Published in final edited form as:

Exp Clin Psychopharmacol. 2020 February ; 28(1): 13–18. doi:10.1037/pha0000288.

Examination of a Mouthpiece-Based Topography Device for Assessing Relative Reinforcing Effects of E-Cigarettes: A Preliminary Study

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Abstract

The assessment of vaping topography has helped to identify characteristics associated with distinct vaping patterns. Available puff topography devices do not alter the subjective effects of vaping. However, one central construct related to drug abuse, unexplored in prior studies, is whether relative reinforcing effects (RRE) of vaping change when using a topography device. We examined the RRE of vaping when individuals vape through an e-cigarette with a mouthpiece topography device attached versus their own e-cigarette. Associations of demand indices for participants' own e-cigarette and for a research e-cigarette with a topography device were also explored. Forty-three e-cigarette users attended one experimental session where they completed two purchase tasks in different units of consumption, mLs and puffs, with their preferred e-cigarette and with an e-cigarette with a mouthpiece. Puff topography was measured in the mouthpiece condition. All four purchase tasks showed the predicted inverse relationship between purchase and price. No differences in most demand indices were observed between both e-cigarettes, except for Breakpoint (lowest price that suppresses consumption) and O_{max} (maximum expenditure) in mL units which both decreased when participants vaped through the mouthpiece device. Demand indices in mL units were more strongly associated. Data from the purchase tasks suggests that the presence of a mouthpiece topography device does not influence the RRE of vaping among e-cigarette users. Demand for e-cigarettes seems more consistent in mL units. Our results further evidence that mouthpiece topography devices represent a valid and reliable instrument to study RRE of e-cigarettes and by extension, abuse liability.

Keywords

E-Cigarettes; RRE; Demand indices; Topography; Puff topography

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Disclosures: The authors have nothing to declare other than the federal research support acknowledged above.

Introduction

E-cigarettes have garnered increased research interest over recent years (Pericot-Valverde, Gaalema, Priest, & Higgins, 2017), but studies struggle to keep pace with rapidly changing technology. One aspect not completely explored is e-cigarette puffing behavior. This represents an important gap in knowledge, especially because for other tobacco products (i.e., cigarettes) puff topography has been useful in identifying individual and situational factors that influence smoking behavior, providing a behavioral index of dependence, and predicting quit attempts and cessation (Lee, Gawron, & Goniewicz, 2015; Perkins, Karelitz, Giedgowd, & Conklin, 2011). Exploring puffing topography is also critical since the manner in which an e-cigarette user vapes can influence the amount of nicotine and other toxicants inhaled (Hiller et al., 2017; Talih et al., 2015).

Topography measurement may involve the recording of various parameters (puff number, duration, volume, flow rate, and inter-puff interval (IPI)). Laboratory settings provide a precise and accurate way to measure puff topography (Blank, Disharoon, & Eissenberg, 2009), with topography measuring devices (attached to the e-cigarette) providing measures of topography in a manner that is more efficient and thorough than other methods such as observation (Spindle, Breland, Karaoghlanian, Shihadeh, & Eissenberg, 2016).

Prior studies showed that using a topography measuring device does not alter the acute effects of vaping. Vaping through the same device with and without a topography device produced similar equivalent reductions in craving and withdrawal symptoms, similar subjective effects in terms of liking/enjoying vaping, and delivered comparable levels of nicotine (Spindle, Breland, Karaoghlanian, Shihadeh, & Eissenberg, 2014; Spindle et al., 2016). However, one central construct related to drug abuse, unexplored in prior studies, is whether relative reinforcing effects (RRE) of vaping change when using a mouthpiece topography device. RRE reflects the behavior-strengthening or behavior-maintaining properties of a given drug. Hypothetical purchase tasks have been extensively utilized as a proxy measure of RRE of tobacco products and have been shown to reflect real world behavior (Amlung, Acker, Stojek, Murphy, & Mackillop, 2012).

Overall, results from previous studies have provided initial evidence that the use of a topography device to measure puff topography does not influence the subjective effects of vaping. It is still unknown, however, if a topography device affects RRE. Thus, this study addresses this gap in the literature by exploring whether the presence of a mouthpiece topography device affects the RRE of vaping. Secondary goals were to examine puffing topography during vaping and to explore associations of demand indices for participants' own e-cigarette and for the mouthpiece device as a function of units of consumption for the purchase task (milliliters (mL) and puffs).

