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Research Article

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Make Your Own Cigarettes: Toxicant Exposure, Smoking Topography, and Subjective Effects

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Abstract

Background: Despite considerable use of make your own (MYO) cigarettes worldwide and increasing use in the United States, relatively little is known about how these cigarettes are smoked and the resultant toxicant exposure.

Methods: In a laboratory study, we compared two types of MYO cigarettes—roll your own (RYO) and personal machine made (PMM)—with factory-made (FM) cigarettes in three groups of smokers who exclusively used RYO ($n = 34$), PMM ($n = 23$), or FM ($n = 20$). Within each group, cigarettes were smoked in three conditions: (i) after confirmed overnight tobacco abstinence; (ii) in an intense smoking paradigm; and (iii) without restrictions. All cigarettes were smoked *ad lib* through a smoking topography unit.

Results: Plasma nicotine significantly increased after cigarettes in all conditions except PMM in the intense smoking paradigm. Puff volume, puff duration, total puff volume, and puff velocity did not differ between cigarette types but the puffs per cigarette and time to smoke were significantly smaller for RYO compared with PMM and FM. Regardless of the cigarette, participants consumed the first three puffs more vigorously than the last three puffs.

Conclusions: Despite the belief of many of their consumers, smoking MYO cigarettes is not a safe alternative to FM cigarettes. Like FM, MYO cigarettes expose their users to harmful constituents of tobacco smoke. Despite differences in size and design their puffing profiles are remarkably similar.

Impact: These data are relevant to health and regulatory considerations on the MYO cigarettes. *Cancer Epidemiol Biomarkers Prev; 23(9); 1793–803. ©2014 AACR.*

Introduction

In response to increases in price and restrictions on the sale, marketing, and advertising of conventional cigarettes, the use of make your own (MYO) cigarettes has increased domestically and internationally (1–3). In the United States, the prevalence of MYO smoking was reported at 6.7% in the 2006 ITC-4 survey (3), but reports in trade journals and the popular press suggest that current U.S. use may be substantially greater. Rosenberry and colleagues (4) found that in the United States, MYO cigarettes could be divided into 2 general categories: roll your own (RYO) that are made by rolling tobacco in a paper leaf; and personal-machine-made (PMM) cigarettes made by injecting loose tobacco into a preformed, filtered cigarette tube, a cigarette quite unique to the U.S. market. Furthermore, in the United States, RYO cigarettes are typically made without a filter (4), whereas the use of a consumer-added filter to RYO cigarettes abroad is quite common (5).

There is limited literature on how MYO cigarettes are smoked and the exposure consequences that follow laboratory smoking. Shahab and colleagues (6, 7) studied RYO smokers in the United Kingdom, Ayo-Yusuf and Olutola (8) in South Africa, and Benjakul and colleagues (9) in Thailand. There are no reported studies of smoking behavior or toxicant exposure from MYO cigarettes made and smoked by the U.S. smokers.

Smoking behavior is usually described by how cigarette smoke is drawn from the tobacco rod into the mouth of the smoker (puff). Puff topography can be used to characterize how established or new tobacco products are smoked. Smoking topography is typically assessed by the use of an orifice flow meter mouthpiece through which the smoke is drawn into the mouth by a study participant. Puff topography was used to quantify smoke exposure and is the basis of the parameters for International Organization for Standardization machine smoking method (10). Measures of smoking topography reflect and correlate with exposure to toxicants from tobacco smoke (11–13). Therefore, puff topography measures such as puff volume, number of puffs taken from a cigarette, and the time taken to

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smoke, have been identified as measures that can reliably quantify smoke exposure from factory-made (FM) cigarettes (14, 15), but there have been no topography studies of U.S. MYO smoking.

This study assessed smoking topography associated with RYO, PMM, and conventional FM cigarette smoking in exclusive RYO, PMM, and FM smokers. A central aim of this study was to determine the nicotine exposure and differences in smoking behavior among regular consumers of MYO and FM cigarettes while smoking cigarettes they had prepared themselves using their own tobacco, paper, tubes, and other paraphernalia. Smoking behavior was assessed in conditions of tobacco abstinence, intense smoking, and when there were no experimentally imposed restrictions. We also assessed the subjective experience from MYO and FM smoking.

The Family Smoking Prevention and Tobacco Control Act (2009) specifically authorized the Food and Drug Administration to regulate the MYO cigarette market. Fundamental to the regulatory process is an understanding of how MYO cigarettes are consumed and the consequent exposure to smoke-delivered toxicants. This study was an initial attempt to capture that information in a laboratory-based clinical study.

Materials and Methods

Participants

Participants ($N = 77$) were recruited from the Baltimore, MD, metropolitan area using local newspapers, direct mailers, and Craigslist. Eligibility was determined through a telephone screener and screening visit in which smoking history was documented. Inclusion criteria were: (i) regular (daily) smoker for at least 2 years; (ii) age from 18 to 65; (iii) smoking at least 10 cigarettes per day (at least 80% of cigarettes smoked were either RYO, PMM, or FM exclusively); (iv) absence of smoking related illness or disease; and (v) not currently trying to quit smoking. Exclusion criteria were: (i) pregnancy or lactation; (ii) high blood pressure or heart rate; (iii) poor venous access; (iv) general health problems (chronic bronchitis, asthma, etc.); (v) heart medications; and (vi) history of blood draw complications. Participants were compensated $275 for completing 3 laboratory visits. Data collection occurred between June 2010 and May 2012 at Battelle's Human Exposure Assessment Laboratory (HEAL) in Baltimore, MD. Participants were assigned to 1 of 3 experimental groups based on the characteristics of their usual cigarette: RYO ($n = 34$), PMM ($n = 23$), and FM ($n = 20$). All participants signed an IRB-approved informed consent form.

