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Original Investigation

Comparison of methods for measurement of smoking behavior: Mouthpiece-based computerized devices versus direct observation

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Abstract

Introduction: Understanding factors that influence tobacco use often involves detailed assessment of smoking behavior (i.e., puff topography) via mouthpiece-based, computerized devices. Research suggests that the use of a mouthpiece to evaluate topography may alter natural smoking behavior. This study was designed to compare topography measurement using mouthpiece-based methods (i.e., desktop and portable computerized devices) to methods that do not use a mouthpiece (i.e., direct observation).

Methods: A total of 30 smokers (≥15 full-flavor or light cigarettes/day) participated in six Latin square–ordered, 2.5-hr experimental sessions that were preceded by at least 8 hr of objectively verified tobacco abstinence (carbon monoxide level ≤ 10 ppm). Each session consisted of participants smoking four cigarettes (own brand or Merit ultra-light) *ad libitum*, conventionally or using a desktop or portable device. Sessions were videotaped using a digital camcorder.

Results: All three measurement methods were sensitive to oft-reported brand- and bout-induced changes. Topography measurement differed little between methods (across methods, all r values > .68), and each method was reliable (across bouts within each condition, most r values > .78). In contrast, participants perceived the use of either mouthpiece-based device to alter aspects of their smoking behavior (e.g., increased smoking difficulty, reduced enjoyment, altered cigarette taste; $p < .05$), relative to video recording only.

Discussion: Although direct observational methods may be optimal for measuring certain smoking characteristics, logistical challenges posed by this method likely limit its usefulness. Together, these results suggest that mouthpiece-based devices offer a convenient and useful tool for researchers examining smoking topography.

Introduction

Detailed examination of smoking behavior has been of interest for decades (e.g., Djordjevic, Hoffman, & Hoffman, 1997; Donny, Houtsmuller, & Stitzer, 2007; Epstein et al., 1982; Robinson & Forbes, 1975). It involves quantitative measurement of puff topography: number of puffs/cigarette, puff duration (milliseconds), puff volume (milliliters), and interpuff interval (IPI; time between successive puffs, in seconds). The ability to measure topography has allowed researchers to understand many factors that maintain regular tobacco use. For example, puff topography has been used to explain why low-yield cigarettes failed to reduce smoking-related harm; smokers take more, bigger, and/or longer puffs when they switch from full-flavor to low-yield brands (e.g., Herning, Jones, Bachman, & Mines, 1981). Topography measurement also has demonstrated the effects of cigarette abstinence. Following a period of cigarette deprivation, smokers may increase the number of cigarettes smoked or the number of puffs taken per cigarette, or they may take larger puffs (e.g., Zacny & Stitzer, 1985). Consequently, this research tool has facilitated the understanding of novel tobacco products and periods of smoking cessation.

Given the utility of puff topography measurement, various methods have been tested in an attempt to maximize the reliability and validity of this tool. Early studies relied on observational methods such as trained observers (Lichtenstein & Antonuccio, 1981) and video cameras (Frederiksen, Miller, & Peterson, 1977). Eventually, research efforts turned to specialized devices: pneumotachographs (Adams, Lee, Rawbone, & Guz, 1983), pocket calculators (Henningfield, Yingling, Griffiths, &

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Pickens, 1980), and flowmeter designs (Puustinen, Olkkonen, Kolonen, & Tuomisto, 1987). These devices are commonly used today, given their convenient, objective, and precise assessment of smoking behavior (e.g., Kashinsky, Collins, & Brandon, 1995). However, most devices require a specialized mouthpiece, which may interfere with natural smoking. Only a few studies have compared mouthpiece and non–mouthpiece-based measurement directly. Relative to lip contact, for example, smoking via a mouthpiece has been shown to increase puff number and duration, as well as decrease IPIs (e.g., Höfer, Nil, & Bättig, 1991a, 1991b; Pickens, Gust, Catchings, & Svikis, 1983). A more recent study found no differences between methods in puff number (Lee, Malson, Waters, Moolchan, & Pickworth, 2003). To complicate matters further, others have suggested that differences in topography depend on device type (desktop vs. portable; Evans, 2003). Thus, these studies suggest that mouthpiece-based devices can influence smoking behavior under some conditions, and they highlight the need for systematic evaluation of topography measurement devices.

