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Brief report
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Brief report

Examining Daily Electronic Cigarette Puff Topography Among Established and Nonestablished Cigarette Smokers in their Natural Environment

Youn Ok Lee PhD[1], James M. Nonnemaker PhD[1], Brian Bradfield BA[1], Edward C. Hensel PhD[2], Risa J. Robinson PhD[2]

[1]RTI International, Research Triangle Park, NC; [2]Department of Mechanical Engineering, Rochester Institute of Technology, Rochester, NY

Corresponding Author: Youn Ok Lee, PhD, RTI International, 3040 E. Cornwallis Road, PO Box 12194, Research Triangle Park, NC 27709, USA. Telephone: 919-541-8735; Fax: 919-541-6683; E-mail: younlee@rti.org

Abstract

Introduction: Understanding exposures and potential health effects of e-cigarettes is complex. Users' puffing behavior, or topography, affects function of e-cigarette devices (eg, coil temperature) and composition of their emissions. Users with different topographies are likely exposed to different amounts of any harmful or potentially harmful constituents (HPHCs). In this study, we compare e-cigarette topographies of established cigarette smokers and nonestablished cigarette smokers.

Methods: Data measuring e-cigarette topography were collected using a wireless hand-held monitoring device in users' everyday lives over 1 week. Young adult (aged 18–25) participants ($N = 20$) used disposable e-cigarettes with the monitor as they normally would and responded to online surveys. Topography characteristics of established versus nonestablished cigarette smokers were compared.

Results: On average, established cigarette smokers in the sample had larger first puff volume (130.9 mL vs. 56.0 mL, $p < .05$) and larger puff volume per session (1509.3 mL vs. 651.7 mL, $p < .05$) compared with nonestablished smokers. At marginal significance, they had longer sessions (566.3 s vs. 279.7 s, $p = .06$) and used e-cigarettes more sessions per day (5.3 s vs. 3.5 s, $p = .14$). Established cigarette smokers also used e-cigarettes for longer puff durations (3.3 s vs. 1.8 s, $p < .01$) and had larger puff volume (110.3 mL vs. 54.7 mL, $p < .05$) compared with nonestablished smokers. At marginal significance, they had longer puff interval (38.1 s vs. 21.7 s, $p = .05$).

Conclusions: Our results demonstrate that topography characteristics differ by level of established cigarette smoking. This suggests that exposure to constituents of e-cigarettes depends on user characteristics and that specific topography parameters may be needed for different user populations when assessing e-cigarette health effects.

Implications: A user's topography affects his or her exposure to HPHCs. As this study demonstrates, user characteristics, such as level of smoking, can influence topography. Thus, it is crucial to understand the topography profiles of different user types to assess the potential for population harm and to identify potentially vulnerable populations. This study only looked at topography of cigarette smokers using disposable e-cigarettes. Further research is needed to better understand potential variation in e-cigarette topography and resulting exposures to HPHCs among users of different e-cigarette devices and liquids.

Introduction

Use of electronic vaping products, often referred to as e-cigarettes, is increasing among adults and youth in the United States and globally. In 2014, e-cigarettes surpassed combustible cigarettes to become the most commonly used tobacco product among US middle and high school students.[1] Yet little is known about the health effects of e-cigarettes or the potential influence of e-cigarettes on conventional cigarette smoking.

Understanding the health effects of e-cigarettes is complex, and not all puffs expose users to the same emissions. Users' puffing behavior, or topography, affects both the function of e-cigarette devices (eg, coil temperature) and the composition of their emissions.[2–5] Measuring e-cigarette consumption in terms of puffing behavior is essential for accuracy in assessing exposures to emissions constituents, and thus the potential harms of these products. Recent studies have found harmful or potentially harmful constituents (HPHC) in e-cigarette emissions, including fine and ultrafine particles, aldehydes, and probable carcinogens.[2]

