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Brief report

# Effects of Filter Ventilation on Behavioral Economic Demand for Cigarettes: A Preliminary Investigation

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## Abstract

**Introduction:** The majority of cigarettes sold in the United States and abroad feature filter ventilation holes designed to dilute mainstream smoke. Although initially intended to produce a safer cigarette, data instead suggest that filter ventilation increases total harm from smoking. In the present study, we examined the effects of blocking ventilation holes on behavioral economic demand for cigarettes (i.e., consumption as a function of price).

**Methods:** In a within-subjects design, regular smokers ($N$ = 15) of ventilated cigarettes sampled vent-blocked cigarettes for 3 days. Subsequently, they completed three sessions in which they used an experimental income to purchase vent-blocked and/or control cigarettes across a range of prices. Participants also completed the Drug Effects/Liking Scale.

**Results:** In sessions in which only one cigarette type was available, demand measures were undifferentiated between cigarette types. However, in sessions in which both cigarettes were available at equivalent prices, significantly greater preference for ventilated control cigarettes emerged in demand measures. Regardless of session type, participants also rated vent-blocked cigarettes more poorly in the Drug Effects/Liking Scale (more bad effects, fewer good effects, and less liking, desire, and less likely to use again).

**Conclusions:** Removing filter ventilation reduced cigarette abuse liability, as measured by behavioral economic demand and the Drug Effects/Liking Scale. However, reduced demand was only apparent when both cigarette types were concurrently available. This selective effect suggests that regulatory action banning filter ventilation would only reduce cigarette consumption when effective substitutes for vent-blocked cigarettes are available.

**Implications:** This preliminary study indicates that regulatory action designed to ban or restrict cigarette filter ventilation may decrease cigarette abuse liability as measured by both behavioral economic demand and self-report measures. However, effects of removing filter ventilation on demand measures appear to depend on concurrent availability of alternative, preferred cigarette types.

## Introduction

The majority of cigarettes sold in the United States and abroad feature ventilated filters, comprising one or more perforated rings around the filter's tipping paper.[1–3] Designed to dilute mainstream cigarette smoke, filter ventilation was intended to reduce tar and nicotine yields as measured by standardized machine regimens under the prevailing assumption that lower tar exposure would lead to reduced disease risk. In contrast, human smoking data suggest that ventilation increases smoking harm because smokers take larger puffs, more puffs per cigarette, inhale more deeply, or smoke more cigarettes to compensate for reduced nicotine.[3–5] Indeed, misperceptions about the safety of low-tar and low-nicotine cigarettes (featuring high levels of filter ventilation, among other design elements) led the Food and Drug Administration in 2010 to ban the use of product identifiers that imply reduced risk, including "light" and "ultra-light."

Citing these ventilation-dependent changes in smoking behavior, some have advocated for banning filter ventilation to reduce smoking harm.[3–6] Such a ban may have broad influence due to the ubiquity of ventilation in commercially available cigarettes. For example, approximately 80–90% of all brands in the United States and United Kingdom feature some level of ventilation,[2] with the majority of smokers choosing brands with moderate to high levels.[3] However, little is known about the role filter ventilation plays in cigarette abuse liability, specifically whether banning ventilation would increase cigarette appeal (e.g., by effectively increasing nicotine yields) or decrease appeal (e.g., by increasing smoke harshness or throat burn). Preliminary research is necessary to avoid untoward effects of regulatory action.

In this preliminary investigation, we used measures of behavioral economic demand (consumption as a function of price) to examine the effects of removing filter ventilation on cigarette abuse liability. Demand methods have been used broadly in tobacco regulatory science to estimate the reinforcing value of existing and emerging tobacco products, including in studies comparing cigarettes that vary in design.[7,8] In the present study, we examined two measures of abuse liability: (1) *demand intensity*, or consumption unconstrained by price (greater intensity = greater abuse liability) and (2) *demand elasticity*, or sensitivity of consumption to price (lower elasticity = greater abuse liability). Under a naturalistic method developed in prior research,[9–11] participants used an experimental income to purchase vent-blocked and/or ventilated control cigarettes for use in the real world. We also examined traditional self-report measures of abuse liability.

## Method

### Participants

We recruited participants from Roanoke, Virginia, restricting eligibility to participants whose usual cigarette brand (e.g., Marlboro) and style (e.g., Gold 100s) featured >15% filter ventilation (tested using methods described previously[12]). Supplementary Table 1 provides a list of participants' usual cigarette brands/styles and levels of filter ventilation. Additional inclusion criteria required that participants smoke at least 10 cigarettes/day, be ≥18 years old, and be willing to try vent-blocked cigarettes. Participants were excluded if they were pregnant, trying to quit smoking, or reported unstable mental or physical health. This study was approved by the Institutional Review Board at Virginia Tech. All participants provided informed consent.

