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Variability in Puff Topography and Exhaled CO in Waterpipe Tobacco Smoking

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Abstract

Objectives—We examined intra-individual variability in puff topography and CO measures collected during laboratory waterpipe (WP) tobacco smoking using a research-grade waterpipe (RWP).

Methods—WP smoking topography and exhaled CO measures were obtained from 10 established WP smokers in a single-blind, crossover design. Using a previously validated RWP, each participant smoked “Two Apples” WP tobacco ad libitum with a single quick-light charcoal to satiation in 3 laboratory sessions spaced at least one week apart. To examine the intra-individual variability, the intraclass correlation coefficient (ρ) for topography and CO measures were estimated. Results: The majority of the topography and CO measures were stable. Most stable were puff frequency (ρ = 0.88), number of puffs (ρ = 0.86), and puff duration (ρ = 0.80). Less stable were peak flow (ρ = 0.57) and total puff volume (ρ = 0.52).

Conclusions—The results provide the first set of empirical evidence that most topography and CO measurements collected using the RWP from a single laboratory smoking session are stable such that they can be representative of a smoker’s puffing behaviors and reproducible among 3 sessions spread equally across 3 weeks.

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Human Subjects Statement
This study was approved by the University of Maryland Institutional Review Board.

Conflict of Interest Statement
The authors have no conflict of interest.

Keywords

research-grade waterpipe; smoking topography; puffing behavior; intra-individual variability; hookah

Cigarette smoking is a complex, repetitive behavior.[1,2] Because most smokers are addicted to nicotine, puffing behaviors are primarily driven by a smoker's desire to take in and maintain a constant level of nicotine.[3] Not only do individuals smoke differently because of individual heritable differences, eg, nicotine metabolism,[4,5] they also may change their puffing behavior as a result of cigarette design such as filter ventilation,[4] added flavors such as menthol,[6] and low nicotine content of tobacco.[7] Although inter-individual variations are wide,[8,9] intra-individual variability is much less so, indicating that the smoking topography collected from a single cigarette smoking episode is reproducible across repeated smoking sessions, and thus, is a reliable index of that person's puffing behavior.[10]

Most cigarettes are commercially mass produced using machines to within precise physical and chemical specifications,[11] and require little from the user to smoke beyond lighting and puffing. In comparison, waterpipe (WP) tobacco smoking presents a much greater variety of equipment, component, and accessory options to the smoker.[12,13] In addition, there is significantly more user interaction with the smoking apparatus, including typical pre-smoking actions such as loading the tobacco into the bowl, wrapping the head with foil, and perforating the foil. Because up to half the weight of WP tobacco is composed of humectants,[14] it will not produce smoke without a constant source of heat. Thus, WP smokers typically light a burning coal and then interact with it by moving the ember across the foil on top of the bowl to distribute heat to the tobacco throughout the session.

As a result of this additional complexity in equipment and human intervention, WP puffing behaviors are more variable in nature than cigarette smoking. Smoking time is significantly longer for WP, ranging from 30 minutes to more than an hour,[15,16] compared to 5–6 minutes for cigarette smoking.[6,17] In addition, users often smoke WP in social settings where smoking is not the singular focus of the human behavior.[18] All of these factors could contribute to a wider range of puffing behaviors for WP smoking in comparison to those recorded during cigarette smoking.

Like cigarette smoking topography,[10] WP smoking topography measurements can serve as an indirect measure of smoke exposure and specific chemical exposure in mainstream smoke. For example, WP tobacco smoking typically involves a level of nicotine exposure that can promote and sustain dependence.[19,20] Maziak et al[21] showed that the total volume and smoking time during a laboratory WP smoking session can be used as a crude measure of nicotine uptake from that session. Indeed, nicotine-dependent WP smokers change their puffing behavior depending on whether the tobacco contains nicotine.[22] WP puffing topography variables such as total puffing time, number of puffs, and total smoke inhaled, also are related to a WP smoker's exposure to harmful gas-phase chemicals such as carbon monoxide.[23,24]

WP topography collection is a low-cost method that can have great utility for estimating the changes in smoke exposure when using specific WP components and parts, as well as specific additives in and nicotine content of the WP tobacco. However, given the greater complexity of WP smoking as a human behavior, we cannot assume that a single WP smoking session is representative of a WP smoker's behavior in general. It is important to understand if topography from a single smoking session can be used to accurately estimate smoker's exposures to harmful chemicals resulting from WP tobacco smoking.