Examining measures of user behavior has proven critical to assessing the health effects of inhaled novel tobacco products. Characteristics of puff topography showed that when combustible cigarette smokers switched to low-nicotine yield combustible cigarettes, they tended to take larger, longer, and more frequent puffs, resulting in similar toxicant deliveries.[6,7] Similar compensatory puffing behavior could result in some e-cigarette users having higher exposures to HPHCs than others if e-cigarette users take larger, longer, and more frequent puffs in efforts to match levels previously received from combustible cigarettes.[8] Reports show that e-cigarette nicotine delivery can exceed that of combustible cigarettes[9] and the total volume inhaled from some e-cigarettes than is needed to achieve a comparable nicotine intake can be up to four times that from a single combustible cigarette.[10]

Research has begun to examine e-cigarette topography; however, this is the first study we are aware of to compare topographies of established cigarette smokers and nonestablished cigarette smokers. There is evidence of significant inter-subject variability in puffing,[11] suggesting user-driven differences in exposure to HPHCs from e-cigarettes. Furthermore, most previous studies of e-cigarette topography are limited in one of two ways: reliance on observational measures[5,12] or collection in laboratory or other unnatural settings.[10,13–15] Studies on conventional cigarette topography show these settings likely alter puffing behavior[16–18] and that topography varies throughout the day,[19,20] suggesting that use behavior is in part situational. Therefore, naturalistic topography measurement over time is necessary,[21] and use patterns may vary in some situations, such as social situations.

Prior analysis of the dataset examined here showed that there can be significant intra- and inter-user variability in puffing topography,[11] suggesting that there may be various puffing types. However, this analysis did not assess whether user characteristics can influence e-cigarette use. It is possible that prior experience smoking cigarettes could result in distinct e-cigarette puffing topography due to factors such as learned inhalation behavior or nicotine dependence. In this study, our objective was to examine the e-cigarette topographies of established cigarette smokers and nonestablished cigarette smokers. We compare e-cigarette puff topography among established and nonestablished cigarette users in the contexts of their everyday lives over 1 week. We also compare topography from weekdays and weekend days since social situations, such as work, school, and socializing, may vary for these days. For example, weekends may provide more social opportunities for using e-cigarettes. In addition, use patterns for established and nonestablished users may differ by day of the week. Established users might have more regular use throughout the week due to higher levels of nicotine dependence, whereas nonestablished users might use more on weekends as part of more social use.

Methods

Study Design

This is a study of experienced adult e-cigarette user topography. Subjects used their own "cigalike" e-cigarettes with a wireless hand-held monitoring device in their everyday lives for 1 week. Subjects (N = 20) were recruited at the Rochester Institute of Technology (RIT) Henrietta campus between April 7 and May 21, 2015. Each subject also completed online surveys at enrollment and conclusion of the study.

Cohort Recruitment and Protocol

The study protocol was reviewed and approved by the RIT Human Subjects Research Office Institutional Review Board (IRB) and the RTI International IRB. Subjects were recruited using posters placed on the RIT campus and paid $200 for participating in the study. Subjects were screened to ensure they were current users of "first generation" or "cigalike" devices and had at least 3 months of e-cigarette use history.

Puffing topography was measured with a wireless personal use monitor (wPUM) described in a previous article.[11] The wPUM uses proven orifice plate technology to measure puff flow rate. The wPUM employed in this study was designed, manufactured, assembled, and tested at RIT in Rochester, NY. The wPUM begins recording when the device is turned on and continues recording until the device is turned off, resulting in one data file stored on the wPUM. Upon enrollment, each subject attended an individual training session on how to use the wPUM, conducted in the Respiratory Technology Lab at RIT. The subjects were asked to use their own preferred disposable or rechargeable e-cigarette during the study.

Subjects completed online surveys during enrollment and at the conclusion of the study. The enrollment survey asked subjects to report demographic characteristics and cigarette smoking status.

