Addictive Behaviors Reports 19 (2024) 100548

Contents lists available at ScienceDirect

Addictive Behaviors Reports

journal homepage: www.elsevier.com/locate/abrep

Short Communication

Switching people who smoke to unfiltered cigarettes: Effects on smoking topography

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ARTICLE INFO

Keywords:
Smoking
Nicotine
Tobacco control
Topography
Regulation
Filtered cigarettes

ABSTRACT

Introduction: Smoking topography (ST) describes smoking behavior and patterns. Removal of the cigarette filter and subsequent impact on ST has not been investigated. This is the first clinical trial comparing ST for filtered and unfiltered cigarettes in a naturalistic experiment.

Methods: We conducted a crossover clinical trial following established people who smoke cigarettes (n = 32) for two weeks under filtered and unfiltered smoking experimental conditions. Participants (50 % female, mean age 38.3 yr.) smoked in each experimental condition followed by a 3-week post-washout period. ST (puff count, volume, duration, peak and average flow) was measured at six time-points. Statistical analysis included a linear repeated mixed-effects model of smoking experimental conditions by visit number and sex.

Results: Average flow (ml/sec) was significantly less for filtered smoking (−6.92 lower (95 % CI: −13.44 to −0.39), $p < 0.05$), thus demonstrating more resistance on inhalation. No significant differences were found between filtered or unfiltered experimental conditions for other ST variables. However, average volume and average peak flow were somewhat higher in unfiltered smoking, and lower mean puff counts/cigarette were observed for unfiltered compared to filtered smoking.

Conclusion: Lower average flow rates were associated with filtered cigarette smoking. No significant differences were found for other ST variables between smoking experimental conditions. ST measurements comparing cigarette smoking conditions may determine if product regulatory changes, such as removing the cigarette filter could impact smoking behavioral patterns among people who smoke. This proof-of-principle study measuring ST may be replicated in larger trials to determine potential behavioral changes in smoking unfiltered cigarettes.

1. Introduction

Commercial cigarette filters are almost all made of a non-biodegradable plastic (cellulose acetate). They mainly help to sustain cigarette sales through fraudulently implied health benefits and by making it easier to smoke (Song et al., 2017; Novotny & Hamzai, 2023). Filter ventilation dilute cigarette smoke to yield less machine-measured tar and nicotine concentrations, however nicotine levels do not necessarily change and may increase. The increase in nicotine delivery effects may be due to increased frequency of puffing, deeper inhalation, or less time between puffs, resulting in compensatory smoking patterns (U.S. Department of Health and Human Services, 2014; Appleton, Liu, Lipowicz, & Sarkar, 2015; Caraway et al., 2017). These modifications in smoking behavior can modulate nicotine dosage and increase overall mouth-level exposure to tar and nicotine yields, while increasing thresholds of nicotine dependence (Caraway et al., 2017). Measures of puffing patterns, or smoking topography (ST), capture behavioral characteristics and adaptations of cigarette smoking (Blank, Disharoon, & Eissenberg, 2009; Lee, Malson, Waters, Moolchan, & Pickworth, 2003; De Jesus, Hsin, Faulkner, & Prapavessis, 2015). ST studies usually employ laboratory or clinical settings that do not reflect routine smoking patterns in real-life settings. Limited randomized clinical trials have mainly involved one-to-six data collection time-points or short study periods and have not employed naturalistic conditions. These studies cannot capture the dynamic nature of ST (Gass, Germeroth, Wray, & Tiffany, 2016; Watson et al., 2017; De Jesus & Prapavessis, 2018; Zacny

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https://doi.org/10.1016/j.abrep.2024.100548
Received 27 December 2023; Received in revised form 18 April 2024; Accepted 24 April 2024
Available online 26 April 2024
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& Stitzer, 1994).