Methods

Participants

Participants were recruited from the Burlington metropolitan area via ads posted on media platforms. Inclusion criteria were being 18 years of age, having used an e-cigarette for 3

months, consuming at least 1mL of e-liquid daily with a nicotine concentration of at least 3mg/mL, and using an e-cigarette with a refillable tank. Current e-cigarette use was verified by a positive urine nicotine test using NicAlert (NicAlert™ by Nymox Pharmaceutical Corporation) test strips (score ≥ 3). Exclusion criteria included being a current cigarette smoker verified via expired air carbon monoxide (CO) levels ≥ 6 parts per million (ppm) measured using the smokerlyzer (Bedfont Scientific Ltd, Rochester, UK), using an e-cigarette with prefilled cartridges or a disposable e-cigarette, having any current DSM-V axis I diagnosis or medical condition, currently using prescription medication, having used any drug of abuse (other than alcohol and marijuana) in the prior 30 days, and being pregnant/breastfeeding.

Measures

Participant Sociodemographic Characteristics—Participants were asked to indicate their sociodemographic characteristics such as gender, age, race/ethnicity, sexual orientation, annual household income, and educational attainment.

E-cigarette and Other Tobacco Products Use—Participants completed a brief questionnaire which assessed their e-cigarette use including history of use, frequency of current use, estimated puff duration, preferred e-cigarette flavor, attempts to quit vaping, and their cigarette smoking history. The Penn State E-Cigarette Dependence Index (Foulds et al., 2014) was used to evaluate e-cigarette dependence. Index scores range between 0 and 20 with higher values indicating more dependence. Craving for e-cigarette use was measured using the Questionnaire of Vaping Craving (QVC) (Dowd, Motscham, & Tiffany, 2018). The QVC is a 10-item questionnaire with 7-point scale response options (1= strongly disagree to 7= strongly agree) and the total score can range from 10 to 70. Finally, the Minnesota Nicotine Withdrawal Symptom Scale (MNWS) (Hughes & Hatsukami, 1986) was administered to evaluate the severity of withdrawal symptoms over the last week. The MNWS includes 15 items that can be rated from 0 (none) to 4 (severe) and the overall score may range from 0 to 60. Participants also provided a sample of expired breath and urine to assess CO levels and urinary cotinine levels, respectively.

Purchase Tasks—Purchase tasks used for cigarettes (MacKillop et al., 2008) were adapted for e-cigarettes and assessed demand in two units (puffs and mLs). Purchase tasks were completed separately for participants' own e-cigarette and for the study e-cigarette with the mouthpiece device. During this task, participants were asked to indicate the quantity (mLs or puffs) of e-cigarette liquid they would purchase and use if it was available at 25 incrementally increasing prices ranged from \$0 (free) to \$100. Participants were instructed to assume they were purchasing e-cigarette liquid for their own consumption in a 24-hour period and they did not have access to any other nicotine/tobacco products (Participant instructions shown in Supplementary Material 1).

E-Cigarette Puff topography—E-cigarette puff topography was recorded using a validated mouthpiece topography device manufactured at the American University of Beirut (Spindle et al., 2014; Spindle et al., 2016). For this study, the mouthpiece was adapted to an e-cigarette tank system (Smoke TFV8 Baby) with a 0.5Ω, dual-coil, and a voltage range

from 3.4 to 4V. The e-cigarette was 83mm in height and 22mm in diameter. Prior to each use the mouthpiece was carefully calibrated using an automatic digital calibrator provided by the manufacturer of the mouthpiece. Puff topography parameters measured included puff number, duration, volume, IPI, and flow rate.

Procedure

After screening, eligible participants were asked to attend a 1-hour laboratory session where eligibility was confirmed through questionnaires and biological samples. Once consented, participants were instructed to take two puffs of their e-cigarette under staff observation to equate time since the last e-cigarette use and nicotine levels across participants. Participants were then asked to complete the QVC and two different purchase tasks (assessing mLs and puffs). Next, participants completed the assessment battery. After a 15-minute countdown, participants completed five puffs through the mouthpiece device using their own brand of e-liquid. Then participants were asked to again complete the QVC and the two purchase tasks. Both times the QVC and the purchase tasks were counterbalanced to avoid order effects. Participants were compensated \$20 for their time. All procedures in this study were reviewed and approved by the University of Vermont Institutional Review Board (Protocol #: 17-0498; Title: Characterization of Subjective, Physiological, and Behavioral Responses among Experienced E-cigarette Users).