Topography Data Processing

Monitoring data are analyzed with the Topography Analysis Program (TAP) developed by an investigator at RIT. Data underwent preliminary analysis for cleaning and quality control to check for inconsistencies in the data that indicate that the wPUM was not functioning or used as intended, such as unusually high levels of noise in the baseline voltage, mid-session powering off, and inadvertent powering on. The TAP was then used to convert the wPUM digital voltage data to a volumetric flow rate using an empirical equation, consistent with first principles of operation of an orifice plate flow meter, based on the wPUM laboratory calibration. This process is described in greater detail elsewhere.[11] For each discretely identified puff, the TAP calculates puff duration, puff volume, puff flow rate (computed as the mean flow rate yielding the observed cumulative volume over the observed duration of the puff), and puff interval and tabulates these along with the date and time stamp for each puff for each subject.

Measures

We examined three types of topography characteristics: session, puff, and daily pattern. A use session was operationalized for this study as the period of time defined by the start of the first puff after the participant turned the wPUM on via switch and the end of the last puff before the participant turned the wPUM off.

- Average session characteristics
  - Session length: sum of all puff durations and intervals in a session in seconds (s)
  - Total no. of puffs per session: count of all puffs in a session
  - Mean puff duration: mean puff duration of each session in seconds (s)
  - First puff of session volume: volume of the first puff of each session in seconds (s)
  - Total puff volume: sum of all puff volumes in a session in milliliters (mL)
- Average puff characteristics
  - Puff duration: duration of each puff in seconds (s)
  - Puff interval: length of time between each puff in seconds (s)
  - Puff volume: volume of vapor produced per puff in milliliters (mL)
  - Puff flow: outflow of vapor calculated as volume divided by duration in milliliters per second (mL/s)
- Daily pattern of sessions across the study days
  - Sessions per day: count of all session in 1 day
  - Total no. of puffs per day: count of all puffs in 1 day
  - Total puff volume per day: sum of all puff volumes in 1 day in milliliters (mL)

Established smoking was measured using the item "have you smoked at least 100 tobacco cigarettes in your entire life?" Subjects who reported smoking "at least 100 tobacco cigarettes" in their lifetime were categorized as established smokers, whereas those who reported that they have not smoked 100 cigarettes in their lifetime were categorized as nonestablished. Participants who reported ever using "tobacco cigarettes (eg, Camel, Marlboro, American Spirit)" even once were considered ever cigarette smokers. We also measured self-reported experiences of strong craving/needing to use e-cigarettes within past 30 days (yes or no), feeling restless or irritable when not using e-cigarettes (sometimes, often, or always), and using e-cigarettes within the first 30 min of waking on days e-cigarettes are used.

We calculated descriptive statistics to describe the e-cigarette session and puffing characteristics of established and nonestablished smokers, accounting for repeated measures. Effect sizes were calculated using Cohen's *d*. In addition, we summarized e-cigarette use characteristics among these groups for data recorded on weekdays and weekend days.

Results

The final sample included 20 young adults aged 18–25, 95% males, 60% non-Hispanic white, and 95% students. Of the 20 participants, $N = 14$ were established cigarette smokers. Of the $N = 6$ that were nonestablished cigarette smokers, 83.3% reported ever smoking. Overall, some established cigarette smokers reported e-cigarette craving (35.7%), abstinence-induced irritability (64.3%), and use of e-cigarettes within 30 min of waking (35.7%).

Participants reported their preferred brand and nicotine level of disposable e-cigarette, though they were not required to exclusively use this brand or nicotine level during the study. The brand that was most frequently reported among nonestablished cigarette smokers was Blu (50%) and among established cigarette smokers was Logic (26%) followed by Vuse (21%). The reported nicotine levels were those indicated on the device or reported by the participant and varied across brands since there is not consistency in how manufacturers express nicotine level (eg, milligrams, 1.8%, "high/med/low",

Table 1. E-cigarette Session and Puffing Characteristics among Nonestablished and Established Cigarette Smokers