The objective of this study was to gain a fundamental understanding of the variability inherent in human WP tobacco smoking behavior. More specifically, we focus on how puffing behaviors vary between and within individuals in WP smoking. To minimize equipment variability, we measured intra-individual variability in a cohort of established WP smokers over a 3-week period using a standardized research-grade waterpipe (RWP) of known accuracy and precision that provided a satisfying smoking experience comparable to that of commercially available WPs.[25] To obtain the most consistent estimate, we minimized the potential human behavioral modifiers by limiting each smoking session to the use of a single quick-light charcoal, and not permitting participants to move the charcoal.

METHODS

Development of Research-grade Waterpipe (RWP)

Because of large differences between cigarette and WP smoking (ie, high flow rate, large puff volume, low pressure drop), standard instruments and methods used in cigarette studies cannot be directly adopted for WP measurements.[19] In addition, commercially available WPs and their components vary widely in design and durability, including differences in fabrication materials used for stems, bases, bowls, and hoses; sealing joint designs and degree of leak-tight fit; and diameter of the flow path. To make a reliable determination of the variability in human WP smoking behavior (topography), we previously developed and qualified the use of a standardized research-grade waterpipe (RWP), equipped with a puffing topography analyzer.[25]

Briefly, the RWP was constructed from commercially available and specially fabricated components. To reduce memory effects and to aid in cleaning, all wetted materials were made of Pyrex, stainless steel, Delrin®, and Teflon®. The commercially available flexible tubing used as the hose was made of corrosive-resistant plastic and was designed to minimize particle adsorption as the smoke passed through the conduit to the smoker. The device was configured with an in-line topography system that allowed continuous measurement and recording of the flow rate of smoke puffed by the user throughout the smoking session. More detailed description of the RWP can be found elsewhere.[25]

Participants

Ten established WP smokers were recruited through advertisements, flyers, and word-of-mouth in the College Park, Maryland (USA) area. Participant inclusion criteria specified individuals who (1) were healthy, (2) were older than 18 years of age, (3) had been smoking a WP at least 3 times in the previous year and at least once in the previous month; and (4) who were willing to complete 3 weekly laboratory visits at the research center. Users of other forms of tobacco (eg, cigarettes, smokeless) were not excluded. Participants were asked to refrain from using any nicotine/tobacco product for 4 hours prior to their laboratory visits to ensure that they would smoke the RWP to satiation. Participants were compensated for their participation in the study.

Study Design and Procedures

The study used a single-blinded within-subjects crossover design. All 3 repeated sessions were scheduled weekly at approximately the same time of day. Upon arrival at the laboratory, the study protocol was explained and written informed consent was obtained. Smoking abstinence was verified by measuring expired carbon monoxide (CO) levels of <10 parts per million (ppmv). Each participant completed a self-administered questionnaire, which included demographics and tobacco use history. Participants were blinded to the study objectives and instructed to smoke *ad libitum*.

Participants were seated in a comfortable chair, with a choice of videos for distraction, and smoked the RWP fitted with a single 150 cm hose and pre-filled with 15 g of *ma'assel* tobacco (Two Apples, Nakhla), which is a typical mass of tobacco for a single-coal smoking session.[23] This brand is a popular type of sweetened and flavored WP tobacco. In addition to its popularity among WP smokers,[22] mainstream smoke generated with this tobacco has been characterized by several research groups.[26] The bowl at the base was filled with 1.5 L of room temperature deionized water. A single quick-light charcoal disk (40 mm diameter, Three Kings, Holland), placed on top of the aluminum foil that was perforated with 16 small holes, was used as a heating source.

While participants were smoking freely under controlled conditions in a clinical laboratory, the puffing flow rate was digitally recorded. The CO levels were measured using a Bedfont Breath CO Analyzer before smoking and within 2 minutes of completion of the smoking session. Participants were asked to smoke until satiated, with no minimum or maximum amount of smoking time required.