The present study compared topography measurement using two mouthpiece-based devices (i.e., desktop and portable versions) to mouthpiece-free video recordings. Previous work (Evans, 2003) predicted that the portable device would allow more naturalistic smoking behavior than the desktop device. All methods were expected to demonstrate oft-reported changes in topography (e.g., cigarette brand- and bout-induced effects), to measure topography across cigarettes reliably, and to suppress withdrawal effectively.

Methods

Participants

Healthy smokers (N = 30; 14 men, 17 non-White) completed this institutional review board–approved study. Participants were aged 18–55 years (M = 32.3, SD = 11.0) and reported smoking at least 15 cigarettes/day (M = 19.6, SD = 4.7) for at least 1 year (M = 8.0, SD = 7.1). Smoking status was confirmed with an expired-air carbon monoxide (CO) level of at least 15 ppm (M = 22.4, SD = 9.2) and an average score of 6.0 (SD = 2.0) on the Fagerström Test for Nicotine Dependence (Heatherton, Kozlowski, Frecker, & Fagerström, 1991). Participants reported smoking regular (n = 21) or light (n = 9) cigarettes (average Federal Trade Commission [FTC], 2000, method, 1.1 mg nicotine [SD = 0.3], 14.9 mg tar [SD = 3.5], and 15.0 mg CO [SD = 3.0]). Current smoking reduction, ultra-light cigarette smoking, history of chronic health or psychiatric conditions, and pregnancy or breast feeding were exclusionary criteria.

Procedures

This laboratory study used a six-condition, within-subject, Latin square–ordered design. Following verification of overnight cigarette abstinence (expired-air CO ≤ 10 ppm), recording of heart rate commenced. Measures of tobacco or nicotine withdrawal and CO were assessed 30 min later. Participants then smoked the first cigarette *ad libitum*: own brand or Merit ultra-light (Philip Morris, Richmond, VA; 0.5 mg nicotine, 5 mg tar, and 7 mg CO, FTC, 2000), covered with opaque rolling paper (Zig-Zag Orange 11/4, Louisville, KY). Cigarettes were smoked using a desktop device (two sessions), a portable device (two sessions), or no device (two sessions). All sessions were videotaped, and the proximity of the camera to the participants ensured that they were aware of the recording. Participants had been familiarized with all measurement equipment and instructed to smoke as normal with each device at screening. After smoking, withdrawal effects and CO were assessed again. This same pattern was repeated three more times at 30-min intervals. Sessions ended with completion of an acceptability questionnaire and payment (U.S.$300 total).

Outcome measures

Puff topography. Puff volume, duration, number, and IPI were measured via mouthpiece-based desktop (Clinical Research Support System [CReSS]) and portable (CReSSmicro) computerized topography devices (Plowshare Technologies, Baltimore, MD. The desktop device consists of a mouthpiece connected to a metal box (21.1 × 14.2 × 15.2 cm) by 152.4 cm of black plastic tubing. For data collection, the metal box must be connected to a microcomputer. The portable device is a battery-powered single unit (6.5 × 5.5 × 2.9 cm) that stores topography data until they are downloaded to a microcomputer. Cigarettes were placed into the devices' mouthpiece connected to a pressure transducer, and pressure changes created by an inhalation were amplified, digitized, and sampled at a rate of 1000 Hz. Software converted signals to airflow (ml/s) and integrated data over time.

Puff number, duration, and IPI were measured via digital video records (Canon Elura 80; Canon USA, Inc., Lake Success, NY) that allowed the use of frame-by-frame time analysis (e.g., Adobe Premier Elements 1.0; Adobe Systems, Inc., San Jose, CA). A puff was defined as contact of the cigarette with smokers' lips accompanied by a red glow from the tip. Puff number was the total number of puffs lasting more than 300 ms. For puff duration and IPI, comparisons were made between two different operational definitions that differed by the frame identifying puff onset: (a) initial contact observed between lip and cigarette/mouthpiece ("lip" duration and IPI) or (b) a red glow first observed in the cigarette tip ("red" duration and IPI). Puff offset was always defined as the last frame in which the cigarette/mouthpiece was enclosed by the lips.