A hand-held, battery-operated portable device, the Clinical Research Support System (CReSS) pocket has been used to measure ST in in various settings (Borgwaldt: Korber Solutions, n.d.). The CReSS device measures differential pressures via a mouthpiece and flowmeter that connects to a combustible tobacco product. Various ST measurements produce puff-level data to evaluate adaptations in smoking behavior during individual smoking sessions (De Jesus et al., 2015). These include puff count (PC, total number of puffs per cigarette); puff volume (PV, total puff intake [mL]); puff duration (PD, total time for a puff [s]); and interpuff interval (IPI, time interval in between the end of and beginning of a new puff [s]). Lastly, average flow (AF, flow throughout puffs [mL]) and peak flow rate (PFR, highest flow rate achieved during puffs per second [mL/s]) measure flow or resistance throughout each puff. Collectively, ST measurements can capture the dynamic smoking process with the CReSS device (Pulvers et al., 2023).

The CReSS device produces valid ST measurements in people who smoke cigarettes with consistent within-subject comparisons and can serve as an alternative to direct observations of smoking (Blank et al., 2009; Hammond, Fong, Cummings, & Hyland, 2005). We have previously reported on the challenges of measuring ST using the CReSS device (Romero et al., 2021). Nonetheless, measuring ST changes in response to proposed product regulatory changes, such as prohibiting filtered cigarette sales (as recommended by the World Health Organization (WHO), 2022) can provide important evidence in consideration of such recommendations. Although cigarette filter modifications and nicotine delivery have been evaluated, complete removal of the filter and its impact on ST has not been investigated (Song et al., 2017; Caraway et al., 2017).

This proof-of-principle study aims to measure changes in ST among persons with established cigarette smoking behavior who switch from smoking filtered cigarettes to smoking unfiltered cigarettes. This is the first clinical trial to measure and compare changes in ST for filtered and unfiltered cigarettes in a naturalistic experiment.

2. Methods

This study utilizes data from a randomized, cross-over trial of filtered and unfiltered cigarette smoking among people who smoke (Supplemental Figure 1). The comprehensive study protocol has been published elsewhere (Oren et al., 2020). We aimed to measure intra-individual changes within experimental conditions to evaluate puffing changes and adaptations of smoking behavior during these conditions. The experimental conditions were categorized as two-weeks of filtered or unfiltered smoking with individuals initially randomized to each arm. We conducted the study was conducted over nine weeks including a baseline visit at Week 1; experimental visits at Weeks: 2, 3, 8 and 9; a post-washout period of three weeks of normal smoking at Weeks 4–6; and a second baseline (post-experimental washout) visit at Week 7. There were then six data-collection time points. The total number of ST observations varied by participants and were recorded daily over five 8-hour periods per week. The trial was designed with a > 80 % power (n = 40 participant recruitment goal) for a moderate within-subject effect sizes (f-0.35) and a moderate correlation between repeated measures (r > 0.50). Because this was a pilot study to assess the feasibility of our clinical trial methodology, we estimated our sample size using standard power calculations without a hypothesis-driven statistical outcome (In, 2017; Oren et al., 2020). Institutional Review Board approval was obtained from San Diego State University, and the clinical trial was approved and registered at ClinicalTrials.gov (NCT03749876). A Data Safety and Monitoring Board (DSMB) charter was established to monitor safety and to oversee adverse event reporting during the study.

2.1. Participants and measures

Participants were 21 to 65 years old with no current serious health conditions, smoked for at least one year, had no intention to quit smoking, and were not pregnant or nursing; they received up to $695 compensation for the entire study. A total of 44 study participants were recruited as part of the larger trial; however, only those who completed both the filtered and unfiltered experimental smoking conditions were included in this study. The final participants (n = 32) who completed all trial visits were given two-weeks of study cigarettes (choosing either Camel or Pall Mall that have both unfiltered and filtered cigarettes), in the first and second arms. Both brands of filtered and unfiltered study cigarettes were analyzed to determine nicotine-yield in mg/cigarette from an established and reputable Nicotine and Tobacco Product testing lab. The purpose of the analysis was to assess nicotine content and emissions from mainstream smoke using gas chromatography-nitrogen phosphorus detector (GC-NPD). Using the Nicotine and Tobacco Product Assessment Resource (NicoTAR, 2020), the nicotine mg/cigarette was consistent across study cigarettes (unfiltered and filtered versions) and used a reference cigarette as a control for comparison purposes.