During all sessions participants smoked their usual cigarettes. MYO smokers (RYO and PMM) prepared their own cigarettes (under observation) using their own tobacco, paper, and tubes as described previously (4). The study cigarettes (3) were selected from 25 as being close to the average weight of 25 cigarettes prepared. FM smoked their usual commercial brand of cigarette (i.e., Newport, Marlboro, or Camel), which they also supplied. All of the PMM and FM cigarettes were filtered; 32 of the 34 of RYO participants smoked unfiltered cigarettes.

Study design and procedures

Every participant visited Battelle's HEAL for 3 separate experimental sessions:

- Condition NR: participants smoked one of their usual cigarette (FM or MYO) without smoking restrictions before the experimental session.
- Condition ABS: participants smoked one of their usual cigarettes after verified overnight tobacco abstinence (exhaled carbon monoxide $\leq$ 12 ppm).
- Condition INT: participants came to the laboratory without any smoking restrictions before the visit and smoked 2 of their usual cigarettes within 1 hour and a third one 20 minutes later. All experimental measures were taken before and after the third cigarette.

Sessions for conditions NR and ABS lasted about 1 hour and for INT about 2 hours. The interval between sessions was not shorter than 24 hours. The presentation of the conditions was randomized. Participants were familiarized with the study procedures and the equipment before the experimental sessions began. At the first visit, participants completed demographic and smoking history questionnaires. Before and after smoking, participants completed subjective questionnaires on cigarette craving and perceptions, blood samples were obtained from a forearm vein for nicotine assessments, and baseline measures of exhaled CO (CO_{ex}) were collected. Each participant smoked a cigarette through the mouthpiece of the puff analyzer.

Dependent measures

Self-report subjective measures. Nicotine dependence was assessed using the Fagerström Test for Nicotine Dependence (FTND; ref. 16) and the total score from nicotine dependence syndrome scale (NDSS; ref. 17). Tobacco craving was measured using the short version of the Questionnaire on Smoking Urges (QSU; refs. 18–20). The appeal and subjective effects of the cigarettes were assessed using the Duke Sensory Questionnaire (DSQ; ref. 21) and the cigarette evaluation scale (CES; ref. 22). Both questionnaires use a 7-points Likert scale. The DSQ queries: (i) puff liking you just took?; (ii) puff satisfaction?; (ii) puff nicotine levels?; (iv) similar to your own brand?; (v) strength of puffs on the tongue; (vi) nose; (vii) mouth and throat; (viii) windpipe; and (ix) chest? Responses to questions 5 to 9 were summed to create a composite score of strength (23). The CES is an 11-item questionnaire that assesses whether cigarettes are: (1) satisfying, (2) taste good, (3) make you dizzy, (4) calm you down, (5) help you concentrate, (6) feel more awake, (7) reduce hunger for food, (8) make you nauseous, (9) feel less irritable, (10) enjoy the sensations of the smoke in your throat and chest, and (11) immediately reduce your craving for cigarettes. For data analyses, question 1 (Satisfaction) and question

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11 (craving relief) were analyzed alone. Composite variables were made from the following items: question 2 and 10; questions 4, 5, 6, and 9; and question 3 and 8 to quantify constructs of interest: peripheral sensation, psychological reward and negative effect (23, 24).

Smoking topography measurements. Puff volume, puff duration, interpuff interval and puff velocity, time to smoke (TTS), and number of puffs were measured with Clinical Research Support System (CReSS; Borgwaldt KC). A series of mouthpiece adaptors (BorgWalt) were used to accommodate the smaller size cigarette RYO cigarettes. Before the study, we confirmed the accuracy of the CReSS device on puff count, puff duration, and puff volume using a calibrated syringe to pull "false" puff whereas the mouthpiece was fitted with various sizes of RYO cigarettes. For statistical analyses, we considered puff volumes $\geq$ 15 mL and puff durations $\geq$ 0.2 seconds using "puff clean up" methods described elsewhere (14).

Plasma nicotine assessments. The change in plasma nicotine level is an excellent proximate marker of smoke exposure that has been used in laboratory studies of nicotine delivery from alternative and FM cigarettes (25–28). Venous blood samples (7 mL each) were collected before and 2 minutes after smoking. The samples were centrifuged and the plasma was stored frozen until analyses for nicotine. Samples were frozen at −20°C for short-term storage and shipped on dry ice overnight to LabStat International ULC (Kitchener), where gas chromatography/thermal-specific ionic detection was used to determine plasma nicotine levels (LOD = 1.2 ng/mL; LOQ = 4.1 ng/mL). Nicotine boost was determined by calculating score between post- and presmoking nicotine measures.

Exhaled carbon monoxide. Exhaled carbon monoxide (CO_{ex}) is a widely used biomarker of recent tobacco smoke exposure, which is correlated with nicotine dependence scales (29–33). CO_{ex} was measured before and within 10 minutes after smoking using a BreathCO monitor (Vitalograph Inc.). CO boost was determined by calculating score between post- and presmoking CO measures.