Hughes–Hatsukami questionnaire. The Hughes and Hatsukami (1986) questionnaire consists of 11 Visual Analog Scale (VAS) items (Table 1) and measures nicotine or tobacco abstinence effects. Items are presented as a word or phrase centered above a horizontal line that ranges from 0 (*not at all*) to 100 (*extremely*). The score is the distance of the vertical mark from the left anchor, expressed as a percentage of line length.

Tiffany–Drobes Questionnaire on Smoking Urges. The Questionnaire on Smoking Urges (QSU; Tiffany & Drobes, 1991) consists of 32 items rated on a 7-point scale (0 = "*strongly disagree*" to 6 = "*strongly agree*"). Items were collapsed into two factors previously defined by factor analysis: "intention to smoke" (Factor 1) and "anticipation of relief from withdrawal" (Factor 2).

Acceptability questionnaire. The acceptability questionnaire asked to what degree the device/video "altered smoking behavior," "made smoking less likely," "reduced smoking enjoyment," "affected the taste of the cigarettes," "made smoking more difficult," and "increased awareness of how much was smoked." A final question asked participants if they were interested to "know more about their smoking behavior." Items were presented in VAS format (0- to 100-point F).

Table 1. Statistical analysis results for all measures collected during four smoking bouts

Measure	Device *F*	Device *p*	Cigarette brand *F*	Cigarette brand *p*	Bout *F*	Bout *p*	Time *F*	Time *p*	Bout × time *F*	Bout × time *p*
Puff topography[a,b]										
Average puff volume (ml)	19.5	<.001	12.2	<.01	3.9	<.05	n/a		n/a	
Total puff volume (ml)	16.7	<.001	6.8	<.05	8.8	<.01	n/a		n/a	
Puff duration (s)	9.9	<.001	73.3	<.001	2.8	*ns*	n/a		n/a	
IPI (s)	3.9	<.05	3.1	*ns*	6.8	<.01	n/a		n/a	
Puff number	1.5	*ns*	3.9	*ns*	13.7	<.001	n/a		n/a	
Nicotine/tobacco withdrawal[c]										
Hughes–Hatsukami VAS										
Urges to smoke	2.8	*ns*	5.2	<.05	102.1	<.001	70.6	<.001	33.0	<.001
Irritability/frustration/anger	1.4	*ns*	<1.0	*ns*	6.3	<.05	20.6	<.001	8.8	<.01
Anxious	1.1	*ns*	<1.0	*ns*	12.9	<.001	25.5	<.001	16.8	<.001
Difficulty concentrating	<1.0	*ns*	<1.0	*ns*	9.0	<.01	2.5	*ns*	1.8	*ns*
Restlessness	1.2	*ns*	<1.0	*ns*	2.1	*ns*	19.9	<.001	14.2	<.001
Hunger	<1.0	*ns*	<1.0	*ns*	2.8	*ns*	4.0	*ns*	8.8	<.001
Impatient	1.3	*ns*	<1.0	*ns*	3.3	*ns*	21.4	<.001	15.9	<.001
Craving a cigarette/nicotine	1.6	*ns*	7.7	<.01	82.1	<.001	80.8	<.001	42.0	<.001
Drowsiness	<1.0	*ns*	<1.0	*ns*	2.8	*ns*	9.0	<.01	1.5	*ns*
Depression/feeling blue	<1.0	*ns*	1.6	*ns*	3.6	<.05	11.3	<.01	4.5	<.05
Desire for sweets	2.7	*ns*	2.3	*ns*	<1.0	*ns*	7.1	<.05	1.3	*ns*
Tiffany–Drobes (Δ to) QSU										
Factor 1	<1.0	*ns*	10.5	<.01	60.7	<.001	58.1	<.001	13.2	<.001
Factor 2	<1.0	*ns*	4.6	<.05	42.9	<.001	25.3	<.001	36.3	<.001
Physiological measures[c]										
Heart rate	<1.0	*ns*	8.6	<.01	4.7	<.05	79.5	<.001	68.8	<.001
Carbon monoxide	<1.0	*ns*	8.7	<.01	157.9	<.001	196.5	<.001	25.6	<.001

Note. ns, nonsignificant; n/a, applicable; IPI, interpuff interval; QSU, Questionnaire on Smoking Urges; VAS, Visual Analog Scale. Results for other interaction effects are omitted (all other F's < 3.6, p's > .05).