Demographic variables included age, income, years smoked, biological sex, race/ ethnicity, educational attainment, and employment status. Smoking history and patterns were assessed by number of years participants smoked, number of days smoked in the past 30 days and number of cigarettes smoked per day (CPD). To capture ST, participants used the CReSS device on at least five-days each week within an eight-hour day of naturalistic conditions. They smoked either filtered or unfiltered cigarettes, with date-time stamped data collected for each cigarette smoked. Participants were given in-lab training and encouraged to use the CReSS device without altering their normal smoking patterns. CReSS device functional verification, calibration, and maintenance were conducted at each study visit according to manufacturer's guidelines for use (Borgwaldt: Korber Solutions, n.d.). CReSS ST measures were collected at six time-points: baseline (week 1), two-weeks within each experimental condition (filtered and unfiltered) (weeks 2, 3, 8, 9), and the second post-washout period (week 7). Perceptual and sensory effects for each cigarette type was measured in the larger trial, there were no differences by ST outcome variables and this data is published elsewhere (Pulvers et al., 2023). Lastly, the larger protocol included collection of biomarkers to examine reliability measures over time and validation of ST measures are analyzed and explored in a different manuscript currently under review.

2.2. Analysis

We established baseline demographic and smoking behavior and repeated these measures at baseline, intervention, and postintervention time points. Means, standard deviations, and 95 % confidence intervals for all CReSS ST were calculated after reducing multiple measures to weekly averages. An independent sample *t*-test was used to compare differences in ST variables for smoking experimental conditions (weeks 2, 3, 8, and 9). A linear mixed-effect model analysis, with compound covariance symmetry, was created for each ST outcome variables (PC, PV, PD, IPI, AF and PFR). Experimental condition was categorized as two-weeks for each filtered and unfiltered cigarette smoking; arms were assigned sequences (filtered 1st/unfiltered 2nd and unfiltered 1st/filtered 2nd); sequence of transitions between experimental condition was included as a variable, and sex (male/female) included as a fixed effect with the visits and random effect by participant ID. Statistical analysis was performed using SAS V.9.4.

3. Results

Of the 44 participants initially recruited and randomized to filtered versus unfiltered experimental conditions, 12 were lost to follow-up. Because the study aimed to compare intra-individual changes of ST within smoking conditions, lost participants were excluded from this analysis. Thus, completers (n = 32) were defined as those who attended all study visits, either in-person or over the phone, and completed all the pre-and post-CReSS ST measures over nine weeks. Participants who completed the study were 50 % female, mean age 38.3 years, 74 % White, and had all ST measurements for both the filtered and unfiltered experimental condition weeks (2, 3, 8, & 9) as well as baseline and post-washout measurements (Table 1). Compliance rates (CR) of using the CReSS device according to the protocol was moderately high (74.1 %) for both study conditions.

Participants reported a mean of 18.7 (SD 9.0) years smoking history, and all reported smoking for 30 days in the past month. Average daily cigarette smoking was 14.4 (SD 6.7). The number of ST observations were reduced to weekly individual participant averages for weeks 2, 3, 8, and 9 (five-days per week and eight-hours of smoking per day) (Table 2). The mean puff count (PC) was 13.9 (4.6), mean puff volume (PV) was 78.5 ml (SD 49.5), mean puff duration (PD) 1.7 ms (SD 0.7), and mean inter-puff intervals (IPI) 22.5 ms (SD 7.9). The average flow rate (AF) was 49.8 ml/s (SD 28.6), with the mean peak flow rate (PFR) 75.8 ml/s (SD 45.7). Average flow rate (AF) was the only ST variable that differed (less) for filtered smoking compared with unfiltered smoking (mean difference 6.9 ml [95 % CI −13.44 to −0.39], $p < 0.05$). By accounting for individual variability in the MEM analysis, we were able to observe a significant difference in AF between filtered and unfiltered cigarettes, which could not be captured by a standard *t*-test. Arm sequence, visit number, and sex had no significant effect on AF. Filtered cigarettes had lower measures of PV and PFR, although non-significant, compared to unfiltered cigarettes. No significant differences were found in any of the other ST variables for filtered versus unfiltered smoking when collapsed to two weeks of each experimental condition (Table 2).