**Table 1.** Drug Effects/Liking Scale ratings (±SD) for vent-blocked and control Cigarettes[a]

| | Cigarette type | | | |
|---|---|---|---|---|
| Measure | Vent-blocked | Control | *t* | *p* |
| Any effects | 4.62 (2.78) | 4.45 (2.66) | 0.333 | .744 |
| Good effects | **3.18 (2.60)** | **4.55 (2.96)** | **4.034** | **.003** |
| Bad effects | **2.97 (2.69)** | **1.73 (1.65)** | **2.798** | **.028** |
| Liking | **3.78 (2.50)** | **6.33 (2.53)** | **5.318** | **<.001** |
| Desire | **3.23 (2.56)** | **6.08 (2.57)** | **5.813** | **<.001** |
| Continued use | **3.45 (2.80)** | **7.28 (2.16)** | **5.204** | **<.001** |

[a]Bolded values indicate statistical significance.

### Study Cigarettes

Vent-blocked cigarettes were modified from participants' usual cigarette brand and style. A single piece of tamper-evident tape (product ID TZE-SE4, Brother International, Bridgewater, NJ) was affixed around the filter ventilation holes to obstruct airflow. Each piece of tape was machine-cut to a size that fit securely around the filter with minimal overlap. Tamper-evident tape was used to detect evidence of tape removal (a distinct checkerboard pattern) upon return of cigarette butts (see below).

Control cigarettes were prepared identically, although tape was located approximately 2 mm above the ventilation holes (toward the tobacco). The purpose of this tape was to control for visual appearance and tactile sensation while smoking.

Compared to unaltered cigarettes (no tape), these preparation methods yielded nearly complete ventilation blocking for vent-blocked cigarettes (reduction in ventilation of 75–90%) and negligible change for control cigarettes (see Supplementary Table 1).

### Procedures

#### Session 1

Participants completed a demographic questionnaire and the Fagerström Test for Cigarette Dependence (FTCD),[13,14] provided a breath carbon monoxide (CO) sample, and reported smoking over the last 30 days using a timeline follow-back survey.[15] Participants then received 10 vent-blocked cigarettes to sample over the next 3 days. Participants were also shown examples of control cigarettes available for purchase later in the study. In this and subsequent sessions, participants were instructed that cigarette butts (to be returned) would be inspected for signs of tampering.

#### Sessions 2–4

Participants returned to the lab approximately once every 2 days to complete three *purchase sessions*. At each session, participants used an experimental income (calculated as cigarettes/day at intake × 2 days × $0.25 [the approximate local price of cigarettes]) to purchase cigarettes at each of five prices ($0.12, $0.25, $0.50, $1.00, and $2.00/cigarette) to use over the next 2 days. Two purchase sessions featured vent-blocked or control cigarettes available alone (*Alone* sessions), and one session featured both cigarette types available concurrently at equivalent prices (*Together* session). Session order was counterbalanced. At the end of each session, participants drew one of the five prices from a bowl and received all cigarettes purchased at that price and any unspent income.

Participants also completed the Drug Effects/Liking Scale,[16] using a visual analog scale (VAS) to rate both cigarette types across six

subscales: any effects, good effects, bad effects, liking, desire, and the likelihood of continued use.

**Session 5**

Approximately 2 days following the final purchase session, participants returned to the laboratory to return cigarette butts, unused cigarettes (if any), and to again complete the Drug Effects/Liking Scale.

### Data Analysis

Application of standardized diagnostic criteria[17] revealed that all demand functions in the Alone purchase sessions were systematically affected by price. In contrast, in the Together purchase session, the majority of demand functions for vent-blocked cigarettes (8 of 15) featured no purchasing at any price (described previously as "null demand"[10,17]). We thus analyzed demand data both with and without these participants.

Group demand functions were fitted using an exponential demand model[19]:

$$Q = Q_0 * 10^{k\left(e^{-\alpha Q_0 P}-1\right)} \quad (1)$$

in which $Q$ is consumption, $P$ is price, $k$ is $\log_{10}$ span of consumption, $Q_0$ provides an estimate of *demand intensity* (consumption when price = $0.00), and α provides an estimate of *demand elasticity* (sensitivity of consumption to price). Values of $k$ in all model fits were set to 1.562, derived from group data. Purchase residuals were heteroscedastic across price in initial curve fitting; thus, residuals were weighted by $1/Q$. Effects of cigarette type and session type on $Q_0$ and α were examined using separate 2 (cigarette type) × 2 (session type) analyses of variance (ANOVAs), followed by sequential Bonferroni-corrected post hoc comparisons.

