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Secondhand smoke in waterpipe tobacco venues in Istanbul, Moscow, and Cairo

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ABSTRACT

Objective: The prevalence of waterpipe tobacco smoking has risen in recent decades. Controlled studies suggest that waterpipe secondhand smoke (SHS) contains similar or greater quantities of toxicants than cigarette SHS, which causes significant morbidity and mortality. Few studies have examined SHS from waterpipe tobacco in real-world settings. The purpose of this study was to quantify SHS exposure levels and describe the characteristics of waterpipe tobacco venues.
Methods: In 2012–2014, we conducted cross-sectional surveys of 46 waterpipe tobacco venues (9 in Istanbul, 17 in Moscow, and 20 in Cairo). We administered venue questionnaires, conducted venue observations, and sampled indoor air particulate matter ($PM_{2.5}$) ($N=35$), carbon monoxide (CO) ($N=23$), particle-bound polycyclic aromatic hydrocarbons (p-PAHs) ($N=31$), 4-methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK) ($N=43$), and air nicotine ($N=46$).
Results: Venue characteristics and SHS concentrations were highly variable within and between cities. Overall, we observed a mean (standard deviation (SD)) of 5 (5) waterpipe smokers and 5 (3) cigarette smokers per venue. The overall median (25th percentile, 75th percentile) of venue mean air concentrations was 136 (82, 213) μg/m^3 for $PM_{2.5}$, 3.9 (1.7, 22) ppm for CO, 68 (33, 121) ng/m^3 for p-PAHs, 1.0 (0.5, 1.9) ng/m^3 for NNK, and 5.3 (0.7, 14) μg/m^3 for nicotine. $PM_{2.5}$, CO, and p-PAHs concentrations were generally higher in venues with more waterpipe smokers and cigarette smokers, although associations were not statistically significant.
Conclusion: High concentrations of SHS constituents known to cause health effects indicate that indoor air quality in waterpipe tobacco venues may adversely affect the health of employees and customers.

1. Introduction

Waterpipes (also known as hookah, nargile, calean, goza, or shisha) have been traditionally used to smoke tobacco in the Eastern Mediterranean region and parts of Asia and Africa for centuries (World Health Organization, 2005). The prevalence of waterpipe smoking has been rising in recent decades, particularly among youth in Europe, the Middle East, and the United States (US) (Maziak et al., 2015). This increase in prevalence and geographic expansion has been related to several factors, including the perception that waterpipe smoking is less harmful than cigarettes, the distribution of flavored tobacco products, the social culture of waterpipes in cafés and restaurants, and aggressive commercial marketing (Maziak et al., 2015). Despite successful legislative bans on indoor smoking in many countries, most indoor smoking legislation exempts waterpipe smoking establishments (Jawad et al., 2015).

A complex mixture of exhaled mainstream smoke and side-stream smoke emitted directly from the burning source (Apelberg et al., 2013), SHS is well known to cause significant morbidity and

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mortality (Centers for Disease Control and Prevention, 2014). SHS is commonly measured using both tobacco-specific markers (e.g., nicotine) and non-specific markers of combustion (e.g., respirable particulate matter [PM]). Smoking machine studies and controlled human experiments suggest waterpipe SHS contains similar toxicants compared to cigarettes, may have higher levels of nicotine, ultrafine PM, carbon monoxide (CO), polycyclic aromatic hydrocarbons (PAH), volatile aldehydes (e.g., formaldehyde), phenols, benzene, and metals, and lower levels of tobacco-specific nitrosamines (Al Rashidi et al., 2008; Daher et al., 2010; Schubert et al., 2011, 2014; Sepetdjian et al., 2013, 2008; Shihadeh and Saleh, 2005; Shihadeh et al., 2015). In contrast to cigarettes, waterpipe SHS includes combustion products both from the tobacco and from the burning source (usually charcoal) (Schubert et al., 2014; World Health Organization, 2005). Other differences in emissions may be related to the lower burning temperature of waterpipe tobacco (Shihadeh, 2003) or the longer length of an average waterpipe smoking session, which usually lasts 20–80 min (World Health Organization, 2005).

Compared to controlled experiments, real-world studies of waterpipe SHS are more likely to capture the expected variability in waterpipe tobacco composition, smoking behaviors, and environmental factors. Recently, several observational studies measuring SHS in waterpipe venues have found elevated concentrations of particulate matter with an aerodynamic size of 2.5 μm or less ($PM_{2.5}$), CO, nicotine, and carbon (Al Mulla et al., 2014; Cobb et al., 2013; Fiala et al., 2012; Hammal et al., 2015; Saade et al., 2010; Zaidi et al., 2011; Zhang et al., 2015; Zhou et al., 2014). However, most existing studies have been conducted with small samples, limited air markers of SHS (i.e., only PM), and relatively short sampling times (less than 2 h). The purpose of this study was to quantify SHS levels and describe the characteristics of waterpipe tobacco venues in Turkey, Russia, and Egypt.