4. Discussion

This study aimed to demonstrate how switching people who smoke filtered cigarettes to unfiltered smoking would affect ST through adaptations of smoking behavior in naturalistic environments. AF was the only ST variable found to significantly differ (decrease) for filtered cigarette smoking. This may indicate that the filter provides resistance when inhaling, requiring more effort and deeper inhalation to obtain smoking 'satisfaction' or nicotine dosage. People who smoke ventilated commercial filter cigarettes may compensate for lower nicotine delivery by obstructing the ventilation holes on filters to achieve this level of 'fulfillment', or satisfactory nicotine dosage (Song et al., 2017). A study from our larger trial, measured perception, addiction, and behavioral effects of smoking and found that participants reported UF to have greater nicotine effects and less desirable sensory effects compared to FU cigarettes (Pulvers et al., 2023). This was despite no differences found between cotinine levels, nicotine dependence and intention to quit smoking. For this study, no significant differences were found in any of the other ST variables for each experimental condition. While not hypotheses driven, we did expect a lower PFR in filtered smoking, with greater ease of inhalation and less resistance without the filter; directionally, changes measured in PFR coincided with this expectation but were not statistically significant. ST changes have been reported in studies of smokers who change to menthol cigarette smoking for two-weeks, with PV and PD higher, given greater ease of inhalation. This seems analogous to smoking an unfiltered cigarette with less obstruction of PV and AF (Watson et al., 2017). Krebs et al. (2016) found that puffing intensity was a more substantial contributor to nicotine uptake (e.g., more nicotine derived per cigarette smoked) compared to frequency or number of cigarettes smoked. These findings support further investigation of puffing behaviors, along with other factors such as compensatory effects with filter, ventilation, or self-regulation of nicotine dosage (Benowitz, 2010; Donny et al., 2015; Song et al., 2017).

There are limitations to consider for this study. The findings may not reflect more established, routine smoking patterns among participants owing to the short experimental times. Other investigations note that after six weeks, PC and IPI were lower in reduced nicotine cigarettes; however, no compensatory patterns of smoking behavior were observed (Denlinger-Apte et al., 2019) (Supplemental Figure 2). A longer time-frame measuring smoking with unfiltered cigarettes may be needed to explore longer-term outcomes on ST and adaptations using different ventilated products and compare overall exposure to tar and nicotine yields. In another analysis based on this trial, currently under review, our team found that among those completing all study components, the

Table 1
Study participant demographics and baseline smoking characteristics.

Demographic/Characteristic	Total N = 32	Filtered First N = 14	Unfiltered First N = 18
	n (%)	n (%)	n (%)
Age, Mean (SD)	38.34 (9.07)	38.36 (9.08)	38.33 (9.33)
Sex			
Female	16 (50.00)	8 (57.14)	8 (44.44)
Male	16 (50.00)	6 (42.86)	10 (55.56)
Ethnicity			
Not Hispanic / Latino	28 (87.50)	13 (92.86)	15 (83.33)
Hispanic/Latino			
Mexican	2 (6.25)	0 (0)	2 (11.11)
Puerto Rican	1 (3.13)	0 (0)	1 (5.56)
Another Hispanic / Latino origin	1 (3.13)	1 (7.14)	0 (0)
Race			
White	24 (74.19)	11 (78.57)	13 (70.59)
Multiple races	4 (12.90)	0 (0)	4 (23.53)
Asian American	2 (6.45)	1 (7.14)	1 (5.88)
African American	2 (6.45)	2 (14.29)	0 (0)
Education			
High school or below	5 (15.63)	3 (21.43)	2 (11.12)
Some college or technical school	17 (53.13)	6 (42.86)	11 (61.11)
College graduate or above	10 (31.26)	5 (35.71)	5 (27.78)
Income (in $1000 s), Mean (SD)	42.22 (36.04)	44.86 (33.61)	40.17 (38.65)
# Years smoked cigarettes, Mean (SD)	18.72 (9.02)	19.36 (8.91)	18.22 (9.33)
# Days smoked in past 30 days, Mean (SD)	30 (0)	30 (0)	30 (0)
# Cigarettes smoked per day, past 30 days	14.41 (6.67)	12.21 (4.59)	16.11 (7.61)

Table 2
CReSS Weekly Mean Smoking Topography Variables.