Data Analysis

Automated analysis of the continuous flow rate curve was conducted as previously described,[23] and the following topography and CO measures were examined: (1) puff duration (s), (2) puff volume (L), (3) interpuff interval (s), (4) puff mean flow rate (L/min), (5) puff peak flow rate (L/min) (6) frequency (puffs per minute), (7) total smoking time (min), (8) number of puffs, and (9) total puff volume (L); as well as (10) CO level at pre-smoking (ppmv), (11) CO level at post-smoking (ppmv), and (12) CO boost (ppmv). Means, standard deviations (SDs), and 95% confidence intervals (CIs) were calculated for each session across participants. Overall means, SDs, as well as coefficients of variation (CVs) were calculated across sessions. To examine the reliability of individual measurements of topography and CO levels across sessions, we calculated the intraclass correlation coefficient (ρ):

$$\rho = \frac{\sigma_b^2}{\sigma_b^2 + \sigma_w^2}$$

where σ_w^2 and σ_b^2 are the within- and between-subject variance, respectively. Intraclass correlation coefficient quantifies the intra-individual variability by calculating the proportion of total variability due to the variability between individuals. Therefore, the smaller the within-individual variance of measurements relative to the between-individual variance, the closer ρ will be to 1.0. The intraclass correlation coefficient, ρ, was estimated for each of the topography measures and CO levels by fitting a mixed model with a random intercept for participants.

RESULTS

Study participants included 10 Asian men between 19 and 24 years of age (21.4±1.5 years old, mean ± SD). Half of the participants (N = 5) reported that they have ever smoked cigarettes, and of these, 3 reported to be current smokers of an average of 9 cigarettes per day. Among these 3 smokers, one reported smoking a cigarette within 6–30 minutes and 2 smokers within 31–60 minutes of waking. The participants reported that they used WP to smoke tobacco about 10.1 days on average (SD = 8.7) in the past 30 days. On those days, they used WP about 1.7 times (SD = 1.1) and their typical session lasted about 49.9 minutes (SD = 27.0).

Table 1 reports mean, SD, and 95% CI for each topography and CO measure at each session for the 10 participants. These results represent typical values for each measure and the variation between the participants. These values are comparable to the values reported in other studies conducted in a café setting[27] or in a laboratory setting.[23,25] Table 2 reports overall mean, SD, and CV across sessions for all 10 participants. The CV was calculated for each participant for each measure across 3 sessions; then, they were averaged over the 10 participants to obtain the overall mean CV. CVs ranged from 8.9% for number of puffs to 28.8% for total puff volume. Table 2 also reports between-subject variance, within-subject variance, and intraclass correlation coefficient (ρ) for each topography and CO measure. Most of the topography measures were stable, with ρ values greater than 0.70 for puff duration, puff volume, interpuff interval, puff frequency per minute, and number of puffs. The most stable values were puff frequency ($\rho = 0.88$), number of puffs ($\rho = 0.86$), and puff duration ($\rho = 0.80$). Less stable were peak flow ($\rho = 0.57$) and total puff volume ($\rho = 0.52$). CO level at post-smoking ($\rho = 0.64$) and CO boost measure ($\rho = 0.64$) were more stable than CO level at pre-smoking ($\rho = 0.56$). Overall, topography and CO measures were stable.

Conclusions

The results indicate that for the majority of the topography measures, within-individual differences among WP smokers are smaller than inter-individual differences and do not introduce significant variability. Total puff volume and peak flow rate were not as stable. Because the WP smoking sessions involved an average of 75 puffs, small variations in puff volume and puffing intensity can add up to significant differences in total puff volume across the replicate smoking sessions. We speculate that more efficient nicotine delivery may be the driver behind these differences. In WP tobacco smoking, sufficient heat must be applied to aerosolize nicotine-containing droplets such that they can then be inhaled by the smoker. During smoking, the tobacco is heated by a coal that sits on top of foil that is above, and not touching, the tobacco. The amount of hot air that is transferred to the tobacco depends on the intensity, or peak flow rate, of the smoker's puff. Depending on the physical nature of the tobacco and the way that it is packed inside the head, the contents of the bowl for one session may transfer heat more or less efficiently than the contents for a replicate session. The tobacco used for this study is not a homogenous product, in that it contains a range of tobacco leaf piece- and stem-sizes (~2–100 mm^2) coated in a viscous, sweet glycerol-containing syrup.[14] Although care was taken to pack each bowl loosely and consistently, no effort was made to sort the tobacco and pack the bowl only using similar size tobacco leaf pieces. Thus, different bowl loadings for a given participant might require larger or more intense puffs to provide sufficient nicotine to the participant. However, more work is needed for a rigorous test of this hypothesis.