2. Methods

2.1. Venue selection and recruitment

This study was conducted in Istanbul, Turkey, Moscow, Russia, and Cairo, Egypt, major cities in countries with a high prevalence of waterpipe smoking (Morton et al., 2014). Within each city, we identified neighborhoods with a high concentration of waterpipe tobacco venues. Although we initially planned a stratified random sample, we switched to a convenience sample strategy due to a low venue response rate. Venues were selected in neighborhoods of low, middle, and high socioeconomic status. The final venue response rate ranged from 32–34% in each city.

Eligible venues provided oral informed consent and had at least one non-smoking adult employee (≥ 18 years of age) willing to provide hair, saliva, urine, and/or exhaled breath samples. Data collection was conducted between January and May 2013 in Istanbul, from December 2013 to May 2014 in Moscow, and November 2013 to April 2014 in Cairo. Field staff fluent in the local language conducted all communications with venues and participants in the native language. The Johns Hopkins Bloomberg School of Public Health Institutional Review Board and the ethics committee at each co-investigator's institution approved the study protocol.

2.2. Venue questionnaires and observations

Field staff administered a questionnaire to the owner or manager regarding venue characteristics (waterpipe availability, preparation practices, customer characteristics and behaviors, and smoking policies) and conducted observations of customer smoking behaviors during two 15 min periods, 45 min apart during peak business hours. Other sources of combustion, including cooking and burning candles or incense, were documented.

2.3. Indoor air sampling

We measured $PM_{2.5}$, CO, particle-bound PAHs (p-PAHs), 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK, a tobacco specific nitrosamine), and nicotine in indoor air. Trained field staff placed a backpack containing air-sampling equipment for $PM_{2.5}$, CO, and NNK in a convenient, central location of the venue. $PM_{2.5}$, NNK, and CO samplers were in place for 24–36 h (the pump for $PM_{2.5}$ and NNK automatically turned off after 23 h). Passive air nicotine monitors were hung for several days in an unobtrusive central location. P-PAHs were measured for 1–2 h during peak business hours.

2.3.1. Particulate matter < 2.5 micrometers ($PM_{2.5}$)

We collected real-time and integrated $PM_{2.5}$ at one-minute intervals using the 1200 personal DataRAM (pDR) aerosol monitor (Thermo Scientific, Franklin, MA), a light scattering photometer with a size-selective cyclone inlet. The pDR was connected to a calibrated air sampling pump (XR5000, SKC Inc., Eighty Four, PA, USA) running at 4 L/m. Integrated $PM_{2.5}$ was collected on a filter (Teflo R2PJ037, Pall Corp. NY) that was pre- and post-weighed using a microbalance (XP6, Mettler, Columbus, OH) according to standard methods (U.S. Environmental Protection Agency, 2011). $PM_{2.5}$ concentrations below the limit of detection (LOD) of 5 μg/m^3 (2%) were replaced with half the LOD.

We collected temperature and percent relative humidity at one-minute intervals using a temperature and relative humidity logger (HOBO U10-003, Onset Computer Corporation, Bourne, MA, USA). We adjusted continuous $PM_{2.5}$ measurements when the relative humidity exceeded 60%, as described previously (Laulainen, 1993; Morabia et al., 2009), to account for bias because of increases in particle size at high humidity. We also applied a waterpipe-specific gravimetric correction factor of 0.60, developed and applied previously (Torrey et al., 2015), to account for the differences between waterpipe SHS aerosol compared to the aerosol source used to calibrate the pDR by the manufacturer.

2.3.2. Carbon monoxide (CO)

We measured CO at one-minute intervals using a data-logging EL-USB-CO300 sampler (Lascar Electronics, Erie, PA, USA). Prior to fieldwork, each monitor was challenged with 5, 10, 30, 40, and 50 ppm CO using a 146C Dynamic Gas Calibrator (Thermo Environmental Instruments, Franklin, MA) connected to a regulator, tank (Matheson TRI*GAS, Twinsburg, OH, USA), and a zero-air source. Only monitors found to be within 5% of the known concentrations were used in the field. CO concentrations below the LOD of 0.5 ppm (3%) were replaced with half the LOD.

2.3.3. Particle-bound polycyclic aromatic hydrocarbons (p-PAHs)

We measured p-PAHs at one-minute intervals using a Photoelectric Aerosol Sensor (PAS2000, EcoChem Inc., League City, TX, USA), which photoionizes p-PAHs (three or more ringed PAHs) by exposing the aerosol to 220 nm ultraviolet light with a pre-set flow rate of 2 L/m. The PAS2000 was manufacturer-calibrated prior to use. Lamp intensity, flow rate, data readings, and operations were checked before sampling. P-PAH concentrations below the LOD of 1 μg/m^3 (5%) were replaced with half the LOD.

2.3.4. 4-(Methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK)

We measured NNK, a nicotine-derived nitrosamine ketone, on $PM_{2.5}$ filters (Wu et al., 2011). Samples were extracted with dichloromethane solution of internal standard (d4-NNK, Toronto

Research Chemicals Inc., Toronto, ON, CA) and then purified with Bond Elut Alumina B solid phase extraction cartridges (500 mg, 3 mL, Agilent, Santa Clara, CA, USA). The solid phase extraction cartridge was preconditioned with 3 mL dichloromethane, loaded with 3 mL extract, washed with 2 mL dichloromethane, and eluted with 3 mL of 8% methanol in dichloromethane (v/v). The eluent was analyzed using gas chromatography and triple quadrupole mass spectrometry (GC–MS/MS, Thermo Scientific, Waltham, MA, USA). NNK was separated using a capillary column (TG-5MS, Thermo Scientific, Waltham, MA, USA). The 23% of NNK values below the LOD of 0.12 ng/mL (equivalent to 0.42 ng/m^3 for a 23 h duration) were replaced with half the sample-specific LOD.