[a]Device factors: three (desktop, portable, video) for duration, IPI, and number and two (desktop, portable) for average and total volume.

[b]$df_{device} = (2, 58)$; $df_{cigarette\ brand} = (1, 29)$; $df_{bout} = (3, 87)$.

[c]$df_{device} = (2, 56)$; $df_{cigarette\ brand} = (1, 28)$; $df_{bout} = (3, 84)$; $df_{time} = (1, 28)$; $df_{bout \times time} = (3, 87)$.

Carbon monoxide. Expired-air CO levels were collected via a BreathCO monitor (Vitalograph, Lenexa, KS) at screening (to verify current smoking status), at session onset (to verify overnight tobacco abstinence), and before and after each smoking bout (before- and after-smoking timepoints).

Heart rate. Heart rate was monitored continuously via noninvasive computerized equipment (Patient Monitor Model 507E; Criticare Systems, Waukesha, WI). Measurements were taken every 20 s.

Data analyses

Interrater reliability was assessed for video data by correlating scores between two independent raters (MDB and SD). Because Pearson's correlation coefficients (r) were high for all outcomes (r's ≥ .94, p's < .01), rater scores were averaged and used in all analyses involving the video condition.

Puff topography data were analyzed using a three-factor, within-subject analysis of variance (ANOVA): measurement method (desktop, portable, video) × cigarette type (own brand, low yield) × cigarette bout (Cigarettes 1–4). Subjective and physiological data also were analyzed using ANOVA, although there were four factors: measurement method, cigarette type, cigarette bout, and time (before and after smoking for withdrawal and CO; before and during smoking for heart rate). Acceptability data were analyzed using a two-factor (device and cigarette type) ANOVA. Huynh–Feldt corrections were used to adjust for potential violations of the sphericity assumption. Differences between means were examined using Tukey's honestly significant difference (HSD; $p < .05$), which controls the familywise Type I error rate.

Video scores of smoking with a mouthpiece (desktop and portable) or without a mouthpiece were correlated with scores generated by each computerized device (desktop and portable). For reliability of measurement for each method, puff topography data for Cigarettes 2 and 3 within a session were correlated.

Results

Statistical analysis results for topography, subjective, and physiological measures are displayed in Table 1. Many interaction effects are omitted due to the paucity of significant findings. For topography measures, we observed no significant effects for device by cigarette brand, cigarette brand by bout, or device by cigarette brand by bout (F's < 3.4, p's > .05) and only one significant effect for device by bout–lip duration, $F(6, 174) = 2.2$, $p < .05$. All other typography results were not significant (F's < 2.0, p's > 0.05) For subjective and physiological measures, only 5 of 75 possible significant two-way interactions (all other F's < 3.6, p's > .05) and only 4 of 75 possible significant three- and four-way interactions (all other F's < 2.5, p's > .05) were significant. Additionally, puff topography data presented in Table 1 and below are based on the "lip" definition because the pattern of results for these data did not differ from those for the "red" definition.

Brand- and bout-induced effects

Several topography variables were influenced by cigarette brand (main effect of brand; F's > 6.8, p's < .05). These effects were demonstrable with all three measurement methods as shown in Table 2. For example, puff duration was longer for ultra-light relative to own brand for desktop (mean difference = 0.26 s, SD = 0.5), portable (mean difference = 0.23 s, SD = 0.3), and video (mean difference = 0.25 s, SD = 0.4; nonsignificant [*ns*], Tukey's HSD). Desktop and portable devices were also sensitive to brand-induced changes in total and average puff volume.

Main effects of cigarette bout (F's > 3.9, p's < .05) were observed for several smoking topography variables. Mean puff number, for instance, decreased from 10.9 puffs (SD = 3.5) at Bout 1 to 8.9 puffs (SD = 2.9) at Bout 4 (*ns*, Tukey's HSD). Compared with Bout 4, participants took more puffs at Bout 1 for desktop (mean difference = 2.1 puffs, SD = 3.3), for portable (mean difference = 2.4 puffs, SD = 3.0), and for video (mean difference = 1.6 puffs, SD = 3.0; $p < .05$, Tukey's HSD).