Statistical analyses

All statistical analyses were conducted with StatSoft, Inc. (2013), STATISTICA (data analysis software system), version 12, www.statsoft.com. Analysis of variance (ANOVA) was performed to find differences among participants as a function of age, cigarettes smoked per day, FTND score, NDSS score, QSU, DSQ, CES, biomarkers levels, and smoking topography parameters (grouping variables: smoking condition or type of cigarettes smoked). In addition, we used ANOVA methods to identify differences in smoking topography parameters (puff volume, duration, and velocity) between the first 3 (1, 2, and 3) and the last 3 (X, Y, and Z) puffs taken during each smoking session (grouping variables: type of cigarette and puff number). *Post hoc* Tukey honest significant difference (THSD) test was used for identifying differences in variables within each cigarette group but across the various smoking conditions. For *post hoc* comparisons between various types of cigarettes, we used THSD with the Spjøtvoll–Stoline modification for unequal *N*.

Sample size. Method described by Bausell and Li was used for sample size calculation for this study (34). A sample size large enough to detect an interaction between smoker group (FM, RYO, PMM) and smoking conditions (no restrictions [NR], abstinent [ABS], and intense [INT]) with sufficient power given that the patterns in the group vectors are truly nonparallel is required. For this study, the null hypothesis can be expressed as: H_0: $\mu_{p,j} - \mu_{q,j} = 0$, j = NR, ABS, and INT; p, q = FM, RYO, and PMM. Sample size for this design is estimated at 17 to 30 participants per group to detect effect moderate to large effect sizes. Moderate to large standardized differences were reported in puffing behavior (volume, average puff flow rates, peak flow rates) when cigarettes of differing tar levels (35) and differences in tobacco products (RYO vs. FM; ref. 7).

Results

Participants

The study was completed by 77 participants who met eligibility criteria and attended all 3 sessions. Participants' characteristics are presented in Table 1.

More whites ($n = 49$) than African Americans ($n = 22$) participated in the study and 6 persons reported more than one race or "other." The self-reported amount of cigarettes smoked per day was significantly higher for the PMM than the FM group ($P < 0.01$). The groups did not differ on age or the level of nicotine dependence. However, there were significant differences between the gender and racial composition of the groups. Specifically, there were more men than women in all groups and more white than African Americans participants in the PMM group. These differences are generally reflective of the participant characteristics of the MYO smokers in the Baltimore area (4) and in the United States (3).

Study cigarettes

The average weight of the RYO cigarettes used in this study was 0.4 ± 0.2 g and was significantly less ($P < 0.01$) than the PMM, 1.0 ± 0.2 g, and the FM, 0.9 ± 0.1 g cigarettes. The PMM and FM cigarettes were all filtered, whereas 94% of RYO cigarettes were unfiltered.

Self report subjective measures

Nicotine dependence. All participants were moderately dependent on nicotine. Nicotine dependence measured with FTND ranged from 5 to 6 across the experimental groups. Furthermore, there were no significant differences in the NDSS overall score among smokers across all types of cigarettes. NDSS overall scores correlated well with FTND scores ($r = 0.58$, $P < 0.01$), which was consistent with findings in other studies (36–38).

Cigarette craving. Results of cigarette craving measured with the QSU questionnaire and the summary of statistical analyses are presented in Table 2. Overnight

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Table 1. Participant characteristics

	RYO ($n = 34$)	PMM ($n = 23$)	FM ($n = 20$)	Total ($N = 77$)
Sex				
Male	88.2% (30)	73.9% (17)	80.0% (16)	81.8% (63)
Female	11.8% (4)	26.1% (6)	20.0% (4)	18.2% (14)
Race				
African American	29.4% (10)	4.3% (1)	55.0% (11)	28.6% (22)
Caucasian	61.8% (21)	87.0% (20)	40.0% (8)	63.6% (49)
Other	8.8% (3)	8.7% (2)	5.0% (1)	7.8% (6)
Age				
Mean (SD)	38 (12)	41 (12)	36 (11)	39 (12)
Cigarettes per day				
Mean (SD)	18 (6)	22 (11)	15 (4)	18 (8)
Baseline plasma cotinine (ng/mL), mean (SD)				
NR	197 (97)	190 (88)	—	—
ABS	135 (82)	128 (85)	—	—
INT	217 (110)	201 (115)	—	—
FTND score				
Mean (SD)	6 (2)	6 (2)	5 (2)	6 (2)
NDSS overall score				
Mean (SD)	0.12 (1.09)	−0.08 (0.97)	−0.36 (0.80)	0.07 (0.99)

NOTE: Baseline plasma cotinine level for subgroups ($n = 26$ for RYO and $n = 10$ for PMM).
Abbreviation: Mean (SD), arithmetic mean with SD.

tobacco abstinence (condition ABS) led to significant increases in the positive desire to smoke for reward (PRE smoking QSU Factor 1), increases in the need to smoke for relief (PRE smoking QSU Factor 2) as well as PRE smoking Total QSU Score. RYO smoking significantly reduced cigarette craving (expressed as a difference between POST- and PRE Total QSU Score) across all 3 smoking conditions whereas PMM and FM significantly reduced craving in NR and ABS conditions. After smoking sessions, participants reported similar craving for cigarettes (assessed with POST Total QSU Score) across all cigarette types and all smoking conditions. In addition, within the same condition (i.e., NR, ABS, and INT), participants reported similar cravings across all cigarettes types ($P > 0.05$) before the session began.

