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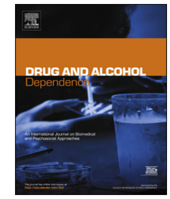

Full length article

Puffing topography and physiological responses in men and women with low versus high waterpipe dependence during smoking: The WiHi Irbid project

Mahmoud A. Alomari[a,b,*], Omar F. Khabour[c], Karem H. Alzoubi[d], Thomas Eissenberg[e]

[a] *Department of Physical Education, Qatar University, Doha 2713, Qatar*
[b] *Division of Physical Therapy, Department of Rehabilitation Sciences, Jordan University of Science and Technology, Irbid 22110, Jordan*
[c] *Department of Medical Laboratory Sciences, Jordan University of Science and Technology, Irbid 22110, Jordan*
[d] *Department of Clinical Pharmacy, Jordan University of Science and Technology, Irbid 22110, Jordan*
[e] *Department of Psychology, Virginia Commonwealth University, Richmond, VA, USA*

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ABSTRACT

Background: Waterpipe smoking is spreading worldwide, and it is associated with many adverse effects. The aim of this study was to investigate the interaction of waterpipe smoking puffing topography, and related physiological measures, with both gender and level of dependence on waterpipe.

Method: Exclusive waterpipe smokers were asked to smoke a single waterpipe session in a specialized laboratory while their smoking topography, and in-breath CO level were recorded pre- and post- smoking. Waterpipe dependence was measured using the LWDS-11 scale.

Results: In the high dependence group, the total number of puffs, was greater in men than women. In addition, the average flow rate was greater in men with high compared to low dependence. For inter-puffing intervals, greater values were recorded in men and women with low versus high dependence. No other differences were found between the subgroups in total session time, average puff duration, average puff volume, and maximum flow rate. Pre-smoking CO content and CO boost were greater in men versus women in both dependence groups. Post-smoking CO content was greater in women with high versus low dependence, whereas it was lower in women versus men with low dependence.

Conclusions: The current results indicate several effects for waterpipe smoking dependence on smoking topography. Many of these differences were gender dependent with men having higher exposure than women in most aspects.

1. Introduction

The adverse effects of smoking are undeniable. It is associated with health, social, psychological, and economic harms (Scarborough et al., 2011). Waterpipe (Wp) smoking involves inhaling smoke from a charcoal-burned tobacco through a jug-like container filled with water using a hose into the smoker's mouth. It has recently reemerged viciously across many countries and social segments (Jawad et al., 2018). This social phenomena is spiraling also in developed countries, including Europe, the US, Australia, Russia, and Asia (Pratiti and Mukherjee, 2019). Acceptance, peer pressure, gathering, publicity, accessibility, misconceptions, and affordability are some of the factors alluring people to smoke Wp (Jawad et al., 2018). Similar to cigarette smoking, it is associated with many devastating diseases, including cardiovascular and respiratory diseases, stroke, cancer, and metabolic syndrome (Qasim et al., 2019).

Previous studies have shown gender-specific effect of smoking (Tsai et al., 2008; Allen et al., 2014; Minutillo et al., 2016; Weinberger et al., 2016; Zhao et al., 2016; Becker et al., 2017; Elmore et al., 2017; Nicolini et al., 2018; Sundberg et al., 2018; Lundberg et al., 2019). Men and women seem to differ in time and conditions of initiation (Elmore et al., 2017), smoking behavior (Tsai et al., 2008; Weinberger et al., 2016), dependence (Minutillo et al., 2016; Becker et al., 2017), and cessation (Weinberger et al., 2016). Additionally, there are smoking-related gender differences in body system responses and alterations (Zhao et al., 2016; Alomari et al., 2018b,c; Alomari et al., 2018a), diseases (Nicolini et al., 2018; Lundberg et al., 2019), morbidity, and mortality (Allen et al., 2014; Sundberg et al., 2018). These gender

* Corresponding author at: Department of Physical Education, Qatar University, Doha 2713, Qatar.
E-mail address: Alomari@just.edu.jo (M.A. Alomari).