In addition to the relative stability of the topography measures within individuals, the results show that CO level at post-smoking and CO boost measure ($\rho = 0.64$) were more stable than CO level at pre-smoking ($\rho = 0.56$). Although cigarette smoking topography is different from WP smoking topography, our results are consistent with those of an earlier study, which found low variability in within-individual cigarette smoking topography.[28] Data from the current study came from just 10 participants over 3 sessions, who were young, male Asians; for generalization, these results need to be replicated in a larger sample of more diverse WP smokers. In addition, it would be important to have a further examination of the variability in a WP smoker's puffing behavior over the course of the smoking session, as WP smoking involves a long smoking time and a distinctive pattern within the session.[21,22,25] Overall, the results of this study provide the first empirical evidence that most topography measurements collected using the RWP from a single smoking session can be representative of a smoker's puffing behaviors and reproducible across a 3-week period, holding nicotine abstinence and time of day constant. Thus, WP topography collected from a single WP smoking episode can be a reliable index of a user's puffing behavior.

IMPLICATIONS FOR TOBACCO REGULATION

With the widespread perception of reduced harm of WP smoking compared to cigarette smoking,[29–31] a better understanding of the variability in WP smoking topography is fundamental to understanding WP puffing behavior and any topography-derived estimated exposure to harmful and potentially harmful constituents. Although the results show total puff volume and peak flow rate are not as stable as other topography measures, they are more stable within than among smokers. Based on the data reported here, sound WP toxicant exposure estimates must stem from aggregate topography data that are representative of multiple WP smokers. The present results contribute to the advancement of the knowledge base related to the mechanisms of how puffing behaviors influence toxic and carcinogenic exposures from WP smoking.

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References

1. Marian C, O'Connor RJ, Djordjevic M, et al. Reconciling human smoking behavior and machine smoking patterns: implications for understanding smoking behavior and the impact on laboratory studies. Cancer Epidem Biomar. 2009; 18(12):3305–3320.
2. Rees VW, Kreslake JM, Wayne GF, et al. Role of cigarette sensory cues in modifying puffing topography. Drug Alcohol Depend. 2012; 124(1–2):1–10. [PubMed: 22365895]
3. National Cancer Institute (NCI). Tobacco Control Monograph No. 13. Bethesda, MD: US Department of Health and Human Services, National Institutes of Health, NCI; 2001. Risks Associated with Smoking Cigarettes with Low Machine-Measured Yields of Tar and Nicotine.
4. Benowitz L, Hukkanen J, Jacob P. Nicotine chemistry, metabolism, kinetics and biomarkers. Handb Exp Pharmacol. 2009; (192):29–60. [PubMed: 19184645]
5. Strasser AA, Benowitz NL, Pinto AG, et al. Nicotine metabolite ratio predicts smoking topography and carcinogen biomarker level. Cancer Epidem Biomar. 2011; 20(2):234–238.
6. Brinkman MC, Chuang JC, Gordon SM, et al. Exposure to and deposition of fine and ultrafine particles in smokers of menthol and nonmenthol cigarettes. Inhal Toxicol. 2012; 24(5):255–269. [PubMed: 22486344]
7. Strasser AA, Lerman C, Sanborn PM, et al. New lower nicotine cigarettes can produce compensatory smoking and increased carbon monoxide exposure. Drug Alcohol Depend. 2007; 86(2–3):294–300. [PubMed: 16930853]
8. Schorp, MK. Summary of literature data on smoking topography. In: Pickworth, W.Houlgate, P.Schorp, MK., et al., editors. A Review of Human Smoking Behaviour and Recommendations for a New ISO Standard for Machine Smoking of Cigarettes; Report of the Ad Hoc WG9 Smoking Review Team to ISO TC126 WG9. Beirut, Lebanon: American University of Beirut; 2005. p. 28-50.Available at: https://www.industrydocumentslibrary.ucsf.edu/tobacco/docs/kkgm0006. Accessed May 3, 2016
9. United States Department of Health and Human Services (USDHHS), Public Health Service (PHS). The Health Consequences of Smoking—Nicotine Addiction: A Report of the Surgeon General. Washington, DC: USDHHS, PHS, Centers for Health Promotion and Education, Office on Smoking and Health; 1988. DHHS Publication No. 88-8406
10. Lee EM, Malson JL, Waters AJ, et al. Smoking topography: reliability and validity in dependent smokers. Nicotine Tob Res. 2003; 5(5):673–679. [PubMed: 14577984]
11. Eldridge A, Betson TR, Gama MV, et al. Variation in tobacco and mainstream smoke toxicant yields from selected commercial cigarette products. Regul Toxicol Pharmacol. 2015; 71(3):409–427. [PubMed: 25620723]
12. World Health Organization (WHO) and WHO Study Group on Tobacco Product Regulation. Advisory Note: Waterpipe Tobacco Smoking: Health Effects, Research Needs and Recommended Actions by Regulators. 2nd. Geneva, Switzerland: WHO; 2015.
13. Maziak W, Ward KD, Afifi Soweid RA, et al. Tobacco smoking using a waterpipe: a re-emerging strain in a global epidemic. Tob Control. 2004; 13(4):327–333. [PubMed: 15564614]
14. Schubert J, Bewersdorff J, Luch A, et al. Waterpipe smoke: a considerable source of human exposure against furanic compounds. Anal Chim Acta. 2012; 709:105–112. [PubMed: 22122938]
15. Shihadeh A. Investigation of mainstream smoke aerosol of the argileh water pipe. Food Chem Toxicol. 2003; 41(1):143–152. [PubMed: 12453738]
16. Primack BA, Carroll MV, Weiss PM, et al. Systematic review and meta-analysis of inhaled toxicants from waterpipe and cigarette smoking. Public Health Rep. 2016; 131(1):76–85. [PubMed: 26843673]