We also found several significant main effects of device (F's > 3.9, p's < .05), as well as a device × bout interaction for puff duration, $F(6, 174) = 2.2$, $p < .05$. Within each device, puff durations were shortest at Bout 1 relative to other bouts, and differences between bouts were least pronounced for video (*ns*, Tukey's HSD). Longer puffs were observed for video than for desktop or portable at all four bouts ($p < .05$, Tukey's HSD). Device influenced IPI, with shorter IPIs observed for desktop (M = 16.7 s, SD = 8.1) compared with portable (M = 17.4 s, SD = 7.7) or video (M = 18.3 s, SD = 8.3; *ns*, Tukey's HSD). Participants took larger puffs when using desktop (M = 58.7 ml, SD = 20.1) compared with portable devices (M = 48.6 ml, SD = 13.7; collapsed across brand and bout, $p < .05$, Tukey's HSD).

Comparison of topography measurement across methods

Data compared for the video-alone condition versus the two device conditions are displayed in Table 3 (cigarette brand by bout). All correlations were high and reliable (r's ≥ .68, p's < .01). In addition, data from video recordings of participants using each device were significantly correlated with data from each mouthpiece-based device (cigarette brand × bout; r's ≥ 0.73, p's < .01). Topography data collected from Bouts 2 and 3 within each condition demonstrated reliability, and correlations yielded by each method were comparable (video [r's ≥ .80, p's < .01], portable [most r's ≥ .78, p's < .01], and desktop [most r's ≥ .83, p's < .01]).

Device acceptability

Statistical analyses for all acceptability measures are displayed in Table 4. Significant device differences were observed for a variety of items (F's > 3.7, p's < .05), although there were no effects of cigarette brand or any interactions between brand and device (F's < 3.1, p's > .05). For the majority of items on which there was a main effect of device (all except "make smoking less likely"), significantly higher scores were observed for both devices relative to video alone ($p < .05$, Tukey's HSD). In contrast, ratings between desktop and portable devices did not differ for any measure (*ns*, Tukey's HSD).

Nicotine and tobacco withdrawal effects

Hughes–Hatsukami questionnaire. As Table 1 demonstrates, significant bout × time interactions were observed for 8 of the 11 VAS measures (F's > 4.5, p's < .05). For "craving a cigarette/nicotine" (largest F value for bout × time interaction), mean scores were similar for each device and both brands at each timepoint. However, within each condition, mean craving decreased from 76.7 (SD = 25.7) to 28.0 (SD = 28.0) for Bout 1, from 44.2 (SD = 29.4) to 20.5 (SD = 25.2) for Bout 2, from 30.2 (SD = 28.8) to 15.6 (SD = 22.5) for Bout 3, and from 26.4 (SD = 26.3) to 14.8 (SD = 22.2) for Bout 4 (from before smoking at Bout 1; $p < .05$, Tukey's HSD). That is, the mean difference between pre- and postsmoking values was greater for Bout 1

Table 2. Means (*SD*) for puff topography measures for device by cigarette brand

	Desktop[a]		Portable[a]		Video[a]	
	Own brand	Ultra-light	Own brand	Ultra-light	Own brand	Ultra-light
Topography measure						
Puff volume (ml)[b]	57.0 (20.1)	60.3 (20.0)	44.4 (13.6)	52.8 (12.6)	n/a	n/a
Total puff volume (ml)[b]	578.7 (327.2)	614.2 (301.1)	411.4 (170.7)	528.5 (207.2)	n/a	n/a
Puff duration (s)[b]	1.7 (0.7)	2.0 (0.8)	1.7 (0.6)	1.9 (0.6)	1.9 (0.8)	2.1 (0.7)
IPI (s)	18.1 (8.8)	15.2 (7.2)	18.2 (7.6)	16.7 (7.7)	18.3 (7.5)	17.8 (9.0)
Puff number	9.7 (3.3)	10.2 (3.1)	9.4 (3.0)	10.1 (3.4)	9.2 (3.2)	9.9 (3.1)

Note. n/a = not applicable; IPI, interpuff interval. Device factors: three (desktop, portable, video) for duration, IPI, and number; two (desktop, portable) for average and total volume.

[a]Collapsed across bout.

[b]Significant main effect of cigarette brand (F's > 6.8, p's < .05).