Data analyses

Five metrics of e-cigarette demand were generated from each purchase task including: intensity (consumption at \$0), breakpoint (the lowest price at which consumption was zero), $O_{\max}$ (maximum expenditure), $P_{\max}$ (price at which expenditure was maximized), and elasticity (sensitivity of consumption to increases in cost). Observed values of intensity, breakpoint, $O_{\max}$, and $P_{\max}$ were estimated from raw values. Elasticity of demand was empirically derived using Hursh and Silberberg's exponential demand curve equation:

$$\log Q = \log Q_0 + k(e - \alpha Q_0 C - 1)$$

Q =consumption at a given price, Q_0 =demand intensity, k = the range of the dependent variable (e-liquid consumption) in logarithmic units, α = elasticity of demand, and C = unit cost. The k parameter was set to the common value ($k=4$) that produced the best fit model across all purchase tasks (mean R^2 own e-cigarette in mL= 0.73 and puffs =0.78, mean R^2 study e-cigarette with topography device in mLs= 0.71 and puffs= 0.79). Consistent with Jacobs and Bickel (1999), when fitting data to Equation 1, the first instance of zero consumption (Breakpoint) and the initial price (\$0) was replaced by an arbitrary low but non-zero value of 0.01 and 0.001, respectively. After computing all demand metrics, each index was examined for non-systematic data and outliers. The criterion of ≥ 2 contradictions at escalating prices was used to determine inattention or low effort when participants fulfilled the task (non-systematic data) (Acker and Mackillop, 2013). Two participants had non-systematic data and consequently were excluded from the study. Outliers were examined using standardized scores (criterion $Z=\pm 3.29$). Twelve outliers were identified, most of them being from the purchase tasks in puff units (8/12). All outliers were recoded as one unit greater than the highest non-outlier value.

Descriptive and frequency analyses were conducted for participant characteristics, craving scores, topography measures, and demand indices. Data from the demand indices and the QVC were non-normally distributed. Consequently, the Wilcoxon Signed-Rank tests were used to compare demand indices for participants' own e-cigarette vs. the study e-cigarette with the mouthpiece device within the same units (puffs vs puffs, mLs vs mLs), as well as to compare QVC scores after using their own e-cigarette vs. the study e-cigarette with the mouthpiece topography device. Finally, Spearman's correlation analyses were used to examine relationships between demand indices. Following guidelines proposed by Cohen, strength of correlations were considered as small ($r = .29$), moderate ($r = .30$ to $.49$), and large ($r = .50$ to 1.0). The exponential demand curve was modeled using GraphPad Prism 7.0 (La Jolla, CA). All statistical analyses were conducted with SPSS version 23 (IBM Corp., Armonk, NY).

Results

Of 45 individuals screened eligible for the study, 43 completed the session and were included in the final analyses. They were 76.7 % male, 21.4 (SD = 5.8) years old on average, and 79.1% had at least some college education (74.4%). Most participants were white (95.3%) and had an annual household income \$75,000 (60.5%). Participants reported consuming an average of 3.8 (SD= 2.8) mL of e-liquid and taking 94.2 (SD = 92.4) puffs every day; and were on average medium dependent e-cigarette users as observed in the PSECDI scores ($M = 9.2$, $SD = 3.7$). Fourteen percent of the sample reported never having smoked a cigarette (even a puff), 39.5% reported having smoked <100 cigarettes lifetime, and 41.9% having smoked 100 cigarettes lifetime. Supplementary Material 2 shows participants' sociodemographic and e-cigarette use history characteristics.

With regard to puff topography, participants exhibited a mean (SD) puff duration of 2.8 (1.4) seconds and a mean puff volume of 93.6 (51.5)mL while vaping with the e-cigarette with the mouthpiece device. On average, the length of IPI was 10.9 (10.4) and the flow rate was 31.7 (13.6) mL/sec.

A statistically significant reduction on QVC scores ($Z = -4.378$, $p < .001$) was observed after participants vaped through the study e-cigarette with the mouthpiece device. More specifically, average QVC scores decreased from 31.1 (SD = 11.9) (score after two puffs from own device to normalize time since last nicotine) to 21.4 (SD = 9.3) after vaping through the study e-cigarette with the mouthpiece topography device.

Table 1 shows mean values and standard deviations of demand indices for participants' own e-cigarette and for the e-cigarette with a mouthpiece topography device. The Wilcoxon Signed-Rank tests comparing these demand indices showed no statistically significant differences in demand indices in either puffs or mL units apart from O_{max} and Breakpoint in mL units (Table 1). In this regard, Wilcoxon Signed-Rank tests indicated that O_{max} ($p = .019$) and Breakpoint ($p = .003$) were statistically significantly higher for participants' own e-cigarette than for the study e-cigarette with the topography device.