2.3.5. Air nicotine

We measured vapor-phase nicotine using a passive diffusion-based sampler containing a filter treated with sodium bisulfate assembled in our laboratory (Jones et al., 2013). Filters were extracted with an internal standard (isoquinoline, Sigma-Aldrich, St. Louis, MO, USA) and analyzed using a gas chromatograph with a nitrogen phosphorus detector (GC-FTD, Shimadzu GC-2014, Shimadzu, Columbia, MD, USA). Nicotine was separated using a capillary column (SHRXI-5MS, Shimadzu, Columbia, MD, USA). We collected 10% field blanks and duplicates. Nicotine concentrations in duplicate monitors were similar and were averaged together. The 17% of nicotine values below the LOD of 0.021 μg/mL (equivalent to 0.049 μg/m^3 for a 72 h duration) were replaced with half the batch-specific LOD.

2.4. Data analysis

Due to logistical difficulties, we were unable to collect 24 h of continuous $PM_{2.5}$ and CO for all venues. Therefore, we selected up to four hours of $PM_{2.5}$ and CO data representative of peak occupancy times to coincide with the field worker observations and PAHs measurements. The entire sampling duration for p-PAHs was used as collected. For NNK, we used 23 hours (the maximum sampling duration), or the recorded duration of the pDR monitor, whichever was shorter. For nicotine sampling duration, we used the fieldworker-reported placement and removal times. Indoor air sampling was conducted during all days of the week, both during the usual working and non-working days in each city. Sampling durations and days of data collection can be found in Supplemental Table S1 and S2.

Active smoking densities were calculated by dividing the number of smokers by the room volume. Chi-square tests of independence and one-way ANOVA were used to assess statistical differences in proportions and means across study cities, respectively. The concentrations of all SHS constituents were right-skewed; therefore, we used log-transformed concentrations and the medians or geometric means for statistical analyses. We examined the associations between SHS constituents using Spearman rank correlation coefficients of summary statistics within each venue (e.g., mean, median, maximum). To examine the association between nicotine, the most specific marker of tobacco exposure, with other SHS constituents, we calculated the geometric mean ratio (crude and adjusted for study city) of each SHS constituent comparing the 2nd and 3rd nicotine tertile relative to the 1st tertile.

Responses at the two observation periods were similar and were pooled for analyses. To assess the association between SHS concentrations and venue characteristics, we calculated geometric mean ratios using linear regressions of log-transformed SHS constituent means on each venue characteristic, adjusted for study city. Continuous variables were categorized into tertiles. Sensitivity analyses of alternative cut-points for continuous variables, and exploratory analyses adjusting for variables related to SHS intensity or venue characteristics yielded similar results.

Statistical analyses were performed with Stata Version 12.1 (StataCorp, College Station, TX, USA) and R Version 2.5.1 (R Foundation for Statistical Computing, www.r-project.org, Vienna, Austria). All statistical tests were two-sided and p-values less than 0.05 were considered statistically significant.

3. Results

3.1. Venue characteristics and observations

We studied 46 waterpipe tobacco venues, including 9 in Istanbul, 17 in Moscow, and 20 in Cairo. Venue characteristics, customer demographics, and smoking behaviors differed by city (Table 1). We observed a mean (SD) of 22 (12) customers, 5 (5) waterpipe smokers, 4 (8) active waterpipes, and 5 (3) cigarette smokers per venue. The mean active smoker density (waterpipe and cigarette smokers) was 5 smokers per cubic meter, and ranged from 1.6 in Moscow to 7.1 in Istanbul and Cairo (Table 1). The proportions of mechanical ventilation and air conditioning system use were highest in Moscow, lower in Istanbul, and lowest in Cairo ($p < 0.001$)(Table 1). In contrast, the proportion of venues with an outdoor area was highest in Istanbul and Cairo, compared to Moscow ($p < 0.001$). Enforcement of policies restricting cigarette smoking inside varied significantly across city ($p < 0.001$). The proportion of venues where fieldworkers saw or smelled food was higher in Moscow and Istanbul ($p < 0.001$).

3.2. Secondhand smoke constituents

We found considerable variability in SHS constituents means across cities (Fig. 1). Continuous measurements of $PM_{2.5}$, CO, and p-PAHs also varied across venues, particularly for CO (Supplemental Fig. S1, Tables S1 and S2). Overall, the median (25th percentile, 75th percentile) of venue mean air concentrations was 136 (82, 213) μg/m^3 for $PM_{2.5}$ ($N=35$), 3.9 (1.7, 22) ppm for CO ($N=23$), 68 (33, 121) ng/m^3 for p-PAHs ($N=31$), 1.0 (0.5, 1.9) ng/m^3 for NNK ($N=43$), and 5.3 (0.7, 14) μg/m^3 for nicotine ($N=46$) (Table 2). The median sampling times were 3.5 h for $PM_{2.5}$ and CO (limited to peak time), 1.7 h for p-PAHs, 23 h for NNK, and 88 h for nicotine.