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variations have been attributed to many factors, including physiological, behavioral, psychological, and social (Ostan et al., 2016). However, some studies have shown variation in smoking topography between men and women (Chen et al., 2017; Kim and Yu, 2018; Soule et al., 2018), that might entail differential effect of smoking (Ostan et al., 2016). Thus, gender-differences in smoking might require special considerations during treatment from smoking (Ostan et al., 2016).

The effect of nicotine dependence on cigarette smoking is well documented. For example, dependence level was related to the maximum flow rate (Higgins et al., 2018). Level of nicotine metabolism in cigarette smokers were associated with dependence level, daily puffs, and total daily puff volume (Chen et al., 2018). A polish study reported that individuals with greater dependence score have more appetite for cigarette smoking. Therefore, these individuals tend to inhale smoke more intensely, more frequently, and for a longer time (Zielinska-Danch et al., 2010). Similar to cigarettes smoking, the authors argue that individuals with a greater smoking dependence score would crave more, thus tend to consume more smoke. In cigar smokers, inhalation behavior was found to be related to nicotine dependence and withdrawal symptoms (Claus et al., 2018). However, information about the effect of nicotine dependence on Wp smoking topography is a scarce. Understanding the contribution of gender and dependence to the variation in Wp smoking topography might, at least partially, explain the gender and dependence differences in physiological responses, diseases, morbidity, and mortality related to smoking (Tsai et al., 2008; Allen et al., 2014; Minutillo et al., 2016; Weinberger et al., 2016; Zhao et al., 2016; Becker et al., 2017; Elmore et al., 2017; Alomari et al., 2018b, c; Alomari et al., 2018a; Nicolini et al., 2018; Sundberg et al., 2018; Lundberg et al., 2019). Subsequently, smoking treatment strategies, including smoking cessation can be better determined.

2. Methods

2.1. Participants

Exclusive Wp tobacco users were recruited to the study using paper advertisements and flyers distributed across the Jordan University of Science and Technology (JUST) campus. The participants were interviewed to check the enrollment eligibility, including collecting demographic/medical records, tobacco use and LWDS-11 dependence score. Apparently healthy participants smoking Wp at least 2 times per month were invited. Exclusion criteria were subjects with chronic/psychiatric diseases, history of hypo/hypertension, current use of medication other than supplements or birth control, pregnant or breastfeeding women, and regular use of other tobacco products (Alzoubi et al., 2013). The study was conducted in the Wp lab at the Faculty of Pharmacy of JUST. Written informed consents that were approved by the Institutional Review Board of JUST, were obtained from all participants before enrollment. The participants were compensated for time/participation cost. The current data are from a larger project, the “Waterpipe and Health in Irbid (Irbid WiHi)” project that assess the health risks of Wp tobacco consumption among men and women (Alomari et al., 2020).

2.2. Experimental procedures

Subjects were asked to load 10 g of their preferred “Ma’assel” brand into a standard Wp apparatus (15 cm diameter, 61 cm height, 750 mL water volume, with a leather hose) (Alzoubi et al., 2013). The Wp apparatus head was then covered with aluminum foil and the Ma’assel was loaded in the head and lit using charcoal disks to smoke it *ad libitum* (Cobb et al., 2015). Subjects were asked to smoke at own rate for at least 30 min. Puff topography was recorded during the smoking session using a portable topography unit attached to the Wp hose as previously described (Alzoubi et al., 2013). Among recorded puff parameters were puff volume/duration/number, flow rate, and inter puff intervals (Maziak et al., 2011). Five minutes after completion of the session, expired CO was assessed via breath CO monitor (Vitalagraph, Lenaxa, KS) (Cobb et al., 2015). A new sterile mouthpiece was used in every session to ensure participant safety.

Table 1
The participants' demographic characteristics (n = 116).