	[a] Mean (SD)			t-value	[b] p-value
	Total	Filtered	Unfiltered		
Smoking Topography					
Puff Count (n)	13.95 (4.63)	14.43 (4.01)	13.46 (4.64)	0.9	0.3735
Puff Volume (ml)	78.56 (49.51)	70.81 (31.47)	85.82 (46.43)	−1.51	0.1353
Puff Duration (ms)	1.71 (0.67)	1.75 (0.68)	1.68 (0.55)	0.47	0.642
Average Flow (ml)	49.82 (28.58)	44.22 (15.33)	55.01 (27.98)	−1.91	0.0604
Average Peak Flow (ml/sec)	75.81 (45.67)	68.29 (25.79)	82.74 (44.47)	−1.59	0.1171
Average IPI (ms)	22.5 (7.91)	22.30 (7.23)	22.57 (7.79)	−0.14	0.8858

Smoking topography was evaluated using multiple measures, including puff count, puff volume, puff duration, flow rate, peak flow rate and inter-puff interval (IPI) Puff count was defined as the number of puffs per cigarette, puff volume as the total volume inhaled per puff in milliliters, puff duration as the total time in milliseconds to inhale per puff, flow rate as the airflow measured per puff in milliliters, peak flow rate as the highest flow rate achieved within a puff in millimeters per second, and IPI as the time interval in milliseconds between puffs.

[a] Averages of ST variables were computed during experimental conditions only (weeks 2, 3, 8 & 9).

[b] Computed from a two-sample *t*-test to test difference in Smoking Topography by experimental condition (alpha = 0.05).

findings were reliable and consistent for this small proof-of-principle study. Specifically, for the results of topography measurements as well as behavioral measures and biomarkers for carcinogen and nicotine exposure. Our projected sample size was lower due to loss to follow-up and COVID-19 restrictions. Despite 20 % attrition, the demographic profiles for initial and final sample participants were comparable. Future studies should aim to over enroll using a power calculation of 0.90 to ensure adequate recruitment and likely attrition. Strengths of this study include utilizing a randomized control trial that captured ST over time including participant crossover and wash out periods. Multiple measures of ST were assessed in a naturalistic environment using participants as their own control or comparison group to reduce confounding. Measurements of intra-individual changes as used here have not been reported in other trials of unfiltered cigarette smoking.

5. Conclusion

To our knowledge, this is the first randomized clinical trial using the CReSS device to evaluate intra-individual differences in ST between smoking filtered and unfiltered cigarettes in naturalistic environments. As this was a proof-of-principle study, we suggest that a larger clinical trial including ST measures and a crossover design, might demonstrate the physiological and psychological effects of switching people who smoke filtered cigarettes to unfiltered cigarette smoking. The implication of puffing intensity's greater influence on nicotine uptake compared to frequency of smoking, warrants future research in ST and limiting total nicotine exposure to impact addiction. Furthermore, because there are no health protections offered by cigarette filters and ventilation may increase exposure to tar and nicotine yields, studies such as this can inform tobacco policy and regulatory decisions regarding sales of filtered cigarettes (Novotny & Hamzai, 2023).

CRediT authorship contribution statement

Devan R. Romero: Writing – original draft, Methodology, Investigation. **Giovanni Appolon:** Writing – review & editing, Formal analysis, Data curation. **Thomas E. Novotny:** Writing – review & editing, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Kim Pulvers:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **LaRee Tracy:** Writing – review & editing, Formal analysis, Data curation. **Nora Satybaldiyeva:** Writing – review & editing, Investigation, Formal analysis. **Jose Magraner:** Investigation. **Eyal Oren:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

This study was funded by the California Tobacco Related Disease Research Program # 28IP-0022S. We are grateful to Casey Barber, Erika Carter, Crystal Marez, Shyla Everett, Kim Thornton, Kai Roach, Cesar Arevalo, Sandra Yun, and Adam Hunn for their assistance with data collection and/or data management and Drs Neal Benowitz, Stephanie Brodine and John Elder for service on the Data Safety and Monitoring Board (DSMB).

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.abrep.2024.100548.

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