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# Group Waterpipe Tobacco Smoking Increases Smoke Toxicant Concentration

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## Abstract

**Introduction:** Waterpipe tobacco smoking is a global health concern. Laboratory research has focused on individual waterpipe users while group use is common. This study examined user toxicant exposure and smoke toxicant yield associated with individual and group waterpipe smoking.

**Methods:** Twenty-two pairs of waterpipe smokers used a waterpipe individually and as a dyad. Before and after smoking, blood was sampled and expired carbon monoxide (CO) measured; puff topography was recorded throughout. One participant from each pair was selected randomly and their plasma nicotine and expired air CO concentrations were compared when smoking alone to when smoking as part of a dyad. Recorded puff topography was used to machine-produce smoke that was analyzed for toxicant content.

**Results:** There was no difference in mean plasma nicotine concentration when an individual smoked as part of a dyad (mean = 14.9 ng/ml; standard error of the mean [*SEM*] = 3.0) compared to when smoking alone (mean = 10.0 ng/ml; *SEM* = 1.5). An individual smoking as part of as a dyad had, on average, lower CO (mean = 15.8 ppm; *SEM* = 2.0) compared to when smoking alone (mean= 21.3 ppm; *SEM* = 2.7). When two participants smoked as a dyad they took, on average, more puffs (mean = 109.8; *SEM* = 7.6) than a singleton smoker (mean = 77.7; *SEM* = 8.1) and a shorter interpuff interval (IPI; dyad mean = 23.8 seconds; *SEM* = 1.9; singleton mean = 40.8 seconds; *SEM* = 4.8). Higher concentrations of several toxicants were observed in dyad-produced smoke.

**Discussion:** Dyad smoking may increase smoke toxicant content, likely due to the dyad's shorter IPIs and greater puff number. More work is needed to understand if group waterpipe smoking alters the health risks of waterpipe tobacco smoking.

**Implications:** This study is the first to measure toxicants in smoke generated from a waterpipe when used by a dyad. Relative to smoke generated by a singleton, dyad smoke had higher concentration of some toxicants. These differences may be attributed to differences in puffing behavior, specifically the shorter IPI and greater puff number observed in the dyad condition. Relative to singleton smokers, dyad smokers were exposed to less CO, but nicotine exposure did not differ. More work is needed to assess the health effects of inhalation of more toxicant-laden smoke during group waterpipe use.

## Introduction

Over 4.9 million deaths each year are attributed to tobacco use world-wide and projections are that, by 2030, tobacco will cause up to 8 million deaths annually.[1] The main cause of these deaths is the exposure to smoke toxicants such as tobacco-specific nitrosamines, aldehydes, polycyclic aromatic hydrocarbons, and carbon monoxide (CO) that are generated during the heating and combustion of tobacco.[2–5] Nicotine, another tobacco smoke toxicant, supports drug dependence and contributes to the difficulty of quitting tobacco smoking.[6] While cigarette smoking is the most prevalent form of tobacco use, smoking tobacco in a waterpipe (hookah, narghile, shisha) is another method that is growing in popularity globally,[7–10] particularly among adolescents[11–15] and young adults.[16–20]

A waterpipe consists of a hose, water bowl, body, and a head filled with flavored, sweetened, and moistened tobacco that is heated with charcoal. The smoke that is generated by the charcoal-heated tobacco passes through water in the bowl prior to inhalation. Like cigarette smoke, waterpipe tobacco smoke contains a variety of cancer-causing and pulmonary and cardiovascular disease-inducing toxicants to which users are exposed[21–25] and also delivers nicotine to the smoker.[26–29] Previous studies examining the toxicant content, or yield, of waterpipe smoke have used puffing profiles produced by solitary smokers to generate smoke.[22] However many waterpipe smokers use the same waterpipe to smoke in groups of two or more smokers.[30,31] Group smoking may involve more puffs being taken from the waterpipe over a given period of time and therefore may lead to hotter tobacco, and hotter tobacco can increase smoke toxicant content.[32–34]