17. Djordjevic MV, Stellman SD, Zang E. Doses of nicotine and lung carcinogens delivered to cigarette smokers. J Natl Cancer Inst. 2000; 92(2):106–111. [PubMed: 10639511]
18. Hammal F, Mock J, Ward KD, et al. A pleasure among friends: how narghile (waterpipe) smoking differs from cigarette smoking in Syria. Tob Control. 2008; 17(2):e3. [PubMed: 18375726]
19. Eissenberg T, Shihadeh A. Waterpipe tobacco and cigarette smoking direct comparison of toxicant exposure. Am J Prev Med. 2009; 37(6):518–523. [PubMed: 19944918]
20. Bahelah R, DiFranza JR, Fouad FM, et al. Early symptoms of nicotine dependence among adolescent waterpipe smokers. Tob Control. 2016 Apr 25.:pii. tobaccocontrol-2015-052809. [E-pub ahead of print].
21. Maziak W, Rastam S, Shihadeh AL, et al. Nicotine exposure in daily waterpipe smokers and its relation to puff topography. Addict Behav. 2011; 36(4):397–399. [PubMed: 21185126]
22. Blank MD, Cobb CO, Kilgalen B, et al. Acute effects of waterpipe tobacco smoking: a double-blind, placebo-control study. Drug Alcohol Depend. 2011; 116(1–3):102–109. [PubMed: 21277706]
23. Cobb CO, Shihadeh A, Weaver MF, Eissenberg T. Waterpipe tobacco smoking and cigarette smoking: a direct comparison of toxicant exposure and subjective effects. Nicotine Tob Res. 2011; 13(2):78–87. [PubMed: 21127030]
24. Maziak W, Rastam S, Ibrahim I, et al. CO exposure, puff topography, and subjective effects in waterpipe tobacco smokers. Nicotine Tob Res. 2009; 11(7):806–811. [PubMed: 19420278]
25. Brinkman MC, Kim H, Gordon SM, et al. Design and validation of a research-grade waterpipe equipped with puff topography analyzer. Nicotine Tob Res. 2016; 18(5):785–793. [PubMed: 26377514]
26. Shihadeh A, Schubert J, Klaiany J, et al. Toxicant content, physical properties and biological activity of waterpipe tobacco smoke and its tobacco-free alternatives. Tob Control. 2015; 24(Suppl 1):i22–i30. [PubMed: 25666550]
27. Shihadeh A, Azar S, Antonios C, Haddad A. Towards a topographical model of narghile waterpipe café smoking: a pilot study in a high socioeconomic status neighborhood of Beirut, Lebanon. Pharmacol Biochem Behav. 2004; 79(1):75–82. [PubMed: 15388286]
28. Gust SW, Pickens RW, Pechacek TF. Relation of puff volume to other topographical measures of smoking. Addict Behav. 1983; 8(2):115–119. [PubMed: 6613709]
29. Aljarrah K, Ababneh ZQ, Al-Delaimy WK. Perceptions of hookah smoking harmfulness: predictors and characteristics among current hookah users. Tob Induc Dis. 2009; 5(1):16. [PubMed: 20021672]
30. Cobb C, Ward KD, Maziak W, et al. Waterpipe tobacco smoking: an emerging health crisis in the United States. Am J Health Behav. 2010; 34(3):275–285. [PubMed: 20001185]
31. Wray RJ, Jupka K, Berman S, et al. Young adults' perceptions about established and emerging tobacco products: results from eight focus groups. Nicotine Tob Res. 2012; 14(2):184–190. [PubMed: 22110049]