Gender (%)	
Male	51.9
Female	49.1
Age (yrs, mean ± Sd)	23.8 ± 5.8
Weight (kg, mean ± Sd)	68.4 ± 14.5
Height (cm, mean ± Sd)	169.8 ± 1.0
BMI (kg/m^2, mean ± Sd)	23.6 ± 4.0
Parent Education (%)	
High	38.3
Low	61.7
Family Income (%)	
High	52.6
Low	47.4

2.3. Statistical analysis

All statistical analyses were performed using SPSS software for Windows (version 22.0; Chicago, IL). Data are expressed either as means ± SD or percentages, and α was set at prior as $p < 0.05$. Two-way (gender*dependence level) ANOCOVA, while covariating for obesity (i.e. BMI), family income, and parent education, was used to compare puffing topography measures. Additional posthoc comparisons were used to determine the differences between specific groups (Lu et al., 2016).

3. Results

3.1. Participants

As in Table 1, 116 men (n = 59) and women (n = 57) agreed to participate in the study, of which 58 individuals were in the high dependence groups. The age, height, weight, and BMI ranges of the participants were 18–45 years, 45 − 122 kg, 152 − 197 cm, and 17.3–39.1 kg/m^2, respectively.

3.2. Gender and dependence differences in waterpipe puffing topography

The 2-way ANCOVA, shown in Table 2, revealed main effects of gender ($p < 0.035$) and dependence ($p < 0.005$) without interaction ($p < 0.46$) effect for total number of puffs. Subsequent comparisons showed greater total number of puffs in the men ($p < 0.031$) versus the women in the high dependence group. In another 2-way ANCOVA comparison, depicted in Table 2, revealed main effects of gender ($p < 0.002$) and dependence ($p < 0.0001$) without interaction ($p < 0.32$) effect for total puffing time were found. Post-hoc comparisons showed greater total puffing time in men ($p <$ 0. 002) and women ($p < 0.05$) with high versus low dependence, and in the men ($p < 0.023$) compared to the women in high dependence. The comparison between groups, in Table 2, also revealed a main effect of dependence ($p < 0.01$) without gender ($p < 0.60$) and interaction ($p < 0.18$) effects for average flow rate. Additional subgroup comparisons showed greater values ($p < 0.01$) in the men with low compared to high dependence. Additionally, main effects of gender ($p < 0.001$) and dependence ($p < 0.0001$) without interaction ($p < 0.17$) effect for inter-puffing intervals were revealed in Table 2. Further comparisons, showed greater values in the men ($p < 0.037$) and the women ($p < 0.004$) with low versus high dependence, as well as in the women ($p < 0.006$) versus the men in the low dependence groups. No differences ($p < 0.05$) were found between the subgroups in total session time, average puff duration, average puff volume, and maximum flow rate.

Table 2
Smoking Topography Differences in Women and Men with Low versus High dependence (n = 116).

	Men (n = 59)		Women (n = 57)	
	Low dependence (n = 28)	High dependence (n = 31)	Low dependence (n = 29)	High dependence (n = 28)
Total session time (min)	31.4 ± 2.1	30.8 ± 1.6	31.5 ± 3.3	32.1 ± 3.6
Total number of puffs	202.2 ± 70.1	283.2 ± 173.9	167.5 ± 82.1	216.2 ± 93.7[†]
Average puff duration (s)	2.3 ± 0.82	2.6 ± 1.2	2.1 ± 0.87	2.1 ± 0.82
Total puff time (s)	431.0 ± 145.3	736.3 ± 226.7[†]	343.8 ± 182.4	445.7 ± 214.1[*,†]
Average puff volume (L)	0.55 ± 0.32	0.45 ± 0.24	0.41 ± 0.23	0.41 ± 0.23
Average inter puff interval (s)	7.7 ± 2.2	5.9 ± 3.4[†]	11.8 ± 6.4[*]	7.6 ± 4.0[†]
Average flow rate (L/min)	13.3 ± 5.5	10.2 ± 3.7[†]	11.6 ± 3.7	10.5 ± 3.2[†]
Maximum flow rate (L/min)	27.0 ± 6.0	27.8 ± 11.6	27.7 ± 5.9	26.2 ± 5.5

* $p < 0.05$ vs gender counterpart in the same dependence group.
† $p < 0.05$ vs dependence counterpart in the same gender.