The purpose of this study was to compare the toxicant yield in smoke produced by a solitary user's (singleton) puff profile with the smoke toxicant yield produced by that of two users (dyad) puff profile using the same waterpipe. We hypothesized that smoke toxicant yield will be higher when the smoke is generated with the dyad's puff profile, because puffs are taken from the waterpipe more frequently under group use conditions (more users, more puffs). In order to test this hypothesis, we first recorded the puff topography from singleton and dyad conditions in the clinical laboratory, also measuring participant nicotine and CO exposure (from individual users in the singleton and dyad conditions), and then, in the analytical laboratory, used previously validated "playback" technology[35] to reproduce waterpipe smoke from singletons and dyads conditions that subsequently was analyzed for toxicant content.

## Methods

### Participants

Nineteen women and 29 men were recruited from the Richmond, VA community for this IRB-approved study. Recruitment involved two steps. First, advertisements were used to elicit calls from individual waterpipe tobacco smokers who "share a waterpipe with a friend." These individuals were screened for eligibility over the phone, and, if eligible, were asked to invite a friend with whom they share a waterpipe to call the laboratory for screening also. Then, when this second individual called, they self-identified as a potential dyad smoker associated with the first individual, and were screened for eligibility. Eligibility criteria included being healthy, aged 18–50 years, and reported smoking waterpipe at least four times per month for at least 6 months. Once both individuals had been deemed eligible by telephone screening, they were invited to the laboratory at Virginia Commonwealth University individually to provide informed consent and further, in-person screening. Participants each consented to participate in two, 2-hour sessions in which they would be asked to smoke a waterpipe. In one session the participant smoked a waterpipe alone (singleton condition), and in another session the participant smoked with the other member of their dyad (dyad condition).

We identified 48 waterpipe users for singleton sessions that also formed 24 existing pairs for dyad sessions. These participants (20 Asian, 12 African American, four Caucasian, three Latin or Hispanic, five other, and four other/Middle Eastern) were healthy, a mean (*SD*) of 20.9 (2.0) years old, and reported smoking waterpipe a mean of 13.9 (5.3) times per month for an average of 23.0 (34.8) months. Participants' average expired air CO concentration at screening was 3.9 (4.6) ppm. Exclusion criteria included current pregnancy (verified by urinalysis) or breastfeeding, self-reported chronic health diseases (eg, cardiovascular disease and seizures) or psychiatric conditions, history of high or low blood pressure, regular use of prescription medications, and use of alcohol more than 25 days and/or use for marijuana more than 5 days over the last 30 day period. Ten of the 48 participants were current cigarette smokers, smoking 13.7 (20.7) cigarettes/wk and had been smoking cigarettes for 9.7 (8.5) months.

### Materials

The one-hose waterpipe consisted of a chrome body (height = 43 cm) screwed into an acrylic base (height = 24 cm; volume = 1230 ml; www.myasaray.com) containing 870 ml of clean tap water. About 2.5 cm of the body's conduit was submerged in this water. A glazed ceramic head (7.6 cm diameter) with five holes in the base was filled with 15 g of preferred brand/flavor commercially available waterpipe tobacco and then covered with an aluminum sheet perforated by a screen pincher (www.smoking-hookah.com). One piece of lit, "quick lighting" charcoal (Three Kings, Holland; 33 mm diameter) was placed on top of the aluminum foil. A single leather hose was fitted with topography measurement hardware and included a wooden mouthpiece with a sterile plastic tip (www.hookahcompany.com). Participants in the same dyad chose their preferred brand and flavor of product. Seventeen dyads chose Starbuzz (United States) brand and flavor choices included: Blue Mist ($n$ = 7), Honeyberry ($n$ = 1), Strawberry ($n$ = 2), Code 69 ($n$ = 1), Piña Colada ($n$ = 1), White Grape ($n$ = 1), Mint ($n$ = 1), Citrus Mint ($n$ = 2). Seven dyads chose Al Fakher (United Arab Emirates) brand and flavor choices included: Mint ($n$ = 3), Watermelon ($n$ = 2), Double Apple ($n$ = 1), Orange ($n$ = 1). Participants smoked the same brand and flavor in singleton and dyad conditions.