Table 3. Correlation coefficients for data collected via computerized device and direct observation methods

	Bout							
	Own brand				Ultra-light			
	1	2	3	4	1	2	3	4
Desktop vs. video								
Puff duration (s)	.79	.79	.83	.87	.84	.78	.75	.68
Interpuff interval (s)	.72	.78	.75	.74	.86	.87	.67	.75
Portable vs. video								
Puff duration (s)	.71	.71	.72	.84	.94	.80	.85	.85
Interpuff interval (s)	.82	.87	.74	.82	.69	.77	.81	.82

Note. All coefficients were statistically significant ($p < .01$).

($M = 48.7$, $SD = 25.7$; $p < .05$, Tukey's HSD) than for Bout 4 ($M = 11.6$, $SD = 14.1$). A similar pattern of results was observed for all other VAS items with a significant bout × time interaction.

We found a significant main effect of cigarette brand for the items "urges to smoke" and "craving a cigarette/nicotine" (F's > 5.2, p's < .05). Scores for both of these items were greater for ultra-light (e.g., craving mean = 34.3, $SD = 32.4$) than for own-brand cigarettes (e.g., craving mean = 29.8, $SD = 32.0$; $p < .05$, Tukey's HSD). Results also showed that scores for "difficulty concentrating" decreased with subsequent bouts—main effect of bout, $F(3, 84) = 9.0$, $p < .01$—and that scores for "drowsiness" decreased from pre- to postsmoking bout—main effect of time, $F(1, 28) = 9.0$, $p < .01$.

Two-way brand × bout interactions were observed for the VAS items "drowsiness" and "hunger" (F's > 4.0, p's < .05). For both measures, scores for own brand were generally greater than for ultra-lights for Bouts 1 and 2 but less than for ultra-lights for Bouts 3 and 4 (*ns*, Tukey's HSD). A significant three-way brand × bout × time interaction was observed for the VAS item "irritability/frustration/anger," $F(3, 87) = 5.2$, $P < .01$. Mean differences from pre- to postsmoking were 16.0 ($SD = 20.4$) versus 0.3 ($SD = 5.3$) for own-brand bouts 1 and 4, and 7.4 ($SD = 15.9$) versus 2.4 ($SD = 5.1$) for ultra-light bouts 1 and 4 (*ns*, Tukey's HSD). Finally, we found a significant four-way interaction for the VAS item "desire for sweets," $F(6, 174) = 3.4$, $p < .05$, although results showed no clear pattern, and differences between means were not reliable (*ns*, Tukey's HSD).

Tiffany–Drobes QSU. A significant four-way interaction was observed for Factor 1, $F(6, 174) = 3.0$, $p < .05$. The mean difference (collapsed across device and brand) from pre- to postsmoking decreased as bout number increased ($p < .05$, Tukey's HSD for Bouts 1 and 2). Greater scores were observed for ultra-light relative to own brand for each method: 47.8 ($SD = 20.4$) versus 42.4 ($SD = 17.6$) for desktop, 44.8 ($SD = 18.3$) versus 42.3 ($SD = 15.1$) for portable, and 48.2 ($SD = 18.3$) versus 40.1 ($SD = 16.9$) for video (*ns*, Tukey's HSD).

A significant bout × time interaction, $F(3, 87) = 36.3$, $p < .001$, and a main effect of cigarette brand, $F(1, 28) = 4.6$, $p < .05$, was observed for Factor 2. Scores decreased from pre- to postsmoking within each bout and also across pre- and postsmoking timepoints: from a mean difference of 17.0 ($SD = 13.9$) for Bout 1 to 5.9 ($SD = 10.0$) for Bout 4 ($p < .05$, Tukey's HSD). Moreover, ratings were greater for ultra-light ($M = 22.8$, $SD = 17.2$) than own-brand cigarettes ($M = 20.8$, $SD = 17.3$; $p < .05$, Tukey's HSD).

