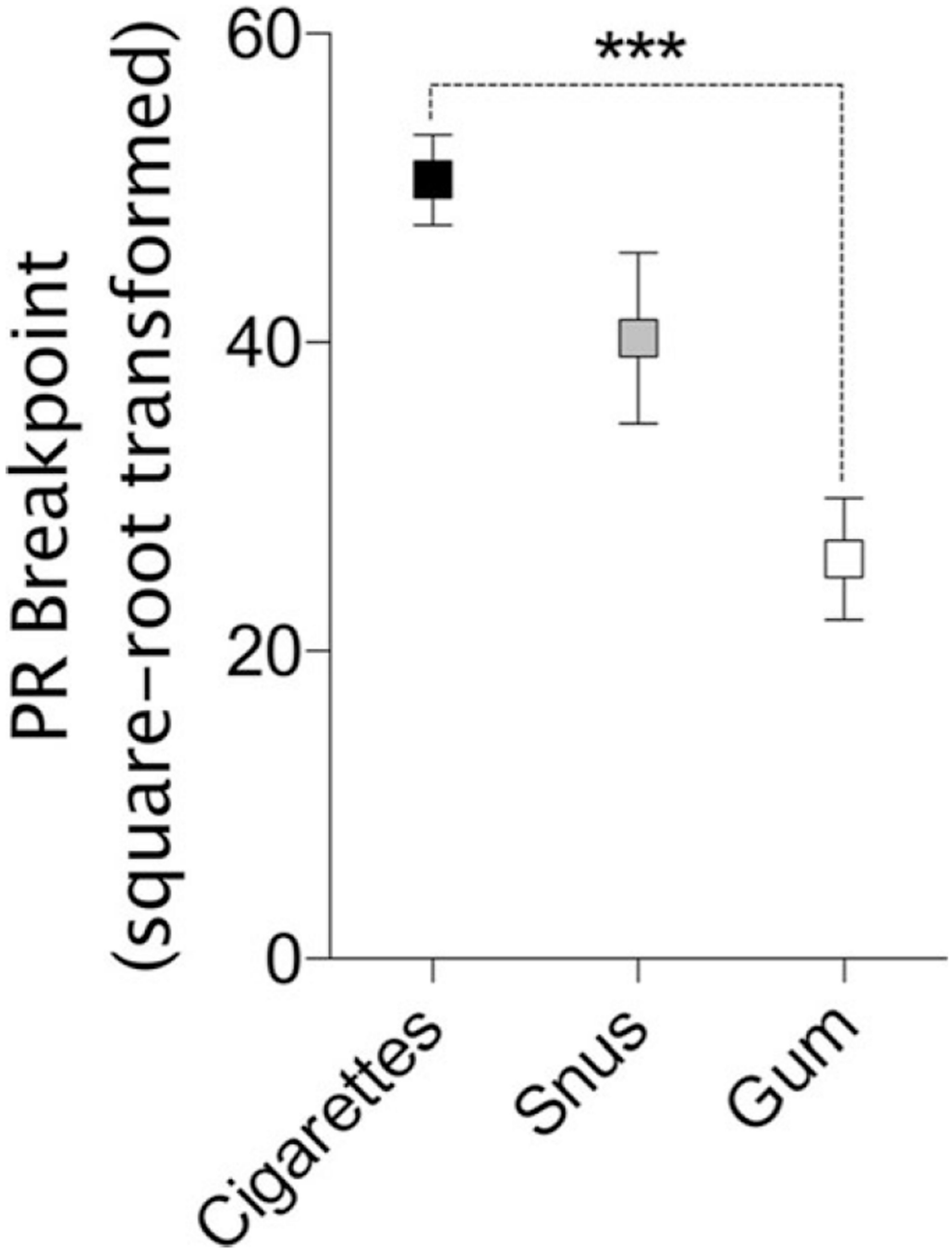

Fig. 1.

Progressive ratio breakpoints for cigarettes, snus, and nicotine gum. *Error bars* represent standard error of the mean. ***$p < 0.001$