We observed moderate and significant correlations between mean $PM_{2.5}$ and p-PAHs ($N=24$, Spearman rho: 0.46, $p=0.02$) at each venue. Mean CO was moderately correlated with both NNK and $PM_{2.5}$ (NNK: $N=21$, Spearman rho: 0.47, $p=0.03$; $PM_{2.5}$: $N=16$, Spearman rho: 0.47, $p=0.06$). Other correlations were less strong and not statistically significant (data not shown).

None of the city-adjusted associations comparing SHS markers by nicotine tertiles were statistically significant (data not shown); however, there was a suggestion of higher levels with increasing nicotine tertiles for CO, p-PAHs, and NNK.

3.3. Associations of secondhand smoke constituents with venue characteristics

We observed moderate and significant correlations between the mean CO and the number of waterpipe smokers ($N=19$, Spearman rho: 0.49, $p=0.03$), number of waterpipes ($N=19$, Spearman rho: 0.53, $p=0.02$), and waterpipe smoking density ($N=19$, Spearman rho: 0.46, $p=0.048$) (data not shown). However, mean CO was not significantly correlated with the number of cigarette smokers ($N=19$, Spearman rho: 0.27, $p=0.3$) or active cigarette smoker density ($N=19$, Spearman rho: 0.21, $p=0.4$).

Geometric mean levels of $PM_{2.5}$, CO, and p-PAHs were generally higher in venues with a higher number of waterpipe smokers, number of waterpipes in use, and number of cigarette smokers,

Table 1
Characteristics of waterpipe tobacco venues in Istanbul, Moscow, and Cairo in 2013–2014.

	Istanbul ($N=9$)[a]	**Moscow** ($N=17$)[a]	**Cairo** ($N=20$)[a]	***p*-Value**[b]
Venue characteristics				
Volume, m^3 (mean ± SD)	377 ± 315	500 ± 316	301 (319)	0.18
Maximum occupancy, persons (mean ± SD)	253 ± 189	108 ± 58	66 ± 44	< 0.001*
Ventilation system[c] (*n*, % yes)	5 (56%)	16 (94%)	3 (15%)	< 0.001*
Air conditioning[c] (*n*, % yes)	3 (33%)	16 (94%)	1 (5%)	< 0.001*
Outdoor area (*n*, % yes)	8 (89%)	3 (18%)	17 (85%)	< 0.001*
Serves food with full kitchen (*n*, % yes)	8 (89%)	17 (100%)	1 (5%)	< 0.001*
Has oven/stove (*n*, % yes)	8 (89%)	14 (82%)	5 (25%)	< 0.001*
≥ 25% of business from waterpipe (*n*, % yes)	7 (78%)	0 (0%)	13 (65%)	< 0.001*
Cigarette indoor smoking policy (*n*, % yes)[d]				< 0.001*
No policy	0 (0%)	13 (77%)	19 (95%)	
Smoking allowed in some indoor areas	3 (33%)	4 (24%)	1 (5%)	
Smoking not allowed indoors, but not enforced	2 (22%)	0 (0%)	0 (0%)	
Smoking not allowed indoors, and enforced	4 (44%)	0 (0%)	0 (0%)	
Venue observations				
Number of people (mean ± SD)	19 ± 11	22 ± 13	23 ± 11	0.75
Number of waterpipe smokers (mean ± SD)	5 ± 6	2 ± 2	7 ± 5	0.011*
Active waterpipe density, smokers/m^3 (mean ± SD)	3.6 ± 6.8	0.7 ± 0.7	3.6 ± 2.9	0.045*
Number of waterpipes (mean ± SD)	4 ± 4	1 ± 1	7 ± 10	0.10
Number of cigarette smokers (mean, SD)	5 ± 5	4 ± 2	6 ± 2	0.032*
Active cigarette density, smokers/m^3 (mean ± SD)	4.2 ± 8.7	1.1 ± 0.6	3.4 ± 2.1	0.07
Active total smoker density, smokers/m^3 (mean ± SD)	7.1 ± 14.8	1.6 ± 1.5	7.1 ± 4.3	0.034*
Cooking (see or smell food) (*n*, % yes)	3 (43%)	16 (94%)	0 (0%)	< 0.001*
Other burning (*n*, % yes)	2 (29%)	9 (53%)	12 (63%)	0.292
Candles	0 (0%)	8 (89%)	0 (0%)	< 0.001*
Fireplace	0 (0%)	0 (0%)	12 (100%)	
Other[e]	2 (100%)	1 (11%)	0 (0%)	
Customer characteristics				
Average number of customers per day (mean ± SD)[f]	234 ± 164	109 ± 105	88 ± 46	0.004*
Average customer age (*n*, % yes)				
18–24 years	3 (33%)	4 (24%)	1 (5%)	0.13
≥ 25 years	4 (44%)	10 (59%)	9 (45%)	
All ages	2 (22%)	3 (18%)	10 (50%)	
Average customer education ≤ high school (*n*, % yes)	5 (56%)	5 (33%)	14 (70%)	0.07
≥ 25% of customers smoke waterpipe (*n*, % yes)	4 (44%)	3 (18%)	13 (65%)	0.015*

* SD, standard deviation. Statistically significant associations indicated by an asterisk.