The appeal and effects of the cigarettes. Analysis of the DSQ results showed no differences in MYO and FM perceptions across all smoking conditions. The participants equally liked puffs just taken, were equally satisfied with puffs just taken, assessed that during all sessions the puffs delivered similar dose of nicotine, reported that puffs were similar to their own brand, and experienced similar strength of puffs taken ($P > 0.05$). CES results analysis showed that neither type of cigarettes nor condition influenced participants' satisfaction, craving for relief, and peripheral sensation. However, RYO smokers in condition ABS scored higher than PMM ($P < 0.01$) in psychological reward (CES parameter that assessed calmness, concentration, awake, and irritation after smoking). According to the CES results, MYO and FM smokers also reported unequal negative effects (dizziness and nauseous) across analyzed smoking conditions. RYO smokers in ABS scored higher than RYO in NR ($P < 0.05$) as well as RYO in INT ($P < 0.01$). PMM in ABS scored higher than PMM in INT ($P < 0.05$).

Smoking topography

The results of smoking topography measurements are summarized in Table 3.

Puff volume, puff velocity, puff duration. Average puff volume, puff velocity, and puff duration were not influenced by the type of cigarettes smoked. No statistically significant differences were found for these smoking topography parameters compared across different smoking conditions or the different cigarettes.

Total puff volume. Average total puff volumes were similar for the same type of cigarettes across different smoking conditions. Average total puff volume was significantly ($P < 0.05$) larger during PMM smoking than during RYO smoking in conditions NR and ABS. In addition, average total puff volume was higher during PMM smoking than FM smoking in Condition ABS ($P < 0.05$).

Number of puffs. Participants took similar numbers of puffs to smoke their cigarette (RYO, PMM, or FM) regardless of the experimental condition. When compared across condition, RYO smokers took significantly ($P < 0.05$) fewer puffs than PMM smokers in conditions NR and ABS (both $P < 0.05$).

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Table 2. Questionnaire of Smoking Urges results

Type of cigarettes	Condition	Factor 1			Factor 2			Total		
		Pre	Post	*P*	Pre	Post	*P*	Pre	Post	*P*
RYO ($n = 34$)	NR	3.8 (1.7)	1.5 (1.7)	[a]	2.2 (1.7)	0.8 (1.4)	[b]	6.0 (3.2)	2.3 (2.9)	[a]
	ABS	5.1 (1.4)	2.4 (1.8)	[a]	3.1 (1.7)	1.4 (1.6)	[a]	8.2 (2.8)	3.7 (3.2)	[a]
	INT	3.0 (1.8)	1.0 (1.4)	[a]	1.7 (1.5)	0.7 (1.3)	NS	4.7 (3.1)	1.7 (2.6)	[a]
		ABS > NR[a]; INT[a]	ABS > INT[a]		ABS > INT[a]	—		ABS>NR[a]; INT		
PMM ($n = 23$)	NR	3.4 (1.9)	1.3 (1.5)	[a]	1.8 (1.5)	0.9 (1.4)	NS	5.2 (3.0)	2.2 (2.7)	[a]
	ABS	5.2 (1.2)	2.5 (1.7)	[a]	3.3 (1.8)	1.5 (1.5)	[a]	8.5 (2.7)	4.0 (2.9)	[a]
	INT	2.6 (1.7)	1.3 (1.7)	NS	1.3 (1.5)	0.8 (1.4)	NS	4.0 (3.0)	2.1 (2.9)	NS
		ABS > NR[a]; INT[a]	ABS > NR[b]; INT[b]		ABS > NR[a]; INT[a]	—		ABS > NR[a]; INT[a]		
FM ($n = 20$)	NR	4.9 (1.1)	1.3 (1.8)	[a]	2.4 (1.4)	0.6 (1.2)	[a]	7.2 (2.3)	2.0 (2.9)	[a]
	ABS	5.6 0.6)	2.4 (1.9)	[a]	3.4 (1.5)	1.3 (1.4)	[a]	9.0 (1.9)	3.7 (3.2)	[a]
	INT	2.6 (1.6)	1.0 (1.2)	[b]	1.3 (1.3)	0.7 (1.1)	NS	3.8 (2.7)	1.7 (2.3)	NS
		ABS > INT[a]	ABS > INT[b]		ABS > INT[a]	—		ABS > INT[a]		
									NR = ABS = INT	

NOTE: Means with SDs are given.

Abbreviations: ABS, overnight tobacco abstinence (12 hours, exhaled CO $\leq$ 12 ppm); pre/post, before/after smoking; *P*, *post hoc* ANOVA test for pre/post difference; NS, statistically nonsignificant.

[a]$P < 0.01$

[b]$P < 0.05$.

Time to smoke. Average TTS was similar for the same type of cigarettes within various smoking conditions. However, for all 3 smoking conditions, average TTS was significantly longer for PMM and FM than for RYO ($P < 0.05$).

Puff by puff analysis

Puff by puff profiles of the first 3 (1, 2, 3) and last 3 (X, Y, Z) puffs during smoking across experimental cigarettes are presented in Fig. 1. Regardless of the cigarette, participants consumed the first 3 puffs more vigorously than the last 3 puffs. Specifically, puff volume and puff duration were generally larger and interpuff interval was shorter at the beginning of a cigarette than at its end. Results showed that puff volumes, durations, intervals, and velocities were not constant throughout smoking. Results of ANOVA and *post hoc* analyses contrasting significant differences between the first and last 3 puffs are summarized in Table 4.

Toxicant exposure

The results of biomarkers measurements and statistical analyses results are summarized in Table 5.