Physiological effects

A significant brand × bout × time interaction, $F(3, 87) = 7.7$, $p < .01$, was observed for heart rate. Within each condition, heart rate increased significantly during each bout relative to presmoking ($p < .05$, Tukey's HSD). Collapsed across time, mean heart rate for Bout 1 was 77.4 bpm ($SD = 9.0$) for own brand and 75.2 bpm ($SD = 9.4$) for ultra-light. By Bout 4, heart rate for own brand ($M = 76.7$ bpm, $SD = 9.6$) remained elevated relative to ultra-light ($M = 74.2$ bpm, $SD = 10.1$). Additionally, own brand produced a greater magnitude of increase from presmoking to during smoking as compared with ultra-light, although only for Bout 1 ($p < .05$, Tukey's HSD).

For expired-air CO, significant device × brand, $F(2, 58) = 4.1$, $p < .05$, brand × bout, $F(3, 87) = 250.3$, $p < .001$, brand × time, $F(1, 29) = 13.5$, $p < .01$, and bout × time, $F(3, 87) = 25.6$, $p < .001$, interactions were observed. Within every condition, CO increased significantly at each timepoint relative to the presession

Table 4. Statistical analysis results for the acceptability questionnaire

	Device[a]		Mean (*SD*)		
	F	*p*	Desktop	Portable	Video
Acceptability item					
Alter smoking behavior	11.9	<.001	51.6 (30.0)*	48.9 (30.1)*	31.9 (26.7)†,#
Increase smoking awareness	<1.0	*ns*	54.7 (28.5)	56.2 (26.9)	50.9 (29.5)
Increase smoking difficulty	14.3	<.001	47.3 (33.6)*	40.1 (29.8)*	19.5 (21.0)†,#
Reduce smoking enjoyment	13.2	<.001	53.5 (34.5)*	47.6 (30.2)*	29.0 (28.6)†,#
Make smoking less likely	3.7	<.05	39.8 (28.8)	38.5 (27.4)	28.8 (28.4)
Affect cigarette taste	10.8	<.001	44.4 (32.9)*	45.6 (31.8)*	25.7 (23.7)†,#
Know more about your smoking	2.3	*ns*	73.3 (26.9)	69.9 (24.6)	72.2 (25.8)

Note. ns, nonsignificant. Statistical analysis results for main effect of cigarette brand and interaction effect of device × cigarette brand were omitted because neither were statistically significant for any measure (F's < 3.1, p's < .05). Symbols denote significant difference from desktop (†), portable (#), or video (*).

[a] $df = (2, 58)$.

value (i.e., Bout 1 pre-cigarette value; $p < .05$, Tukey's HSD), and scores at both pre- and postsmoking timepoints increased with successive bouts. Additionally, CO was significantly greater for own-brand cigarettes ($M = 16.5$ ppm, $SD = 8.7$) relative to ultra-light cigarettes ($M = 14.8$ ppm, $SD = 6.9$; $p < .05$, Tukey's HSD). These brand-induced changes were more pronounced for desktop (mean difference = 3.2 ppm, $SD = 5.5$) than for portable (mean difference = 1.0 ppm, $SD = 5.3$) and video (mean difference = 0.2 ppm, $SD = 4.6$; *ns*, Tukey's HSD).

Discussion

Study results showed that measurement of smoking topography differed little between the computerized devices and video recordings. All three methods demonstrated brand- and bout-induced changes effectively, measured smoking topography reliably, and were correlated highly across all topography measures.

Measurement of brand- and bout-induced effects

Consistent with past work (e.g., Gust & Pickens, 1982; Zacny & Stitzer, 1985), characteristic brand- and bout-induced changes in smoking behavior were observed. Participants took significantly longer puff durations and larger average and total puff volumes for ultra-light than for own-brand cigarettes. Participants also took significantly more puffs from the first cigarette relative to subsequent cigarettes. These findings were demonstrable with all three measurement methods, and the magnitude of these changes did not differ across methods (*ns*, Tukey's HSD). Thus, all methods were sensitive to differences in cigarette brand and bout number.

Comparison of computerized devices versus video recordings

Topography data collected via mouthpiece-free video recordings did not differ from topography data collected via mouthpiece-based desktop or portable devices. We observed high and reliable correlations across cigarette brands and smoking bouts (all r's $\geq .69$, $p < .01$). Additionally, the computerized devices measured smoking topography precisely as is observed via direct observational methods (comparison of data from video recordings of device use vs. data from each device; all r's ≥ 0.73, $p < .01$). Furthermore, the reliability of each method (most r's $\geq .67$, $p < .01$) confirms past work (Evans, 2003). Collectively, these data support the notion that topography measurement via direct observation or mouthpiece-based devices does not differ.