[a] All mean (standard deviations) and *n* (%) are calculated on a sample excluding venues missing responses. For *N* (%), the sample size for each venue characteristic can be calculated by the given statistics. For continuous variables, shown as mean (standard deviation), all statistics were calculated with complete samples except for the following with missing data: Room volume ($N=19$, Cairo), Maximum occupancy ($N=15$, Moscow; $N=19$, Cairo), Number of people ($N=6$, Istanbul; $N=19$, Cairo), Number of waterpipe smokers ($N=7$, Istanbul; $N=14$, Moscow), Waterpipe density ($N=7$, Istanbul; $N=14$, Moscow; $N=19$, Cairo), Number of waterpipes ($N=7$, Istanbul; $N=14$, Moscow), Number of cigarette smokers ($N=6$, Istanbul), Cigarette density ($N=6$, Istanbul; $N=19$, Cairo), Average number of customers per day ($N=16$, Moscow; $N=18$, Cairo).

[b] *p*-Values are chi-square test of independence for proportions and one-way ANOVA differences in group means for continuous variables.

[c] Ventilation and air-conditioning both available and in use during business hours.

[d] Turkey was the only country with indoor smoke-free legislation during the study period. Legislation banning smoking in indoor public places passed in 2009, did not extend to water pipe cafes until January 2013, and was not enforced until after the data collection was completed.

[e] Other burning was identified as a “gas burning oven/heater” and “tea kettle, double broiler” in venues in Istanbul. The source of burning was missing for the venue in Moscow.

[f] Weighted average of the number of customers on weekdays and weekends.

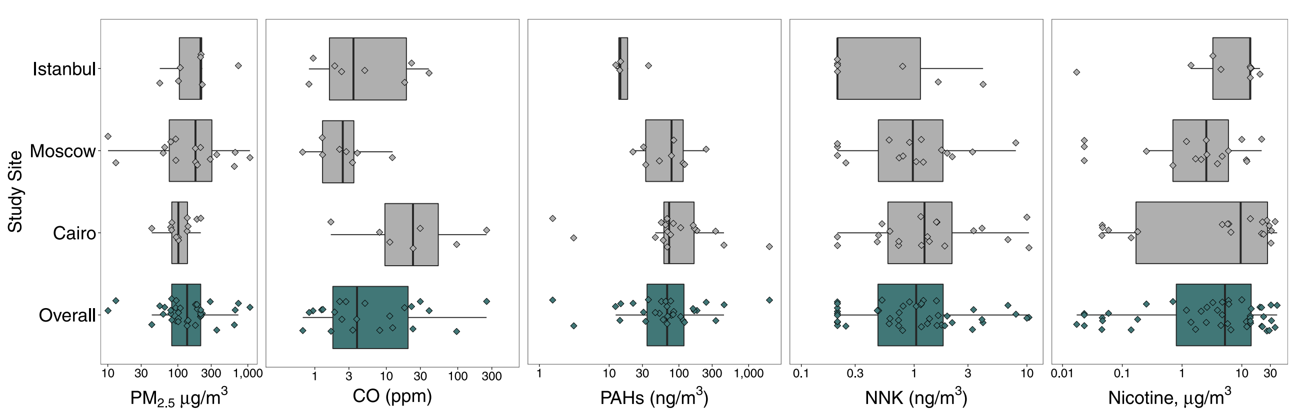

Fig. 1. Median (interquartile range) of the venue means of indoor air secondhand smoke constituents in waterpipe tobacco venues in Istanbul, Moscow, and Cairo in 2013–2014. For continuously measured SHS constituents ($PM_{2.5}$, CO, and PAHs), each diamond is the mean within each venue. For SHS constituents with a single measurement per venue (NNK and nicotine), each diamond is the time-weighted average concentrations for each venue. Boxplots represent the overall median and interquartile range of the venue-specific means for $PM_{2.5}$, CO, and PAHs, and the median and interquartile range of the time-weighted average values of NNK and nicotine.

Table 2
Median (interquartile range) of venue mean indoor air secondhand smoke constituent concentrations in waterpipe tobacco venues in Istanbul, Moscow, and Cairo in 2013–2014, overall and by city[a].