Table 3. Smoking topography parameters by cigarette type and condition

Cigarette type	Condition	Number of puffs	Puff volume (mL)	Total puff volume (mL)	Puff duration (s)	Puff velocity (mL/s)	TTS (s)
		Mean (SD)					
RYO ($n = 34$)	NR	11.0 (5.1)	53.1 (20.1)	584 (332)	1.68 (0.48)	38.4 (14.3)	234 (87)
	ABS	11.5 (6.0)	54.4 (24.5)	633 (382)	1.60 (0.53)	42.0 (15.5)	221 (107)
	INT	12.4 (5.9)	63.3 (33.4)	745 (440)	1.84 (0.69)	40.7 (16.9)	241 (92)
PMM ($n = 23$)	NR	15.3 (6.6)	61.5 (16.1)	935 (453)	1.90 (0.40)	41.1 (10.4)	340 (107)
	ABS	15.8 (6.4)	61.9 (17.8)	947 (357)	1.90 (0.49)	40.9 (9.4)	341 (113)
	INT	14.7 (5.1)	58.3 (13.6)	840 (291)	1.81 (0.28)	40.2 (11.5)	330 (114)
FM ($n = 20$)	NR	13.3 (3.6)	58.7 (18.2)	740 (179)	1.94 (0.48)	37.8 (12.1)	312 (69)
	ABS	13.1 (3.7)	53.3 (19.6)	656 (194)	1.77 (0.49)	37.7 (13.8)	316 (74)
	INT	13.3 (3.9)	55.7 (20.1)	694 (198)	1.87 (0.50)	37.0 (12.9)	322 (64)

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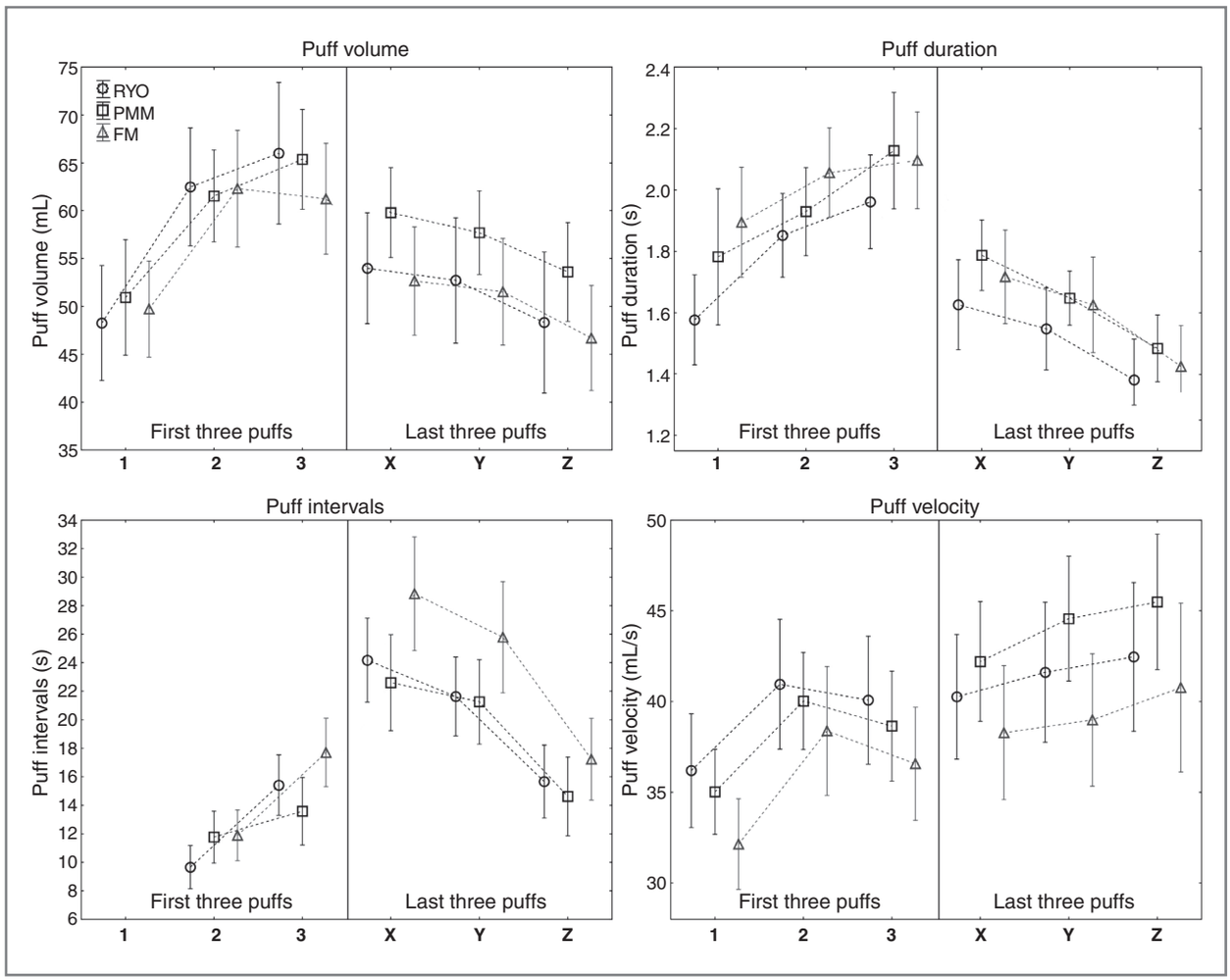

Figure 1. Puff by puff smoking topography profiles: puff volumes, durations, intervals, and velocities illustrating topography in first 3 puffs (1, 2, and 3) and the last 3 puffs [X, Y, and Z; means with confidence intervals are presented; grouping variable: cigarette type; experimental conditions (NR, ABS, and INT) are combined].