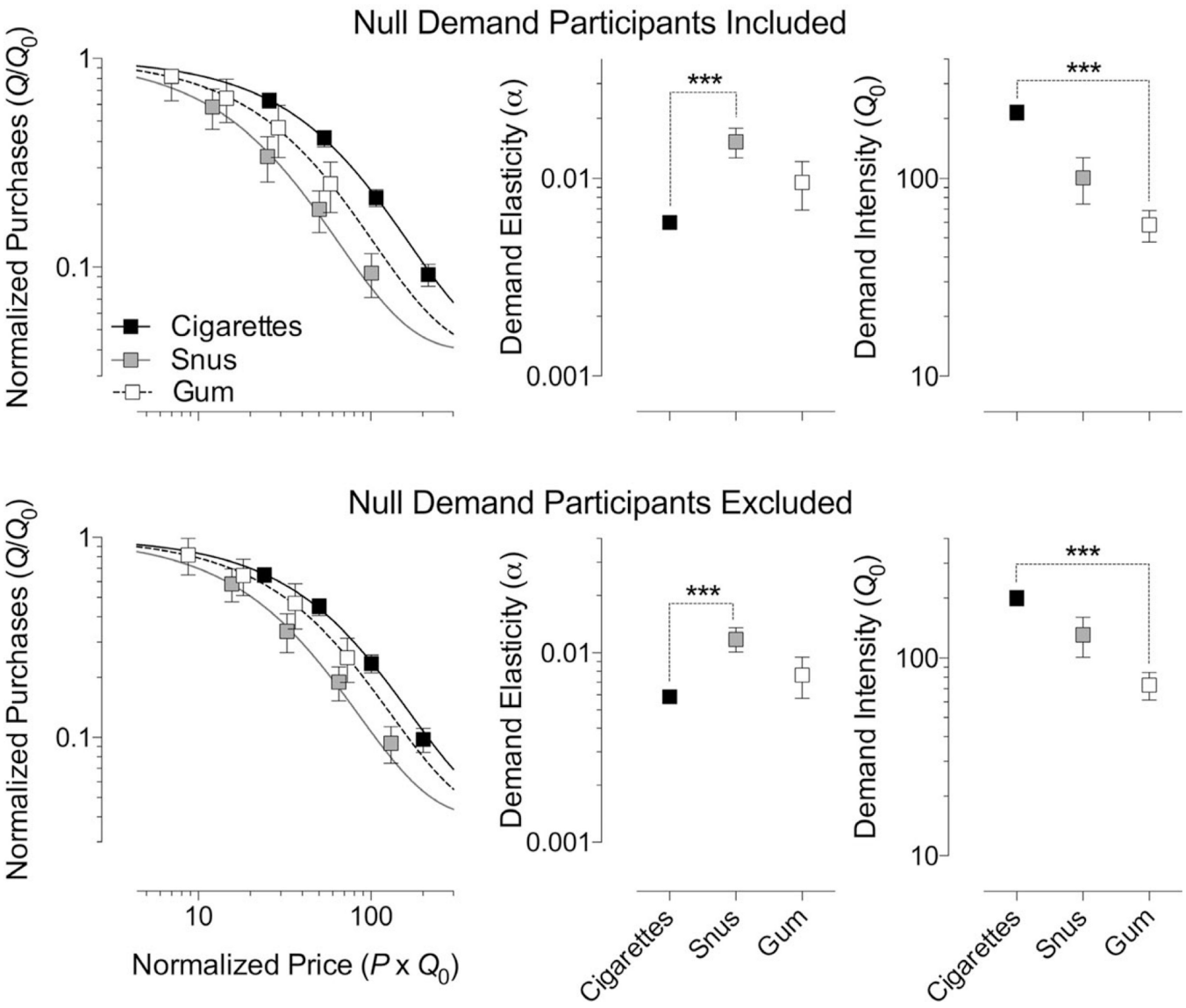

Fig. 2.

Normalized demand functions for cigarettes, snus, and nicotine gum, as well as corresponding estimates of demand elasticity (*left and middle panels*). Also depicted are estimates of demand intensity prior to normalization (*right panels*). *Top and bottom panels* depict data when participants contributing null demand functions for snus or gum were either included or excluded from analyses, respectively. *Error bars* represent standard error of the mean. ***$p < 0.001$

Table 1

Sample size, demographic characteristics, and smoking measures for the snus and gum groups

	Snus group	Gum group
N	22	20
% Female	45.45	50.00
% Caucasian	59.09	55.00
Age (yrs; ±SD)	39.50 (12.11)	39.70 (10.90)
Educ. (yrs; ±SD)	13.00 (1.38)	12.95 (1.43)
C/d (±SD)	19.83 (7.69)	21.06 (8.52)
FTCD (±SD)	6.14 (1.36)	5.95 (1.43)

yrs years, *Educ*. education, *C/d* cigarettes per day at intake, *FTCD* Fagerström Test for Nicotine Dependence

Table 2

Non-normalized, mean (±SD) cigarettes, pouches of snus, and pieces of nicotine gum purchased at each price

		Product		
Null demand treatment	**Price**	**Cigarettes**	**Snus**	**Gum**
Included	$0.12	135.45 (71.62)	59.00 (60.85)	47.75 (50.08)
	$0.25	89.36 (50.76)	34.32 (39.69)	37.55 (39.38)
	$0.50	46.36 (27.81)	19.09 (20.29)	27.20 (33.86)
	$1.00	19.83 (15.64)	9.46 (10.54)	14.65 (17.87)
Excluded	$0.12	130.61 (62.45)	76.35 (58.76)	59.69 (49.16)
	$0.25	90.69 (50.52)	44.41 (39.89)	46.94 (38.66)
	$0.50	47.15 (28.18)	24.71 (19.83)	34.00 (34.72)
	$1.00	9.64 (15.47)	12.24 (10.47)	18.31 (18.25)

Table 3

Spearman rho correlations (and *p* values) between progressive ratio breakpoints for cigarettes, snus, and nicotine gum and the quantities of the same product purchased at each price in the purchase sessions

	Price			
Product	**$0.12**	**$0.25**	**$0.50**	**$1.00**
Cigarettes	**0.46 (0.002)**	−0.09 (0.592)	−0.05 (0.754)	−0.09 (0.581)
Snus	0.15 (0.513)	0.11 (0.620)	0.10 (0.651)	0.11 (0.621)
Gum	−0.20 (0.405)	−0.19 (0.434)	−0.30 (0.198)	−0.32 0.163)

Bolded coefficients indicate statistical significance