Characteristic	Established cigarette Smoker, *N* = 14		Nonestablished cigarette smoker, *N* = 6		*p*-Value of *F*-test	Cohen's *d*
	% or mean	95% CI	% or mean	95% CI		
Participant characteristic						
Age	19.7		19.5			
Male	92.9%		100.0%			
White	64.3%		50.0%			
Non-White	35.7%		50.0%			
Ever smoke cigarettes	100.0%		83.3%			
Past 30-day e-cigarette craving	35.7%		16.7%			
Irritable when not using e-cigarettes	64.3%		16.7%			
Use e-cigarette within 30 min of waking	35.7%		16.7%			
Session characteristic						
Sessions per day	5.3	[3.4–7.2]	3.5	[2.1–5.0]	.136	0.244
Session length (s)	566.3	[278.9–853.7]	279.7	[176.7–382.7]	.064	0.113
Total number of puffs	13.7	[9.4–18.0]	11.9	[9.1–14.7]	.481	0.046
Volume of first puff (mL)	130.9	[73.9–187.9]	56.0	[36.3–75.6]	.018	0.149
Total puff volume (mL)	1509.3	[767.4–2251.1]	651.7	[443.4–859.9]	.031	0.131
Puffing characteristic						
Puff duration	3.3	[2.3–4.3]	1.8	[1.5–2.1]	.005	0.048
Puff interval	38.1	[24.7–51.4]	21.7	[12.1–31.4]	.052	0.037
Puff volume (mL)	110.3	[10.4–150.3]	54.7	[41.5–67.9]	.012	0.042
Puff flow rate (mL/s)	26.6	[23.1–30.1]	30.5	[23.3.–37.8]	.321	–0.030

Table 2. E-cigarette Use Characteristics among Nonestablished and Established Cigarette Smokers on Weekday and Weekend Days

Characteristic	Weekday					Weekend day				
	Established smoker	Nonestablished smoker	Weekday difference	*p*-Value	Effect size	Established smoker	Nonestablished smoker	Weekend day difference	*p*-Value	Effect size
Mean sessions per day	5.2 [2.9–7.4]	3.7 [2.1–5.3]	1.5	.289	0.189	5.9 [4.3–7.5]	2.6 [2.0–3.2]	3.3	.001	1.190
Mean puffs per day	76.6 [38.7–114.4]	44.4 [23.1–65.7]	32.2	.137	0.258	57.4 [33.1–81.6]	29.0 [13.7–44.3]	28.4	.052	0.675
Mean total volume per day	8682.5 [2709.2–14655.8]	2315.8 [1592.1–3039.5]	6366.7	.039	0.333	5421.9 [1771.9–9071.8]	2267.0 [1015.9–3518.2]	3154.9	.101	0.504

etc.). The nonestablished cigarette smokers reported nicotine levels of 17–24 mg and 4.4%, which were relatively high compared to what is typically available in the market. The established cigarette smokers reported a wider range of nicotine levels, including 3–24 mg as well as 0.6%–4.8% and one reported a level of "high." Results comparing e-cigarette puff topography in terms of session characteristics and puff characteristics among established and nonestablished cigarette smokers are reported in Table 1.

Results show several differences in session characteristics between established and nonestablished cigarette smokers. On average, established cigarette smokers in the sample used e-cigarettes for more sessions per day (5.3 s vs. 3.5 s, $p = .14$), had longer sessions (566.3 s vs. 279.7 s, $p = .06$), had more puffs per session (13.7 vs. 11.9, $p = .481$), and had larger puff volume per session (1,509.3 mL vs. 651.7 mL, $p < .05$). Mean puffing characteristics also varied when comparing established and nonestablished cigarette smokers. Established cigarette smokers in the sample used e-cigarettes for longer puff durations (3.3 s vs. 1.8 s, $p < .01$), had longer puff interval (38.1 s vs. 21.7 s, $p = .05$), had larger puff volume (110.3 mL vs. 54.7 mL, $p < .05$), and had lower puff flow rate (26.6 mL/s vs. 30.5 mL/s, $p = .32$).