Nonetheless, a few differences were observed across methods: significantly shorter puffs for computerized devices relative to video ($p < .05$, Tukey's HSD) and larger average and total puff volumes for desktop relative to portable devices ($p < .05$, Tukey's HSD). This finding deviates from previous laboratory-based work (larger total volumes for portable than for desktop; Evans, 2003). Thus, across studies, mouthpiece-based devices have been shown to produce differences in one direction (e.g., longer puffs; Höfer et al., 1991a, 1991b), the other direction (e.g., shorter puffs; present study), or no differences at all (e.g., Lee et al., 2003). This pattern may be reflective of chance variation or the manner in which various device designs measure topography.

Acceptability of device

Participants in this study reported that, relative to video alone, the mouthpiece-based devices influenced aspects of their smoking (e.g., increased smoking difficulty, reduced smoking enjoyment, and affected cigarette taste; $p < .05$, Tukey's HSD). Ratings between the two computerized devices, however, did not differ on any acceptability item (*ns*, Tukey's HSD). These self-report data are in contrast to behavioral data (i.e., smoking topography), with which few differences were observed across measurement methods. Similar dissociations between behavioral (e.g., bar pressing, driving) and subjective (e.g., self-reports of drug liking, impairment) data have been reported in research examining a variety of drugs (e.g., opioids, Lamb et al., 1991; alcohol, Liguori, D'Agostino, Sworkin, Edwards, & Robinson, 1999).

Influence of method on nicotine/tobacco withdrawal and physiological response

Symptoms of nicotine/tobacco withdrawal, following overnight cigarette abstinence, were independent of measurement method. However, withdrawal symptoms were reliably suppressed by smoking; ratings for VAS measures such as craving a cigarette/nicotine and irritability/frustration/anger were significantly decreased from pre- to postsmoking at all bouts ($p < .05$; Tukey's HSD). Withdrawal suppression also was observed for both cigarette brands, although the magnitude of these differences was affected by brand on some measures (e.g., VAS item "urges to smoke"; Zacny & Stitzer, 1988).

As expected, heart rate was not affected differentially by measurement method. Within each method, however, heart rate increased significantly from pre- to during-smoking bouts (Buchhalter & Eissenberg, 2000). Additionally, heart rate was generally greater for own brand than for ultra-light, although this effect was most pronounced for the first bout. Unlike in previous work (Evans, 2003), we found that expired-air CO levels were influenced by measurement method. Each method demonstrated brand-induced changes in smoking behavior, but the effect was most pronounced for the desktop condition, relative to the portable and video conditions. This finding may be a consequence of the larger puff volumes observed for desktop (collapsed across brand and bout; $M = 58.7$, $SD = 20.1$) than portable (collapsed across brand and bout; $M = 48.6$, $SD = 13.7$). Research supports this idea. Larger puff volumes result in greater CO boosts (i.e., increase from pre- to postsmoking) than do smaller volumes (i.e., 73.8 vs. 50.4 ml; e.g., Zacny & Stitzer, 1986). However, average CO for measurement method (i.e., collapsed across bout and brand) did not differ significantly.

Study limitations

The present study was conducted in a laboratory setting; thus, results may not generalize to smoking in a natural environment. Smoking behavior likely varies according to factors outside the laboratory (time of day and concurrent drug intake; Henningfield & Griffiths, 1981; Morgan et al., 1985). These factors were controlled in this study, thus potentially limiting its external validity.

Conclusions and future directions

Although the use of video recordings minimizes influence on smoking characteristics, this method poses notable limitations on topography measurement. Video recordings cannot be used to measure puff volume, a valuable index of smoke constituent intake (e.g., Herning et al., 1981). Additionally, scoring video records is labor intensive and time consuming (240 hr in this study), compared with instantaneous scoring via the computerized devices. Participant behavior must be controlled tightly to prevent missing data: puffs out of frame cannot be scored (ca. 1% in this study) and finger placement on the cigarette prohibits detection of puff onset. Thus, the sensitivity, reliability, and convenience of mouthpiece-based measurement devices support their continued use in the laboratory.

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