Plasma cotinine and nicotine levels. Comparisons of the baseline plasma cotinine levels in a subset of RYO and PMM smokers indicated similar levels suggesting their nicotine exposure was equivalent at baseline (Table 1). Across all cigarettes, overnight tobacco abstinence (condition ABS) significantly lowered plasma nicotine levels. Nicotine levels after smoking were similar across all cigarette types and conditions. There were no statistically significant differences between RYO, PMM, and FM cigarettes in nicotine levels before smoking for the same smoking condition. All cigarettes, across all smoking conditions increased plasma nicotine levels, except PMM in condition INT. Condition ABS for RYO and FM cigarettes resulted in significantly higher nicotine boost than condition INT. Of all 462 plasma nicotine measures, about 20% were below LOQ. As expected most (two third) of the samples below LOQ were those from participants after overnight tobacco abstinence (pre-ABS).

Exhaled carbon monoxide levels. Across all cigarette types, overnight tobacco abstinence resulted in significantly decreased CO_{ex} level. In all 3 conditions, smoking FM cigarettes resulted in significantly higher CO_{ex} boost than RYO and PMM cigarettes. After smoking in condition ABS, participants had significantly lower CO_{ex} than after NR and INT, for all types of cigarettes.

Discussion

This study is the first to examine differences in smoking topography between MYO and FM cigarettes among U.S. smokers. By manipulating preexperimental smoking conditions, we were able to evaluate *ad lib* smoking topography and toxicant exposure in RYO, PMM, and FM smokers across a wide range of baseline cigarette cravings. In spite of significant differences in cigarette craving, many variables of smoking topography remained constant. For example, regardless of the type of cigarette or

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Table 4. Puff by puff smoking profiles by cigarette type and puffing parameter

Cigarette type	Smoking topography parameter	ANOVA (*F*)	First 3 puffs			Last 3 puffs		
			1	2	3	X	Y	Z
RYO ($n = 34$)	Volume	[a] (5.01)	2^b, 3^a	1^b, Z^b	1^a, Y^b, Z^a	—	3^b	2^b, 3^a
	Duration	[a] (8.75)	3^a	Y^b, Z^a	1^a, X^b, Y^a, Z^a	3^b	2^b, 3^a	2^a, 3^a
	Intervals	[a] (21.86)	—	3^a, X^a, Y^a, Z^a	2^a, X^a, Y^a	2^a, 3^a, Z^a	2^a, 3^a, Z^a	2^a, X^a, Y^a
	Velocity	NS	—	—	—	—	—	—
PMM ($n = 23$)	Volume	[a] (4.31)	2^b, 3^a	1^b	1^a, Z^b	—	—	3^b
	Duration	[a] (8.56)	3^b	Z^a	1^b, X^b, Y^a, Z^a	3^b	3^a	2^a, 3^a
	Intervals	[a] (12.88)	—	X^a, Y^a	X^a, Y^a	2^a, 3^a, Z^a	2^a, 3^a, Z^a	X^a, Y^a
	Velocity	[a] (6.26)	X^b, Y^a, Z^a	—	Z^b	1^b	1^a	1^a, 3^b
FM ($n = 20$)	Volume	[a] (5.11)	2^b, 3^b	1^b, Z^a	1^b, Z^a	—	—	2^a, 3^a
	Duration	[a] (11.41)	Z^a	X^b, Y^a, Z^a	X^a, Y^a, Z^a	2^b, 3^a	2^a, 3^a	1^a, 2^a, 3^a
	Intervals	[a] (19.68)	—	X^a, Y^a	X^a, Y^a	2^a, 3^a, Z^a	2^a, 3^a, Z^a	X^a, Y^a
	Velocity	[b] (2.73)	Z^a	—	—	—	—	1^a

NOTE: Grouping variable: cigarette type; all conditions are combined; ANOVA/*post hoc* ANOVA test.
[a]$P < 0.01$.
[b]$P < 0.05$.

the experimental condition, puff volume, puff duration, TTS, and interpuff interval and puff velocity were similar. Some of the variables (TTS and number of puffs) differed between the smaller RYO cigarette and the larger PMM and FM cigarettes. In addition to the similarity in puffing, there were similar increases in plasma nicotine and CO_{ex}.

Table 5. Nicotine and exhaled carbon monoxide measurements by cigarette type and condition

Cigarette type	Condition	Plasma nicotine (ng/mL)				Exhaled CO (ppm)			
		Pre	Post	*P*	Boost	Pre	Post	*P*	Boost
RYO ($n = 34$)	NR	12.3 (8.1)	26.6 (13.3)	[a]	14.3 (10.2)	29 (17)	34 (16)	NS	4 (3)
	ABS	2.4 (2.0)	21.8 (16.6)	[a]	19.4 (16.9)	9 (3)	14 (4)	NS	6 (3)
	INT	16.2 (8.1)	25.7 (12.2)	[a]	9.5 (8.2)	32 (12)	36 (12)	NS	4 (3)
		ABS < NR[a]; INT[a]	—		ABS > INT[a]	ABS < NR[a]; INT[a]	ABS < NR[a]; INT[a]		ABS > INT[b]
PMM ($n = 23$)	NR	13.3 (7.1)	33.1 (19.8)	[a]	19.8 (18.3)	27 (13)	32 (11)	NS	5 (3)
	ABS	2.8 (1.9)	20.4 (17.4)	[a]	17.6 (17.8)	9 (2)	15 (3)	NS	6 (3)
	INT	22.1 (11.9)	31.0 (17.7)	NS	8.9 (17.9)	36 (13)	40 (13)	NS	4 (3)
		ABS < NR[a]; INT[a] INT > NR[a]	—		—	ABS < NR[a]; INT[a] INT > NR[a]	ABS < NR[a]; INT[a] INT > NR[a]		ABS > INT[b]
FM ($n = 20$)	NR	10.3 (7.5)	29.1 (13.1)	[a]	18.8 (12.2)	22 (14)	39 (26)	[a]	9 (5)
	ABS	1.6 (1.0)	23.5 (11.9)	[a]	21.9 (11.6)	8 (3)	16 (4)	NS	9 (3)
	INT	18.2 (9.2)	31.0 (12.2)	[a]	12.2 (9.9)	33 (13)	44 (20)	NS	7 (5)
		ABS < NR[a]; INT[a] INT > NR[a]	—		ABS > INT[b]	ABS < NR[a]; INT[a] INT > NR[a]	ABS < NR[a]; INT[a]		—