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Table 1

Summary of Topography and CO Measures of 10 participants by Session

Measures	Mean	Standard Deviation	95% Confidence Interval
Puff Duration (s)			
Session 1	4.6	1.5	3.6–5.6
Session 2	4.1	1.3	3.2–4.9
Session 3	4.1	1.1	3.4–4.9
Puff Volume (L)			
Session 1	0.608	0.335	0.391–0.824
Session 2	0.582	0.262	0.412–0.752
Session 3	0.605	0.241	0.449–0.761
Interpuff Interval (s)			
Session 1	27.7	15.2	17.9–37.5
Session 2	29.1	14.4	19.9–38.4
Session 3	28.2	14.6	18.7–37.6
Mean Flow Rate (L/min)			
Session 1	11.3	4.5	8.4–14.3
Session 2	12.0	3.1	10.0–14.0
Session 3	12.3	3.1	10.3–14.3
Peak Flow Rate (L/min)			
Session 1	16.3	5.5	12.6–19.9
Session 2	17.5	4.3	14.7–20.3
Session 3	17.9	3.1	15.2–20.5
Total Puff Volume (L)			
Session 1	41.6	23.2	26.6–56.6
Session 2	40.5	20.3	27.4–53.6
Session 3	44.6	18.5	32.6–56.5
Frequency (puffs/min)			
Session 1	2.3	1.1	1.6–3.0
Session 2	2.3	1.1	1.5–3.0
Session 3	2.3	1.0	1.6–2.9
Total Smoking Time (min)			
Session 1	33.5	7.5	28.6–38.3
Session 2	32.7	5.5	29.2–36.3
Session 3	33.5	7.8	28.5–38.5
Number of Puffs			
Session 1	75.6	31.5	55.2–96.0
Session 2	72.2	32.5	51.2–93.2
Session 3	73.8	29.7	54.6–93.0
CO level at Pre-smoking (ppmv)			

Measures	**Mean**	**Standard Deviation**	**95% Confidence Interval**
Session 1	6.1	2.5	4.5–7.7
Session 2	7.0	3.5	4.7–9.3
Session 3	5.9	2.9	4.0–7.8
CO level at Post-smoking (ppmv)			
Session 1	48.7	26.8	31.3–66.1
Session 2	42.2	22.7	27.5–56.9
Session 3	40.8	17.8	27.8–53.7
CO Boost (Post-Pre) (ppmv)			
Session 1	42.6	26.2	25.6–59.6
Session 2	35.2	22.3	20.7–49.7
Session 3	34.4	16.7	22.2–46.5

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Table 2

Descriptive Topography and CO Measures from 10 Participants Smoking RWP in 3 Sessions

Measures	Mean (SD)	95% CI for Mean	Average Coefficient of Variation Within Subjects (%)	Between-Subject Variance σ_b^2	Within-Subject Variance σ_w^2	Intraclass Correlation Coefficient (ρ)
Puff Duration (s)	4.3 (1.3)	(3.4–5.1)	12.4	1.276	0.315	0.80
Puff Volume (L)	0.60 (0.27)	(0.42–0.78)	23.3	0.051	0.021	0.71
Interpuff Interval (s)	28.3 (14.2)	(18.8–37.9)	17.9	145.0	50.05	0.74
Mean Flow Rate (L/min)	11.9 (3.5)	(9.6–14.2)	15.8	8.12	3.74	0.68
Peak Flow Rate (L/min)	17.2 (4.6)	(14.4–20.1)	14.8	11.30	8.59	0.57
Frequency (puffs/min)	2.3 (1.1)	(1.6–3.0)	15.9	0.92	0.13	0.88
Total Smoking Time (min)	33.6 (7.1)	(29.0–37.5)	16.0	26.4	17.5	0.60
Number of Puffs	74.1 (30.1)	(52.6–95.2)	8.9	756.7	121.6	0.86
Total Puff Volume (L)	42.2 (20.1)	(30.0–54.5)	28.8	202.2	185.2	0.52
CO Level at Pre-smoking (ppmv)	6.3 (2.9)	(5.2–7.4)	28.5	4.5	3.6	0.56
CO Level at Post-smoking (ppmv)	44.1 (22.5)	(35.4–52.8)	21.3	304.6	172.7	0.64
CO Boost (Post-Pre) (ppmv)	37.6 (21.9)	(29.1–46.1)	23.7	290.9	160.4	0.64

Note. SD = Standard Deviation; CI = Confidence Interval