Results comparing e-cigarette use among established and nonestablished smokers on weekdays and weekend days are reported in Table 2. As reflected in the overall results, established cigarette smokers used e-cigarettes more than nonestablished smokers on both weekdays and weekend days. However, some of the differences between established and nonestablished smokers were more pronounced when comparing results for weekdays and weekend days. On weekend days, established smokers recorded more than twice as many mean sessions per day (5.9) as nonestablished smokers (2.6) ($p < .01$); on weekdays, mean sessions per day were not significantly different for established and nonestablished smokers. Established smokers consistently recorded more mean puffs per day than nonestablished smokers on weekend days, with both groups recording lower mean puffs per day on weekend days. Although higher for established smokers, mean total volume per day was not significantly different for established and nonestablished smokers for weekend days. However, on weekdays, established smokers recorded over three times as much (8682.5 mL vs. 2315.8 mL, $p < .05$) total volume per day.

Discussion

Dual use of e-cigarettes and cigarettes is the most prevalent combination of multiple tobacco product use among youth and adults.[22] There are also concerns that e-cigarette use may lead to subsequent combustible cigarette smoking among never smokers or relapse among former smokers. It is currently unknown whether combustible cigarette smoking status influences e-cigarette topography and subsequent exposure to nicotine or other e-cigarette constituents. Understanding how e-cigarettes are used by combustible cigarette smokers is needed to assess individual and population level risks of e-cigarettes, especially because some smokers report using e-cigarettes as part of cessation attempts. Our results show that established and nonestablished cigarette smokers puff on e-cigarettes in different ways. On average, established smokers in this study inhaled twice as much volume (milliliters) per puff, took longer puffs at lower puff flow rates, used e-cigarettes for longer use sessions, and inhaled over twice the total puff volume per session when using e-cigarettes. Various parameters affect emissions of toxic compounds, particularly those that determine coil and vapor temperature. Due to this, HPHCs of e-cigarettes can be emitted at higher rates as vapor temperatures increase during use until reaching a steady state.[2] Our results suggest that some users' e-cigarette puffing patterns could result in inhalation of larger puff volumes and longer puff durations, thus potentially resulting in higher exposures to e-cigarette emissions constituents and HPHCs.

In addition, subjects' use on weekdays and weekend days varied, suggesting that use may be, in part, situational. Monitoring puff topography in natural settings may provide a more accurate and nuanced picture of e-cigarette exposure than single session or lab-based studies alone.

The methods used here address several of the limitations of other topography studies of e-cigarette use, specifically by measuring use in users' naturalistic settings and over multiple sessions and days. All subjects used the same type of device, a first generation "cigalike," and used their preferred brand. This enhances our confidence that results are not due to device type or introduction to a new brand. It is currently unknown whether different e-cigarette device types or brands affect the topography of users, though some evidence suggests variation across types.[23] Future studies are needed to compare device types to determine whether these affect topographies in ways that impact emissions exposure or health effects. Regulators will need information about how device type, including cigalike type, might affect individual and population health to inform potential regulations for e-cigarettes.

Our study has several limitations. Results are limited to the device type used and may not generalize to second-generation tank or other devices. We did not collect data on cigarettes smoked per day or carbon monoxide levels, future studies would benefit from these additional data. In addition, our sample was small and consisted primarily of young adult male students, so results do not necessarily generalize to all e-cigarette users. While we did see some established cigarette smokers report indications of possible nicotine dependence, this study was designed to primarily examine puff and session-level characteristics. Given the limitations of the sample size for analyzing person-level characteristics we cannot draw conclusions from these dependence results.

Despite the limitations of our study, our results make an important contribution to the literature on the topography of e-cigarette users. Limited research is currently available examining inter-user variation between types of users and products or intra-user variation across use days. Furthermore, most studies are single session or lab-based. Our study examines topography characteristics in a users' natural setting. This study demonstrates that user characteristics, such as level of smoking, can influence topography. Given that a user's topography affects his or her exposure to HPHCs, it is crucial to understand the topography profiles of different user types to assess the potential for population harm and to identify potentially vulnerable populations.

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Declaration of Interests

None declared.

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