### Procedures

All sessions began at approximately the same time of day and, for each individual, sessions were separated by at least 48 hours (ie, a singleton session could occur 24 hours after another singleton session because these are different individuals, but no singleton session could occur within 48 hours of a dyad session). All sessions occurred between 8:00 AM and 2:00 PM. Session order (singleton 1, singleton 2, dyad) was randomized across dyads. Prior to every session, participants were provided with a new, sterile, disposable mouthpiece (www.hookahcompany.com) for their exclusive use. During dyad sessions the mouth pieces differed in color and the participants were instructed not to share mouthpieces. All participants were told a second bowl filled with 15 grams of the preferred brand and flavor was available and two dyads but no singletons requested the second bowl.

Sessions commenced with a 20-minute adaptation period to the lab environment where the participant(s) sat quietly in the session room followed by a 10-minute physiological recording baseline period. During this time, overnight tobacco abstinence was verified (expired CO concentration <10 ppm, as reported elsewhere[26]). Following baseline recordings of physiological measures, a needle was inserted into the forearm vein(s) and ~7 ml of blood was sampled. Immediately following blood draws, participants responded to subjective measures on a computer. Participants were then given a minimum of 45 minutes to smoke the waterpipe *ad libitum* while watching a movie of their choice. At the conclusion of the session, another ~7 ml blood was sampled and subjective measures were again completed. Expired CO concentration was recorded 5 and 15 minutes following the last puff. Sessions terminated 30 minutes after the last puff. While heart rate, blood pressure, and subjective effects were recorded, these measures are not primary outcomes in this study, and thus are not described further.

## Primary Outcome Measures

Smoke toxicant exposure (plasma nicotine and expired air CO concentration) was assessed from individual participants and puff topography was measured and recorded from the single waterpipe hose used in each session (singleton and dyad conditions), as described below. Puff topography records were used to generate smoke for subsequent analysis of smoke toxicant content, also described below.

### Smoke Toxicant Exposure

For plasma nicotine, blood sampled before and after smoking was centrifuged immediately after sampling and the plasma was stored at −70°C until it was sent Virginia Commonwealth University's Bioanalytical Analysis Core Laboratories for analysis of nicotine concentration (limit of quantitation 2.0 ng/ml; modified LC-MS/MS version of that reported elsewhere[36,37];) For plasma nicotine, values below the limit of quantitation were replaced by the limit of quantitation as in previous work.[38,39] Expired-air CO was assessed with a BreathCO monitor (Vitalo-graph, Lenexa, KS) 5 and 15 minutes after waterpipe use, as in previous work.[26,40]

### Puff Topography

Waterpipe topography was measured using a nozzle integrated into the waterpipe hose.[41] Inhalation-induced pressure changes across the nozzle were amplified, digitized, and sampled. Previously calibrated software converted digital signals to smoke flow (liters per minute, l:00 PM) and integrated these data to produce measure of puff volume, duration, number, and interpuff interval (IPI). Importantly, this device recorded all topography measures so that they could be reproduced exactly for subsequent smoke toxicant analysis.[42]

### Smoke Generation and Smoke Toxicant Measures

Once the session was complete, the digital recording of instantaneous puff velocity was re-played in the analytical laboratory at the American University of Beirut using a smoking machine[42] connected to a waterpipe (described above) and the same batches of waterpipe tobacco and charcoal used in the clinical study. The vapor and particle phases of the smoke were sampled continuously during the smoking machine session and analyzed for CO, nitric oxide, nicotine, volatile aldehydes, polycyclic aromatic hydrocarbons, and total particulate matter using materials and methods described previously.[43]

## Study Design and Data Analysis

The study used repeated measures design wherein singleton and dyad outcomes were compared across sessions and, where appropriate, across time (eg, pre- and post-smoking) within sessions. Although each individual completed a singleton session, plasma nicotine and expired air CO data from only one singleton were required for analysis in this design (to compare with that same individual's data when smoking as a dyad). Thus, after all data collection was completed, one individual was selected randomly from each dyad and that participant's nicotine and CO data when smoking as part of a dyad were compared to the same individual's nicotine and CO data when smoking as a singleton.