	$PM_{2.5}$ (μg/m³)	CO (ppm)	p-PAHs (ng/m³)	NNK (ng/m³)	Nicotine (μg/m³)
Overall (*N*=46)	136 (82, 213)	3.9 (1.7, 22)	68 (33, 121)	1.0 (0.5, 1.9)	5.3 (0.7, 14)
Istanbul (*N*=9)	212 (102, 224)	3.7 (1.4, 20	14 (13, 36)	0.21 (0.21, 1.6)	14 (3.3, 14)
Moscow (*N*=17)	179 (72, 325)	2.5 (1.3, 3.6)	78 (33, 115)	0.98 (0.42, 1.9)	2.5 (0.7, 6)
Cairo (*N*=20)	102 (82, 138)	24 (8.1, 96)	73 (60, 167)	1.2 (0.56, 2.6)	10 (0.16, 28)

N, Number of venues; SHS, Secondhand smoke; $PM_{2.5}$, Particulate matter with an aerodynamic size of 2.5 μm or less; CO, Carbon monoxide; p-PAHs, Particle-bound polycyclic aromatic hydrocarbons; NNK, 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone

[a] Sample sizes for each secondhand smoke constituent mean and standard deviation vary by constituent. For continuously measured markers ($PM_{2.5}$, CO, and p-PAHs), we report overall median (interquartile range) of the venue-specific means. For NNK and nicotine, we report overall median (interquartile range) of the venue-specific time-weighted averages.

Table 3
Ratio of geometric means of indoor air secondhand smoke constituents by venue characteristics in waterpipe tobacco venues in Istanbul, Moscow, and Cairo in 2013–2014, adjusted by city.

	Geometric mean ratio (95% Confidence Interval) of SHS constituents, adjusted by city									
	N	$PM_{2.5}$ (μg/m³)	*N*	CO (ppm)	*N*	p-PAHs (ng/m³)	*N*	NNK (ng/m³)	*N*	Nicotine (μg/m³)
Ventilation system										
No	15	1.00 (Ref)	9	1.00 (Ref)	16	1.00 (Ref)	21	1.00 (Ref)	22	1.00 (Ref)
Yes	20	0.39 (0.15, 1.06)	14	0.80 (0.22, 2.89)	15	5.62 (0.86, 36.79)	22	0.90 (0.34, 2.38)	24	1.70 (0.23, 12.70)
Air conditioning										
No	17	1.00 (Ref)	12	1.00 (Ref)	20	1.00 (Ref)	25	1.00 (Ref)	26	1.00 (Ref)
Yes	18	0.67 (0.23, 1.98)	11	0.93 (0.22, 3.96)	11	0.72 (0.15, 3.47)	18	0.63 (0.19, 2.13)	20	5.28 (0.48, 57.77)
Outdoor area										
No	17	1.00 (Ref)	9	1.00 (Ref)	11	1.00 (Ref)	17	1.00 (Ref)	18	1.00 (Ref)
Yes	18	0.64 (0.28, 1.46)	14	0.75 (0.14, 4.10)	20	0.41 (0.06, 2.93)	26	1.49 (0.60, 3.70)	28	2.65 (0.37, 18.86)
See or smell food or cooking?										
No	15	1.00 (Ref)	10	1.00 (Ref)	20	1.00 (Ref)	22	1.00 (Ref)	24	1.00 (Ref)
Yes	17	**4.53 (1.32, 15.59)***	11	2.11 (0.26, 17.38)	10	2.66 (0.12, 58.80)	18	0.72 (0.09, 5.53)	19	0.16 (0.01, 3.14)
Number of waterpipe smokers										
Tertile 1 (0–2.5)	12	1.00 (Ref)	10	1.00 (Ref)	9	1.00 (Ref)	13	1.00 (Ref)	14	1.00 (Ref)
Tertile 2 (3–5.5)	12	1.18 (0.38, 3.67)	6	1.42 (0.28, 7.32)	10	1.02 (0.07, 14.2)	13	1.04 (0.27, 4.10)	14	0.43 (0.03, 5.24)
Tertile 3 (6–25.5)	6	1.63 (0.45, 5.84)	5	5.07 (0.67, 38.69)	10	2.96 (0.21, 40.99)	12	1.10 (0.27, 4.50)	13	1.28 (0.09, 17.86)
Number of waterpipes										
Tertile 1 (0–1.5)	13	1.00 (Ref)	10	1.00 (Ref)	8	1.00 (Ref)	13	1.00 (Ref)	15	1.00 (Ref)
Tertile 2 (2–3)	9	2.61 (0.58, 11.82)	6	1.15 (0.11, 12.21)	11	1.21 (0.06, 26.22)	13	0.79 (0.14, 4.33)	13	0.44 (0.02, 10.89)
Tertile 3 (3.5–47.5)	8	3.57 (0.62, 20.69)	5	1.52 (0.11, 21.69)	10	2.72 (0.12, 63.19)	12	0.68 (0.10, 4.05)	13	0.31 (0.01, 10.40)
Waterpipe smoker density (smokers/m³)										
Tertile 1 (0–0.7)	12	1.00 (Ref)	10	1.00 (Ref)	10	1.00 (Ref)	13	1.00 (Ref)	14	1.00 (Ref)
Tertile 2 (0.7–2.4)	7	0.74 (0.26, 2.16)	7	2.39 (0.63, 9.02)	7	0.22 (0.04, 1.22)	12	0.80 (0.29, 2.21)	13	0.24 (0.03, 1.93)
Tertile 3 (2.4–18.6)	10	0.82 (0.17, 3.88)	4	0.85 (0.15, 4.92)	11	0.77 (0.14, 4.13)	12	0.49 (0.14, 1.66)	13	0.28 (0.02, 3.26)
Number of cigarette smokers										
Tertile 1 (0–3.5)	16	1.00 (Ref)	10	1.00 (Ref)	14	1.00 (Ref)	17	1.00 (Ref)	19	1.00 (Ref)
Tertile 2 (4.5–5.5)	19	1.82 (0.79, 4.18)	4	1.60 (0.32, 7.94)	10	0.49 (0.15, 1.60)	12	0.65 (0.26, 1.63)	12	0.88 (0.12, 6.60)
Tertile 3 (6–13.5)	7	2.48 (1.00, 6.11)	6	1.46 (0.34, 6.25)	6	2.63 (0.61, 11.24)	11	0.95 (0.36, 2.48)	12	0.68 (0.09, 5.28)
Cigarette smoker density (smokers/m³)										
Tertile 1 (0–0.7)	11	1.00 (Ref)	8	1.00 (Ref)	10	1.00 (Ref)	13	1.00 (Ref)	14	1.00 (Ref)
Tertile 2 (1.0-2.7)	10	1.07 (0.42, 2.69)	7	0.38 (0.10, 1.38)	8	0.50 (0.12, 2.20)	13	0.59 (0.24, 1.45)	14	0.89 (0.12, 6.43)
Tertile 3 (2.9–21.8)	10	2.40 (0.57, 10.22)	5	1.01 (0.24, 4.26)	11	2.54 (0.44, 14.77)	13	0.46 (0.15, 1.42)	14	1.61 (0.15, 16.93)
Number of total smokers										
Tertile 1 (0–6)	13	1.00 (Ref)	9	1.00 (Ref)	10	1.00 (Ref)	14	1.00 (Ref)	15	1.00 (Ref)
Tertile 2 (6.5–10.5)	12	1.85 (0.76, 4.54)	8	0.86 (0.20, 3.70)	11	1.17 (0.18, 7.72)	14	1.50 (0.49, 4.61)	15	0.65 (0.07, 6.16)
Tertile 3 (11–31.5)	8	2.81 (0.93, 8.47)	4	3.29 (0.47, 23.19)	10	3.08 (0.40, 23.67)	13	1.12 (0.32, 4.00)	14	0.99 (0.08, 12.67)
Total smoker density (smokers/m³)										
Tertile 1 (0–1.44)	13	1.00 (Ref)	9	1.00 (Ref)	12	1.00 (Ref)	15	1.00 (Ref)	14	1.00 (Ref)
Tertile 2 (1.57–4.95)	9	0.86 (0.34, 2.18)	7	1.89 (0.50, 7.19)	6	0.28 (0.06, 1.25)	14	1.01 (0.40, 2.54)	13	0.38 (0.05, 2.65)
Tertile 3 (5.35–40.4)	10	1.26 (0.12, 12.98)	5	0.55 (0.10, 3.11)	12	1.90 (0.34, 10.59)	14	0.49 (0.13, 1.88)	13	0.59 (0.04, 8.31)