For the Drug Effects/Liking Scale, preliminary univariate ANOVAs revealed no main effect of session (2–5) for any subscale; thus, we collapsed data across session. Mean VAS ratings (possible range: 0–10) were analyzed using separate paired $t$ tests, including sequential Bonferroni correction.

We conducted all analyses in GraphPad Prism (ver. 7.00, La Jolla, California).

## Results

### Sample Characteristics

Fifteen participants enrolled in and completed the study (0% attrition). On average, participants were 46.2 years old (±2.2 SD), had 13.4 years of education (±8.6 SD), smoked 25.0 cigarettes/day (±7.0 SD), scored 6.2 on the FTCD (±1.8 SD), and provided a breath CO level at intake of 25.7 ppm (±10.0 SD). Forty percent of participants identified as female, and 86.7% participants identified as white (13.3% black).

### Cigarette Sampling

Participants smoked all vent-blocked cigarette samples. Inspection of cigarette butts following the sampling period, as well as all subsequent sessions, revealed no evidence of tampering.

### Demand

Figure 1A depicts group mean purchasing (all participants included) in both session types, with Figure 1B and C depicting corresponding estimates of demand intensity and elasticity. Mean purchasing was well described by Equation 1, with $R^2$ values of .996 and .987 for vent-blocked and control cigarettes, respectively, in the Alone sessions and .979 and .988 for vent-blocked and control cigarettes, respectively, in the Together session. $R^2$ values in group models incorporating intersubject variability were .763 and .746 for vent-blocked and control cigarettes, respectively, in the Alone sessions; and .224 and .719 for vent-blocked and control cigarettes, respectively, in the Together session.

We observed main effects of cigarette type, $F(1, 56) = 8.072$, $p = .006$, and session type, $F(1, 56) = 27.42$, $p < .001$, on demand intensity as well as a Cigarette Type × Session Type interaction, $F(1, 56) = 16.24$, $p < .001$. In post hoc comparisons within the same session type, we observed lower demand intensity for vent-blocked versus control cigarettes in the Together session ($p < .001$) but not in the Alone session ($p = .404$). Likewise, in post hoc comparisons between session types, we observed lower intensity for vent-blocked cigarettes in the Together versus the Alone session ($p < .001$) but no differences in intensity for control cigarettes between session types ($p = .397$).

We also observed main effects of both cigarette type, $F(1, 56) = 78.050$, $p < .001$, and session type, $F(1, 56) = 67.91$, $p < .001$, on demand elasticity as well as a Cigarette Type × Session Type interaction, $F(1, 56) = 65.79$, $p < .001$. In post hoc comparisons within the same session type, we observed greater elasticity for vent-blocked versus control cigarettes in the Together session ($p < .001$) but not in the Alone session ($p = .611$). Likewise, in post hoc comparisons between session types, we observed greater elasticity for vent-blocked cigarettes in the Together versus Alone sessions ($p < .001$) but no differences in intensity for control cigarettes between session types ($p = .927$).

In supplementary analyses, excluding null demand data ($n = 8$) yielded similar conclusions. That is, for both demand measures, we observed main effects of cigarette type, in both cases, $F(1, 24) > 4.66$, $p < .05$, and session type, in both cases, $F(1, 24) > 18.88$, $p < .001$. The Cigarette Type × Session Type interaction was significant for elasticity, $F(1, 24) = 13.72$, $p < .01$, but not for intensity, $F(1, 24) = 2.72$, $p = .112$. Post hoc comparisons revealed directional effects on both measures identical to the full-sample analysis (see Supplementary Table 2).

### Drug Effects/Liking Scale

Compared to control cigarettes, participants rated vent-blocked cigarettes higher on the bad effects subscale ($p = .028$) and lower on the good effects ($p = .003$), liking ($p < .001$), desire ($p < .001$), and likelihood of continued use ($p < .001$) subscales (see Table 1).

## Discussion

The present investigation suggests that removing filter ventilation reduces cigarette abuse liability, as measured by both behavioral economic demand and the Drug Effects/Liking Scale. However, removing ventilation reduced demand only when preferred control cigarettes were concurrently available. In contrast, removing filter ventilation had no effect on demand when cigarette types were available in isolation.