Inspection of the raw data revealed that one plasma nicotine concentration data point from one participant was three standard deviations greater than the mean of all other participant's data at that time point. This outlier was removed from the analysis, resulting in the exclusion of that participant's data (singleton and dyad) from all statistical analyses concerning this outcome measure. In addition, one dyad's topography data were excluded due to technical issues with recording during the session and this dyad/singleton's data were therefore excluded from all analyses. Thus, the analyses are based on the 22 singletons/dyads with complete data.

For plasma nicotine and CO concentration, a repeated measures analysis of variance (ANOVA) was performed with two factors: condition (singleton, dyad) and time (nicotine: 10 minutes before, immediately after the waterpipe session; CO: 10 minutes before, 5 and 15 minutes after). Puff topography measures were averaged within condition and compared using a paired sample $t$ test, equal variances not assumed. These measures included the puff topography recorded when a singleton was smoking the waterpipe and when both members of the dyad were smoking the waterpipe. For smoke toxicants, on average the two participants in the dyad group session produced more smoke then the one participant in the singleton group session. To account for the difference in smoke volume (likely due to the number of participants in each session), within each singleton and dyad session the toxicant yield was divided by the volume creating a concentration ratio. These ratios were then averaged within each condition and compared using a paired sample $t$ test, equal variances not assumed.

# Results

Reported below are the results relating to waterpipe smoker toxicant exposure (plasma nicotine and expired CO concentration), puff topography, and then waterpipe smoke toxicant content (CO, nicotine, volatile aldehydes, nitric oxide, etc).

## Waterpipe Smoker Toxicant Exposure

No significant main effect of condition [$F(1,21) = 2.5$; n.s.] or condition by time interaction [$F(1,21) = 2.6$; n.s.] was observed for plasma nicotine concentration though there was a significant main effect of time [$F(1,21) = 25.8$; $P < .001$; see Figure 1A]. For the participant in the singleton session condition, mean plasma nicotine concentration increased from 2.1 (standard error of the mean = 0.1) ng/ml at baseline to 10.0 (1.5) ng/ml after 45 minutes of waterpipe tobacco smoking, and for the participant in the dyad session condition mean increases from 2.0 (0.0) ng/ml at baseline to 14.9 (3.0) ng/ml after smoking were observed. In contrast, for expired air CO, there was a significant main effect of condition [$F(1,21) = 10.7$; $P < .01$] and a main effect of time [$F(2,42) = 44.5$; $P < .01$] as well as a significant