N, number of venues; SHS, Secondhand smoke; $PM_{2.5}$, Particulate matter with an aerodynamic size of 2.5 μm or less; CO, Carbon monoxide; p-PAHs, Particle-bound polycyclic aromatic hydrocarbons; NNK, 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone.

[*] Statistically significant associations indicated by an asterisk.

after adjusting for city, although these associations were not statistically significant (Table 3). After adjusting for city, venues with ventilation systems, air conditioning, or an outdoor area had generally lower geometric mean $PM_{2.5}$ and CO concentrations compared to venues that did not (Table 3). Geometric means of p-PAHs were lower in venues with air conditioning or outdoor areas, and geometric means of NNK were lower in venues with a ventilation system or air conditioning. Venues where fieldworkers reported seeing or smelling food or cooking had 4.53 (95% CI: 1.32–15.59) times higher geometric mean $PM_{2.5}$ concentrations and non-significant increases in mean CO and p-PAHs concentrations, compared to venues without food or cooking (Table 3).

4. Discussion

In this study of 46 waterpipe tobacco venues in Istanbul, Moscow, and Cairo, we found high concentrations of $PM_{2.5}$, CO, p-PAHs, NNK, and nicotine, indicating the presence of high SHS concentrations that could affect the health of venue employees and customers. Other studies have found that waterpipe tobacco venues have similar or higher levels of SHS compared to cigarette-only venues (Cobb et al., 2013; Hammal et al., 2015; Saade et al., 2010; Zaidi et al., 2011). We observed considerable variability in venue characteristics and smoking behaviors between countries, likely reflecting heterogeneity in the cultural, economic, and tobacco regulatory environments in each city. We did not identify many significant associations between venue characteristics and SHS levels. Other studies of SHS in waterpipe tobacco venues have reported positive associations between smoker density and mean $PM_{2.5}$ (Abuelaish et al., 2013; Al Mulla et al., 2014; Cobb et al., 2013; Saade et al., 2010; Zaidi et al., 2011; Zhang et al., 2015).