NOTE: Arithmetic means with SDs are presented.
Abbreviations: pre, biomarker level before smoking; post, biomarker level after smoking; boost, difference between biomarker levels after and before smoking; *P*, *post hoc* ANOVA test.
[a]$P < 0.01$.
[b]$P < 0.05$.

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Dependence and cigarettes smoked per day

Analyses of the NDSS and FTND results confirmed that all participants (across all types of cigarettes) were similarly, dependent on nicotine and had similar levels of plasma cotinine (Table 1). However, the PMM group smoked significantly more [22 cigarettes smoked per day (CPD)] compared with FM smokers (15 CPD) while having similar plasma nicotine levels before smoking within the same smoking condition. This finding cannot be explained by smoking topography variables or the average weight of the cigarette (these factors were also similar in both groups). One of the possible explanations for that difference in CPD between those 2 groups might be the lower capability of PMM cigarettes to deliver nicotine, which might reflect different cigarette construction, tobacco characteristics (nicotine content in raw product before smoking), or different combusting processes during smoking.

Exposure to nicotine

Before smoking sessions, PMM smokers had slightly (not significantly) higher plasma nicotine levels than RYO and FM smokers, which might reflect that this group smoked significantly more cigarettes than FM smokers (22 CPD vs. 15 CPD) and slightly more than RYO smokers (18 CPD). Before smoking in condition ABS (overnight tobacco abstinence), nicotine plasma levels decreased significantly comparing to conditions NR and INT, which confirms participants' compliance with the study protocol. Within the same smoking conditions but across different types of cigarettes, participants were able to extract almost similar amount of nicotine, which confirms that all examined types of cigarettes were equally efficient in nicotine delivery. Similar and substantial quantities of nicotine delivery across all types of cigarettes, despite differences in their size (RYO significantly smaller than FM or PMM) might be explained in cigarette design. RYO are usually not filtered (4) and as a result more nicotine (as well as other toxicants) is delivered with smoke. This finding is consistent with research by Darrall and Figgins (5) who studied RYO in United Kingdom. The authors reported that adding a filter to RYO had little effect on CO yield, but reduced nicotine and tar levels by 48% and 46%, respectively.

Exposure to carbon monoxide

Exposure to CO (expressed as CO boost) was significantly higher during FM than RYO and PMM cigarettes smoking. The average weight of the FM cigarette was significantly higher than RYO cigarettes, which might explain the FM/RYO differences in CO exposure as a function of the amount of tobacco consumed during smoking (the higher mass of the cigarette, the higher exposure to CO). However, PMM and FM cigarettes had similar weights but different CO delivery. The finding cannot be explained by differences in smoking behavior, because smoking topography parameters were similar across these both types of cigarettes. Taken together these findings suggest that CO exposure depends not only on the mass of combusted tobacco but also additional factors must play a role. Toxicant generation during smoking is a very complex process that depends on cigarette construction, presence, and characteristics of the filler and temperature–oxygen conditions during smoking. Tobacco in FM cigarettes is packed denser, and FM cigarettes have filters (RYO are usually unfiltered). As a result, the combustion processes might be different (lower oxygen delivery during FM comparing to PMM smoking might result in higher CO generation and exposure).

Smoking topography

Smoking topography parameters may be divided into 2 groups: (i) those that are independent of the size the smoking article (puff volume, puff duration and velocity) and (ii) those that are dependent on the size of the article (TTS, puffs per cigarette). Three average topography parameters (puff volume, puff duration, and puff velocity) were similar across all 3 types of cigarettes and 3 smoking conditions. Although the puffing was similar between MYO and FM cigarettes studied here, puffing patterns may not be consistent with other smoking articles such as cigars, little cigars, and cigarillos (39).