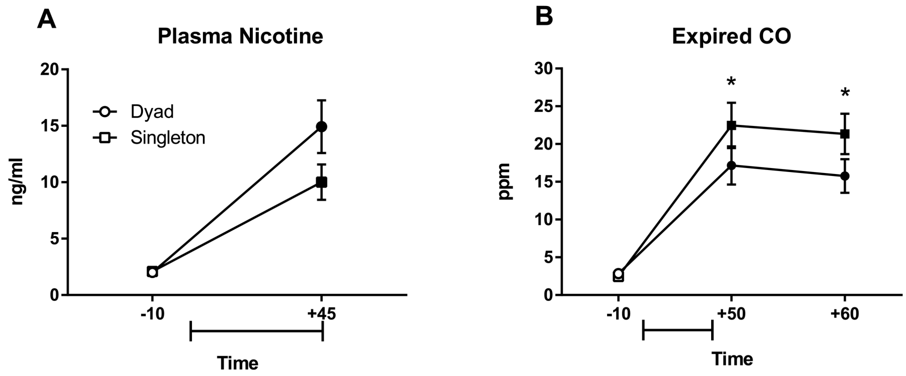


**Figure 1.** Plasma nicotine and expired carbon monoxide (CO) concentration. Mean (±standard error of the mean [*SEM*]) plasma nicotine (Panel A) and expired CO concentration (Panel B) for 22 experienced waterpipe users before and immediately after (Panel A) or 5 and 15 minutes after (Panel B) smoking waterpipe during a 45-minute *ad libitum* session as part of a dyad (circles) or as a singleton condition (squares). The 45-minute smoking period is denoted by the black bar parallel to the X-axis. Filled symbols indicate a significant difference from baseline; asterisks (*) indicate a significant difference between singleton and dyad conditions at that time point.

condition by time interaction [$F(2,42) = 10.6$; $P < .01$]. As Figure 1B shows, mean CO concentration increased following both sessions, with the greater increase observed after the singleton session. Dyad condition mean expired air CO concentration started at 2.7 (0.5) ppm and increased to 15.5 (2.2) ppm 5 minutes after and 14.3 (2.0) ppm 10 minutes after smoking. Singleton condition mean expired air CO concentration started at 2.5 (0.5) ppm and increased to 21.1 (3.2) ppm 5 minutes after and 20.1 (2.7) ppm 10 minutes after the waterpipe session (Figure 1B).

### Puff Topography

As Table 1 shows, more puffs, on average, were taken from the waterpipe when two people were using it relative to when one person was using it [$t(21) = 4.0$; $P < .01$], the mean IPI was significantly less in the dyad session relative to the singleton condition [$t(21) = 4.0$; $P < .01$], and in the dyad session, with two participants, participants puffed longer in total relative to the singleton participant [$t(21) = 2.2$; $P < .05$]. Interestingly, the total volume (liters) inhaled and flow rate did not differ between dyad and singleton. Significantly more charcoal and tobacco was consumed in the dyad session, with two participants, than in the singleton session [$ts(21) = 3.4$; $Ps < .01$] (Table 1).

### Waterpipe Smoke Toxicant Content

Toxicant concentrations (yield/smoke volume) for the two conditions were compared. As Table 2 shows, significant differences were observed for CO [$t(21) = 2.4$; $P < .05$], tar [$t(21) = 4.0$; $P < .01$], nicotine [$t(21) = 2.3$; $P < .05$], propionaldehyde [$t(21) = 2.1$; $P < .05$], butyraldehyde [$t(21) = 2.2$; $P < .05$], and anthracene [$t(21) = 2.3$; $P < .05$].

**Table 1.** Mean (Standard Error of the Mean) Puff Parameters, Charcoal, and Tobacco Used

| | Dyad | Singleton |
|---|---|---|
| # of puffs | 109.8* (7.57) | 77.73 (8.06) |
| Total puff time (min) | 7.23* (0.82) | 5.07 (0.81) |
| Total volume (L) | 73.17 (7.96) | 55.95 (9.55) |
| Flow rate (L/s) | 11.8 (0.60) | 13.06 (0.88) |
| Puff duration (s) | 3.58 (0.20) | 3.58 (0.33) |
| Interpuff interval (s) | 23.82* (1.87) | 40.81 (4.84) |
| Charcoal used (g) | 6.36* (0.3) | 5.39 (0.3) |
| Tobacco consumed (g) | 6.34* (0.31) | 4.91 (0.31) |

*Indicates a significance difference between Dyad and Singleton on that measure ($N = 22$; $P < .05$; paired sample $t$ test, equal variances not assumed).