Some have argued that banning filter ventilation may reduce smoking-related harm by minimizing compensatory smoking behavior.[3–6] The present study suggests that an additional benefit of such regulatory action would be a reduction in cigarette abuse liability; however, this would likely only reduce cigarette demand when

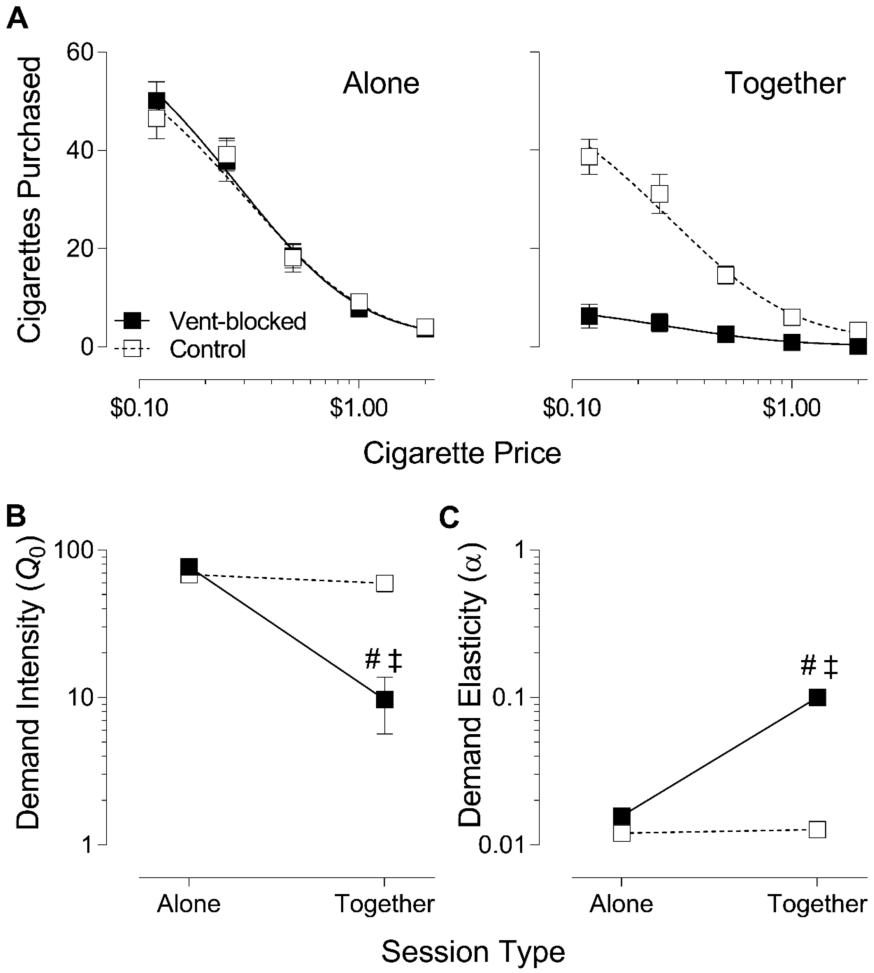


**Figure 1.** Vent-blocked and control cigarettes purchased as a function of price when available either alone or together at equivalent prices (Panel A); also depicted are corresponding estimates of demand intensity (Panel B) and elasticity (Panel C). #Significantly different than opposite cigarette type in same session type ($p < .001$). ‡Significantly different than same cigarette type in opposite session type ($p < .001$).

effective substitutes for vent-blocked cigarettes are available. Future investigations should explore this possibility further as a method of harm reduction by examining effects of filter ventilation in contexts that more closely model the real-world marketplace,[20] in which both cigarettes and an array of potentially less harmful tobacco products are available (e.g., electronic cigarettes, snus, and medicinal nicotine). Most relevant to public health, these investigations should include examinations of cross-price elasticity of demand in order to determine whether a ventilation ban would increase the extent to which alternative tobacco products serve as economic substitutes for cigarettes.[8]

A few limitations of this preliminary investigation generate critical questions for future research. First, the present sample featured largely white (87%), middle-aged (46 years old), and heavy-smoking (25 cigarettes/day) participants. In addition, study eligibility was restricted to smokers whose usual cigarette featured moderate to high levels of filter ventilation (styles formerly known as "light" or "ultra-light"). Future investigations should examine the generality of these phenomena in larger and more heterogeneous samples, as the effects of filter ventilation may interact with demographic and smoking characteristics. Second, the present study featured relatively brief exposure to vent-blocked cigarettes. Future investigations should examine extended exposure to determine whether smokers habituate to the apparently aversive properties of unventilated cigarettes over time. Finally, blocking ventilation holes with tape introduces error, and the choice of tape may impact the efficacy of blocking. Use of cigarette designs that differ only in ventilation level are needed in future research.

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## Declaration of Interests

*W.K.B. is a principal of HealthSim, LLC and Notifius, LLC; a scientific advisory board member of Sober Grid, Inc. and DxRx, Inc.; and a consultant for ProPhase, LLC and Teva Branded Pharmaceutical Products R&D, Inc. All authors declare that they have had access to the data reported in this manuscript and take responsibility for the integrity and accuracy of the data analysis.*

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