Figure 1 depicts the mean numbers of puffs and mL that participants would consume at 25 escalating prices for their own e-cigarette and the study e-cigarette with the topography device. As expected, e-cigarette liquid consumption decreased as price of the liquid rose and was ultimately suppressed to zero.

Spearman's correlations between demand indices for participants' own e-cigarette and study e-cigarette with mouthpiece device are presented in Supplementary Material 3. For each unit of measure (mLs and puffs) 45 correlations were generated of which 37 were statistically significant for the mL units and 31 for the puff units.

Discussion

This is the first study to examine whether the RRE of vaping is affected when e-cigarette users vape through an e-cigarette with a mouthpiece-based topography device. Data from all the e-cigarette purchase tasks exhibited the predicted inverse relationship between price and consumption. Results also showed no significant differences in demand indices between devices except for $O_{\max}$ and Breakpoint for mL units. Finally, demand indices derived from the purchase task demonstrated different degrees of overlap and independence. Overall, these findings match those observed in earlier studies that showed that a mouthpiece recording device did not interfere with acute effects of vaping (Spindle et al., 2014; Spindle et al., 2016) and expands scientific knowledge by reporting results from estimates of demand for vaping.

Consistent with prior studies using purchase tasks to estimate demand for e-cigarettes as well as other tobacco products (e.g., conventional cigarettes), data from the purchase tasks demonstrated the inverse relationship between consumption and price (MacKillop et al., 2008; Secades-Villa, Pericot-Valverde, & Weidberg, 2016). More specifically, consumption of e-liquid was initially high at \$0 (i.e., Intensity), was progressively reduced as a function of increasing prices, and was ultimately suppressed to zero (Breakpoint), suggesting that e-cigarette users alter their purchase patterns to respond to price increases of e-liquid (elastic demand) similarly to users of cigarettes. Of importance, the current study provides further evidence of the utility of purchase tasks to explore demand among users of a variety of nicotine products.

An interesting aspect of the results was that $O_{\max}$ (maximum expenditure across intervals of price) and Breakpoint (price at which consumption is suppressed to zero) differ between participants' own e-cigarette and the study e-cigarette with the mouthpiece. While each of the demand indices provide unique information to characterize drug motivation, there is evidence that $O_{\max}$ and Breakpoint are more closely related to cigarette smoking (MacKillop, et al., 2008). It is possible that $O_{\max}$ and Breakpoint also represent the most sensitive indices of demand for other tobacco products (Amlung, Yurasek, McCarthy, MacKillop, and Murphy, 2015), in this study e-cigarettes. An alternative explanation related to the unit of measure could also be possible. E-liquid is typically purchased in mL units (Cassidy, Tidey, Colby, Long, & Higgins, 2017); thus, the use of ml units could have enhanced the sensitivity of these indices, and, consequently, its ability to detect differences between e-cigarettes. Finally, it merits further mention that both indices ($O_{\max}$ and

Breakpoint) reflect an individual's willingness to consume as price increases (MacKillop et al., 2009). Our findings may suggest that measures of persistence (i.e., price insensitivity) may have more utility in determining the malleability of RRE for e-cigarettes than measures of amplitude (i.e., volumetric consumption).

A secondary result is that demand indices for vaping evidenced different degrees of overlap and independence. This finding is consistent with prior studies that explored associations among demand indices for other drugs of abuse, such as cigarettes and alcohol (MacKillop & Murphy, 2007; MacKillop et al., 2008) and further supports Bickel, Marsch, and Carroll (2000) claim that RRE is a heterogeneous construct comprised of components functionally related to each other. In addition, our results indicate stronger associations among demand indices in mL units compared to puff units which is consistent with a prior study examining the validity of purchase tasks for e-cigarettes (Cassidy et al., 2017). Given the small amount of research that has been carried out on identifying the optimal measure, it is imperative that future studies continue to explore in which instances a unit of measure, namely puffs and mLs, is more appropriate for e-cigarette purchase tasks. To date, the examination of e-cigarette puffing behavior has helped to characterize patterns in puffing behavior (e.g., many short uses vs a few short puffs during the day)(Helen et al., 2016; Lee et al., 2015), to identify users' profiles related to these distinct vaping patterns (naïve users, experienced users) (Farsalinos et al., 2015; Yip & Talbot, 2011), as well as to determine other aspects that influence vaping topography including device features (e.g., power) and type of juice vaped (e.g., nicotine concentration and flavor) (Hiler et al., 2017; Robinson, Hensel, Al-Olayan, Nonnemaker, & Lee, 2018; Talih et al., 2015). Nonetheless, prior studies did not explore whether puff topography assessment influences the RRE of vaping and thus makes these findings less generalizable to the real world. This study evidences how this instrument can allow the study of puff topography under a broad array of experimental conditions by changing study parameters (e.g., deprivation of users, presence of e-cigarette related cues, use of different flavors) or procedures (e.g., real or simulated drug-administration tasks) without altering the RRE of vaping, and consequently preserving the external validity.