## Discussion

This study is the first to measure and compare user toxicant (CO and nicotine) exposure, puff topography, and smoke toxicant content during singleton and dyad waterpipe tobacco smoking sessions. With regard to singleton waterpipe tobacco smoking, the results reported here are consistent with previous reports demonstrating that waterpipe tobacco smoking increases smoker plasma nicotine and expired air CO concentration reliably, and involves over 50 liters of smoke intake.[26,27,44] The toxicant content of the singleton-generated smoke observed in this study is also consistent with previous reports.[21,22,45,46] Thus, this study adds to the existing literature that demonstrates that singleton waterpipe tobacco smoking is associated with exposure to the dependence-producing drug nicotine as well as a variety of disease-causing smoke toxicants, including several known carcinogens.

Though many previous studies have focused on individual waterpipe users, waterpipe is often used in a group setting. Results reported here demonstrate that use of a waterpipe by a dyad does not alter individual nicotine exposure reliably (Figure 1) though it does reduce CO exposure. This lower level of CO exposure in dyad smokers likely reflects lower individual smoke inhalation volumes when two people are sharing a waterpipe. Indeed, puff topography records demonstrate that singletons inhaled, on average, 56 liters of smoke while the dyad inhaled, collectively, an average of 73 liters. If each dyad member is assumed to be inhaling approximately equal amounts of smoke, then the individuals in the dyad inhaled approximately 36.5 liters each.

We also note that, in addition to nicotine and CO, dyad-generated smoke had significantly greater concentrations of several other smoke toxicants: tar, propionaldehyde, butyraldehyde, and anthracene. We hypothesize that the greater concentration of toxicants in dyad smoke was caused by the tobacco becoming hotter in that condition. That is, in a waterpipe, shorter IPIs increase tobacco temperature[34] because there is less time for the tobacco to cool between puffs. Hotter tobacco is known to increase tobacco smoke toxicant content.[32,33] In this study, the IPI observed for the dyad condition was, on average, about 17 seconds shorter than that observed for the singleton condition. This observation is consistent with the hypothesis that, relative

**Table 2.** Mean (Standard Error of the Mean) Smoke Toxicant Concentration (Yield/Volume)

| Toxicant | Dyad | Singleton | Toxicant | Dyad | Singleton |
|---|---|---|---|---|---|
| Carbon monoxide (mg/L) | 2.35* (0.11) | 2.03 (0.13) | Polycyclic aromatic hydrocarbon (ng/L) | | |
| Nitric oxide (μg/L) | 5.70 (0.33) | 4.85 (0.32) | Naphtalene | 4.3 (0.52) | 3.96 (0.58) |
| Tar (mg/L) | 11.50* (0.57) | 7.87 (0.95) | Acenaphtylene | 2.85 (0.28) | 2.93 (0.51) |
| Nicotine (mg/L) | 0.04* (0.00) | 0.029 (0.003) | Acenaphtene | 0.31 (0.15) | 0.21 (0.07) |
| Volatile aldehydes (μg/L) | | | Fluorene | 2.14 (0.91) | 1.11 (0.25) |
| Formaldehyde | 0.49 (0.05) | 0.57 (0.06) | Phenanthrene | 12.57(1.48) | 10.15 (1.65) |
| Acetaldehyde | 5.65 (0.56) | 4.61 (0.44) | Anthracene | 3.76* (0.49) | 2.66 (0.38) |
| Acetone | 1.52 (0.23) | 1.06 (0.15) | Fluoranthene | 9.84 (0.88) | 8.14 (1.14) |
| Acrolein | 0.03 (0.01) | 0.011 (0.008) | Pyrene | 9.72 (0.90) | 8.19 (1.01) |
| Propionaldehyde | 0.64* (0.09) | 0.46 (0.06) | Benzo[a]anthracene | 2.00 (0.42) | 1.79 (0.29) |
| Crotonaldehyde | 0.04 (0.01) | 0.02 (0.01) | Chrysene | 2.13 (0.26) | 1.97 (0.25) |
| Methacrolein | 0.14 (0.03) | 0.09 (0.02) | Benzo[k]fluoranthene | 1.66 (0.11) | 1.58 (0.17) |
| Butyraldehyde | 0.47* (0.03) | 0.38 (0.03) | Benzo[a]pyrene | 3.07 (0.22) | 2.77 (0.25) |
| Valeraldehyde | 0.35 (0.04) | 0.37 (0.07) | Benzo[g,h,i]perylene | 0.81 (0.10) | 0.83 (0.14) |
| Total aldehydes | 9.32 (0.95) | 7.56 (0.71) | Dibenz[a,h]anthracene | ND | ND |
| | | | Indeno[1,2,3-cd]pyrene | 1.40 (0.12) | 1.37 (0.17) |
| | | | Total polycyclic aromatic hydrocarbon | 56.56 (5.51) | 47.66 (5.43) |