In this study, the mean $PM_{2.5}$ concentrations in almost all venues were above both the US Environmental Protection Agency (EPA) 24 h ambient air standard (35 $\mu g/m^3$) and the World Health Organization 24 h indoor air standard (25 $\mu g/m^3$) (U.S. Environmental Protection Agency, 2013; World Health Organization, 2014). Other studies of waterpipe tobacco venues in the US (Cobb et al., 2013; Fiala et al., 2012; Zhang et al., 2015; Zhou et al., 2014), Qatar (Al Mulla et al., 2014), Lebanon (Saade et al., 2010), Pakistan (Zaidi et al., 2011), and Palestine (Abuelaish et al., 2013) have all found elevated $PM_{2.5}$ concentrations, with mean concentrations ranging from 117 $\mu g/m^3$ to 1419 $\mu g/m^3$.

The concentrations of CO in this study are consistent with previous evidence that waterpipe SHS produces a significant quantity of CO. The overall median CO concentrations in this study were similar to three studies with real-time CO measurements in waterpipe tobacco venues in Canada and New York City (Hammal et al., 2015; Zhang et al., 2015; Zhou et al., 2014). Nine (39%) venue means for CO exceeded the EPA 8 h standard (9 ppm) and three (13%) venue means exceeded the EPA 1 h standard (35 ppm).

This is the first study of total p-PAHs, which are carcinogenic (International Agency for Research on Cancer, 2004) and associated with respiratory and cardiovascular disease (Centers for Disease Control and Prevention, 2014), in SHS from waterpipe tobacco venues. We observed a median of 50 ng/m^3 p-PAHs overall, with the highest concentrations in Cairo and lowest concentrations in Istanbul.

No previous studies have examined concentrations of NNK in waterpipe tobacco venues, and few real-world studies have measured NNK exposure levels from cigarette SHS (Apelberg et al., 2013; Brunnemann et al., 1992). Our study shows that workers and customers are exposed to this carcinogen (Hecht, 2014) in waterpipe tobacco venues. There is some evidence that NNK may be lower in mainstream waterpipe tobacco smoke compared to cigarettes, potentially due to non-tobacco additives common in waterpipe tobacco (Schubert et al., 2011).

Air nicotine concentrations in our study were similar to previous studies, which found a mean of 3.3 $\mu g/m^3$ in Toronto, Canada waterpipe cafes and 4.2 $\mu g/m^3$ in New York City waterpipe cafes (Zhang et al., 2015; Zhou et al., 2014). These concentrations are also comparable to an international study of bars and nightclubs (median of 3.5 $\mu g/m^3$) (Jones et al., 2013).

This study had several strengths. Our multi-city study is one of the largest samples of waterpipe tobacco venues with SHS measurements. We have collected the most comprehensive set of SHS markers in an observational study of real venues where SHS exposure is occurring. We are the first to measure concentrations of the carcinogens NNK and p-PAHs in waterpipe venues and we had longer SHS sampling durations compared to previous studies. Previous studies were conducted without permission from the venues, which can avoid disruption of normal activities but is often at the expense of extensive data collection from venues.

This study also had some limitations. The generalizability of the findings might be limited due to low participation rates and the convenience sampling strategy. Relatively modest to low participation is not uncommon in similar studies with detailed data collection in tobacco venues (Navas-Acien et al., 2004). Particularly in Turkey, where cigarette smoking was banned in 2009 in many public places and extended to include waterpipe venues in early 2013 (Jawad et al., 2015), fear of regulation may have hampered recruitment of venues. Assuming that venues with higher SHS exposure would be less likely to participate, the results of this study are likely conservatively biased. Waterpipe tobacco venues and customer smoking behaviors, including the style of waterpipe apparatus, tobacco additives, charcoal source, and typical puff topography of the smoker may vary across venues, cities, or within countries. Although no available markers can distinguish sources of SHS, patrons and employees of waterpipe tobacco venues are exposed to a mixture of SHS from cigarettes and waterpipe in the real world. We used a waterpipe-specific correction factor for continuous PM measurements using a pDR, which is less conservative than cigarette SHS correction factors in the literature (Cobb et al., 2013; Travers et al., 2012). Isolating the source of p-PAHs exposure remains a challenge because they can also come from many non-cigarette sources, including automobile exhaust, cooking, candles, and incense (Apelberg et al., 2013). We had limited ability to assess the presence or absence of alternative burning sources. We may not have accurately captured venues during their peak business hours or our convenience sample may have preferentially selected smaller, less busy venues. Venue characteristics or smoking behaviors may have varied over the different climates and seasons of data collection.

This study's comprehensive indoor air sampling and data on venue characteristics adds to the growing body of evidence reporting that SHS emissions in waterpipe venues are a potential threat to the health of employees and patrons. Our study expands on previous research findings that SHS concentrations are similar to or greater than those typically found in cigarette venues by measuring SHS in indoor air in real-world conditions. Of particular concern are the relatively high levels of CO measured in several of the venues. Our findings support that smoke-free legislation in public places should also ban waterpipe smoking. In addition to incorporating a wider range of markers of SHS exposure, including CO, PAHs, and NNK, future studies should collect measurements of air markers, smoking behaviors, and venue observations at multiple time points in order to understand the temporal and spatial heterogeneity of SHS within venues.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2015.08.012.

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