The findings from this study also have important regulatory implications that should be mentioned. One major concern for the Food and Drug Administration (FDA) is the abuse liability of e-cigarettes, which characterizes the potential that this new tobacco product could produce persistent, problematic patterns of use. The existence of reliable and valid instruments for assessing puff topography that do not influence RRE of e-cigarettes gives the opportunity to determine the abuse potential of this product and hence inform potential FDA regulations.

Limitations of this study merit mention. First, the sample size was relatively small due to being a pilot study. Future studies should be conducted with larger sample sizes. Second, participants were mostly male and relatively young. Nonetheless, it should be noted that this is the most predominant profile of e-cigarette users in the US (Pericot-Valverde et al., 2017). Third, the type of e-cigarette used was not counterbalanced, although using participant' own e-cigarette first allowed us to equalize the levels of nicotine across e-cigarette users. Finally, participants were not able to use their personal e-cigarette with the mouthpiece as standardization was needed to accommodate the mouthpiece. Even with these limitations,

this study presents novel and timely information by showing that the presence of a mouthpiece topography device largely does not influence the RRE of vaping among experienced e-cigarette users. Thus, this study provides further evidence of the validity of using topography mouthpiece devices to measure topography and by extension, abuse liability of e-cigarettes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Funding: This project was supported by Tobacco Centers of Regulatory Science award P50DA036114 from the National Institute on Drug Abuse (NIDA) and Food and Drug Administration (FDA), and Center of Biomedical Research Excellence award P20GM103644 from the National Institute of General Medical Sciences (NIGMS). The content is solely the responsibility of the authors and does not necessarily represent the official views of NIDA, FDA, or NIGMS.

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Public Significance Statements

This study explored whether vaping through a mouthpiece-based topography device provides similar relative reinforcing effects (RRE) in e-cigarette users compared to vaping with their own e-cigarette. Results showed that the presence of a mouthpiece topography device largely does not influence the RRE of vaping. This topography device has the potential to help characterize puff behavior in e-cigarette users, as well as to identify the underlying factors that affect puff topography among e-cigarette users.

Figure 1.

Hypothetical demands curves. The x-axis provides price in dollars and the y-axis plots reported consumption of e-cigarette liquid.

Table 1.

Indices of demand for participants own e-cigarette and the study e-cigarette with the mouthpiece device and the results for Wilcoxon Signed Rank Tests.

Metric	No Mouthpiece		Mouthpiece		Difference		Range		WRS	
	M	SD	M	SD	M	SD	Min	Max	z-value	p-value
Intensity (mLs)	10.72 ± 10.64		10.41 ± 18.80		0.31	11.22	-46	25	14.5	.658
Intensity (puffs)	118.88 ± 84.03		112.02 ± 88.95		6.86	27.43	-50	100	28	.119
P _{max} (mLs)	4.37 ± 1.44		4.50 ± 8.46		-0.13	6.60	-32	13	110	.083
P _{max} (puffs)	0.91 ± 1.23		1.38 ± 1.87		-0.47	1.85	-5.1	4.5	-57	.337
O _{max} (mLs)	11.76 ± 14.67		9.22 ± 12.05		2.54	10.26	-42	32	159	.019
O _{max} (puffs)	21.68 ± 42.00		13.94 ± 16.58		7.74	34.24	-23	174	69.5	.240
Breakpoint (mLs)	12.62 ± 20.30		8.18 ± 16.70		4.44	12.92	-14	72	138.5	.003
Breakpoint (puffs)	4.58 ± 8.78		4.47 ± 6.20		0.10	5.58	-14	21	-20.5	.631
Elasticity (mLs)	0.01 ± 0.01		0.03 ± 0.05		-0.01	0.05	-0.23	0.04	-106.5	.186
Elasticity (puffs)	0.02 ± 0.03		0.03 ± 0.07		-0.01	0.05	-0.22	0.03	-74	.308

Note. mLs = milliliters; M= Mean; SD = Standard deviation; Differences were calculated by subtracting the participant's device score from his/her own score; Min = Minimum; Max = Maximum; Differences were calculated by subtracting the participant's device score from his/her own score; WRS: Wilcoxon Signed Rank Test