*Indicates a significance difference between Dyad and Singleton on that measure ($N = 22$; $P < .05$; paired sample $t$ test, equal variances not assumed).

to singleton-generated waterpipe smoke, dyad-generated smoke is more toxicant-laden because the tobacco in the waterpipe that the dyad is using becomes hotter due to the shorter time between each puff the users take (collectively) from the pipe.

As noted above, the higher toxicant concentrations of the dyad-generated smoke are offset by the lower inhalation volumes of individuals smoking as part of a dyad, generally resulting in the same or lower toxicant exposure for individuals in the dyad condition. Nonetheless, as with singleton smokers, toxicant intake for dyad smokers is significant, and is generally much greater than that associated with a single cigarette. As shown in Table 3, per-smoker toxicant yields for the dyad condition, while lower than the singleton condition, still represent approximately 1 to 10 cigarette equivalents for the key toxicants listed.

One limitation of this study is that it was conducted in a laboratory setting that may have influenced user behavior. The laboratory had many features of an American commercial waterpipe café, including dim lighting, comfortable seating, and audiovisual entertainment (movies selected by participants prior to each session). Nonetheless, participants were obviously aware of the research setting and this awareness may have influenced puff topography. Also, the timing of sessions (between 8:00 AM and 2:00 PM) and ethnicity of participants may influence the generalizability of these results. Another potential limitation is group size—studying groups of three or more was not practical for this study. Indeed, larger groups may display different puff topography outcomes: an observational study of several waterpipe cafés in Richmond, Virginia revealed more puffs taken by small groups and longer IPI observed in larger groups, although these results were influenced by the number of waterpipes in use by these groups.[30] Many of these study limitations might be addressed with the ability to sample waterpipe smoke unobtrusively in naturalistic settings.

**Table 3.** Selected Mean (Standard Error of the Mean) Toxicant Yields per Session for Singleton and Dyad Conditions

| | Yield per user | | |
|---|---|---|---|
| Toxicant | Singleton | Dyad | Cigarette |
| Nicotine, mg | 1.67 (0.28) | 2.63 (0.27) | 0.73[47] |
| Carbon monoxide, mg | 123 (24.7) | 179 (23.1) | 12.0[47] |
| Nitric oxide, μg | 287 (51.2) | 438 (54.4) | 218.1[49] |
| Benzo(a)pyrene, ng | 153 (30.0) | 220 (27.3) | 6.6[48] |
| Formaldehyde, μg | 36 (11) | 39 (7.0) | 20.6[49] |

Data are not adjusted to account for the volume of smoke generated. Cigarette data from previous studies shown for comparison.

## Conclusion and Future Work

In conclusion, these results are the first to compare the toxicant exposure in dyad versus individual waterpipe tobacco smoking. They provide no support for the argument that group waterpipe use limits exposure to the dependence-producing drug nicotine, and suggest that group waterpipe users inhale smoke that has high concentrations of other smoke toxicants, though they may inhale less of that smoke than singleton users. Of course, even when using as a dyad, users were exposed to 1 to 10 cigarettes worth of various smoke toxicants measured here—supporting the oft-reported statement that waterpipe tobacco smoking contributes to tobacco-caused dependence, disease, disability, and death.

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## Declaration of Interests

*None declared.*

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