Smoking topography parameters reported in this study are similar to those measured by others using FM (11, 14, 40–44) and MYO cigarettes (6). There have been reports in the literature (40, 45–49) that smoking topography may change over the course of smoking a single cigarette. In adults (40, 45–47) and adolescents (48, 49), initial puffs are larger, longer, and more closely spaced than the last puffs of a cigarette. The usual explanation for differences is that the smokers are trying (with their initial puffs) to satisfy a nicotine "need" that becomes satisfied over the course of a cigarette. Our results support that trend in both RYO and PMM smokers across all experimental conditions. However, if the pattern of smoking truly changes in response to nicotine need, we would expect to see greater differences when comparing across experimental conditions. For example, in the intense condition, INT (full tobacco satiation) there should be fewer differences between the first and last puffs of a cigarette whereas in the overnight abstinent condition, ABS, there might be more difference between the first and last puffs. This expectation was not evident—all cigarettes in all conditions were smoked with the same pattern suggesting that the pattern of cigarette puffing in established smokers is constant regardless of immediate nicotine need. The smoking history of the participant may influence this pattern. In this study, almost all (96%) of the RYO and PMM participants had begun cigarette smoking as FM smokers (and had later changed to exclusive MYO smoking). It must be considered that the patterns of smoking were established very

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early in the smoking history (with FM cigarettes) and persisted years later smoking while smoking MYO cigarettes. Because the speed of nicotine delivery seems to be directly related to the addiction potential of the product (50, 51), the constancy of the puffing profile may be an example of behavioral autonomism, suggesting that once established a pattern of smoking persists regardless of the nicotine need. It would be interesting to compare puffing patterns and their relation to nicotine need in new smokers or in smokers using novel products such as little cigars or electronic cigarettes.

Subjective effects of cigarettes

Overall there were very few significant differences in the subjective experience associated with smoking the experimental cigarettes. Participants reported moderate to high levels of satisfaction, craving relief, and sensations across all products. Furthermore, the conditions of the experiment did not change the subjective evaluation of the cigarettes (e.g., the cigarettes were no better liked in the abstinence than in the intense smoking conditions). In a previous study comparing novel cigarettes of differing nicotine content, the delivery of nicotine (but not menthol flavoring) was related to the subjective experiences (23). Others have shown differences in subjective response to novel cigarettes (52, 53). That there were few differences in subjective evaluations in this study may be because the assessments were made using a familiar cigarette that delivered equivalent and expected quantities of nicotine.

MYO smoking and ISO standard

Measured average puff volumes for all tested cigarettes, in all smoking conditions were higher than standard puffing regime required by ISO method for cigarette testing (35 mL). The differences ranged from +51% (RYO) to +80% (RYO) in NR and INT conditions, respectively. Average puff duration in all smoking conditions and for all cigarettes were lower than required by ISO method (2 seconds). The differences were not high, but still ranged from −20% (RYO) in NR condition to −6% (FM, INT condition). Measured average puff velocities were also higher than in ISO method (17.5 mL/s) in all analyzed cases. They ranged from +111% (RYO, ABS condition) to +150% (FM, INT condition). Our data confirm again that current ISO testing regime is an inappropriate standard for evaluating cigarette toxicity and setting regulatory restrictions not only for FM cigarettes, but also cannot be used for accurate assessment of toxicants intake from RYO and PMM cigarettes. Other standard methods for cigarette testing: Massachusetts method (puff volume: 45 mL; puff duration 2 seconds; puff velocity: 22.5 mL/s) and Canadian regime (puff volume: 55 mL; puff duration 2 seconds; puff velocity: 27.5 mL/s) also do not correspond well to the smoking topography parameters we measured in this study. Although the Canadian regime has been called a "maximum" smoking regime, the puffing parameters of some participants exceeded those of the Canadian intense method.

Summary

The study demonstrated that despite differences in their size, tobacco weight, and design, RYO, PMM, and FM cigarettes delivered similar amounts of nicotine, CO, and presumably other toxicants. Toxicant delivery and smoking patterns were similar across a wide range of experimentally manipulated conditions of tobacco craving. Participants of this study were exclusive RYO, PMM, or FM smokers. Puffing profiles, toxicant exposure, and subjective responses may differ among people who do not exclusively use these products. Furthermore, the participants were largely white men. Although that is the typical demographic of smokers of self-made cigarettes in the Baltimore area, the results must be viewed as a characteristic of this group. Our study group was not racially homogenous, but we observed no differences in puffing behavior. The study described above was conducted in a laboratory conditions, thus, we cannot generalize to smoking in a natural environment. Smoking thru topography devices are commonly used. Computer based smoking topography proven to be a reliable measure of smoking behavior and toxicant exposure (14, 15) but some experimental evidence suggests that a portable topography device (not used in this study) may increase smoking difficulty, reduce smoking enjoyment, and alter cigarette taste (54). Our results indicate that MYO cigarettes deliver toxicants similar to FM cigarettes and contradict the consumer perceptions that MYO cigarettes are safer or less toxic than FM cigarettes (55–57). The results of this clinical study support the conclusions from machine smoking of MYO cigarettes (58, 59), where MYO cigarette delivered substantial levels of nicotine, CO, and "tar." Machine smoking and clinical studies of MYO cigarettes and cigarette smoking affirm their delivery of toxicants and strengthen the need for their continued regulation.

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

Authors' Contributions

Conception and design: L.C. Viray, J.L. Potts, W.B. Pickworth
Development of methodology: B. Koszowski, J.L. Potts, W.B. Pickworth
Acquisition of data (provided animals, acquired and managed patients, provided facilities, etc.): L.C. Viray, J.L. Potts
Analysis and interpretation of data (e.g., statistical analysis, biostatistics, computational analysis): B. Koszowski, Z.R. Rosenberry, W.B. Pickworth
Writing, review, and/or revision of the manuscript: B. Koszowski, Z.R. Rosenberry, L.C. Viray, J.L. Potts, W.B. Pickworth
Administrative, technical, or material support (i.e., reporting or organizing data, constructing databases): B. Koszowski, Z.R. Rosenberry, L.C. Viray
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Make Your Own Cigarettes: Toxicant Exposure, Smoking Topography, and Subjective Effects

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