Table 3
Differences in Physiological Responses to Waterpipe Smoking in Women and Men with Low versus High Dependence (n = 116).

	Men (n = 59)		Women (n = 57)	
	Low dependence (n = 28)	High dependence (n = 31)	Low dependence (n = 29)	High dependence (n = 28)
Presmoking CO (PPM)	3.1 ± 1.5	5.4 ± 2.2[†]	1.7 ± 0.59[*]	3.1 ± 2.0[*,†]
Postsmoking CO (PPM)	62.6 ± 36.1	73.0 ± 41.6	36.8 ± 17.2[*]	62.0 ± 48.0[†]
CO Boost (U)	59.5 ± 35.8	67.5 ± 41.2	35.1 ± 16.9[*]	58.9 ± 47.5[†]
Total smoked inhaled/session (L)	100.9 ± 58.3	106.4 ± 50.2	68.0 ± 47.6	83.1 ± 55.0

* $p < 0.05$ vs gender counterpart in the same dependence group.
† $p < 0.05$ vs dependence counterpart in the same gender.

3.3. Gender and dependence differences in physiological responses to waterpipe smoking

Comparisons for the effect of gender and dependence score for the physiological responses to Wp smoking are presented in Table 3. The results showed main effects of gender ($p < 0.0001$) and dependence ($p < 0.0001$) without interaction ($p < 0.17$) effect were also found for pre-smoking CO content. Additional comparisons showed greater values in the men ($p < 0.0001$) and women ($p < 0.001$) in the high dependence versus gender counterparts in the low dependence groups. Furthermore, greater pre-smoking CO content was found in the men ($p < 0.0001$) versus the women in the low dependence and in the men ($p < 0.0001$) versus the women in the high dependence groups. The 2-way ANCOVA revealed main effects of gender ($p < 0.008$) and dependence ($p < 0.016$) without interaction ($p < 0.30$) effect for post-smoking CO content. Further comparisons showed greater values in the women in the high ($p < 0.014$) versus low dependence as well as in the men ($p < 0.003$) than the women with low dependence. Main effects of gender ($p < 0.014$) and dependence ($p < 0.030$) without interaction ($p < 0.27$) effect were revealed for CO boost. Further comparisons showed greater CO boost in the women in the high ($p < 0.018$) versus low dependence as well as in the men ($p < 0.004$) than the women with low dependence. The 2-way ANCOVA also revealed a main effect for gender ($p < 0.017$) without dependence ($p < 0.34$) and interaction ($p < 0.56$) effects for total inhaled volume in the session. No differences ($p < 0.05$) were found between specific subgroups.

3.4. Relationship of physiological responses with puffing topography during waterpipe smoking

Pearson correlation revealed relationships of physiological measures with puffing topography. As in Table 4, presmoking and post-smoking CO content, CO boost, and total inhaled volume were correlated ($p < 0.05$) with the number of puffs, average puff duration, total puff time, average puff volume, inter-puff interval, average flow rate, and maximum flow rate.

4. Discussion

This study examined behavioral and physiological measures during smoking Wp among men and women smokers with high versus low dependence level. The results showed gender differences in total number of puffs, total puffing time, and average inter puff interval. Additionally, total puffing time, average flow rate, and inter puffing interval were different between the low and high dependence groups. Additionally, blood CO content, CO boost, and smoke volume in the lungs were greater in the men versus women. Furthermore, the study found a relationship of smoking behavior with the physiological responses to Wp smoking. These results indicate that gender and dependence level might influence smoking behavior and the physiological responses to Wp smoking reflects smoking behavior.

Smoking is a behavior influenced by a complex interaction between social/cultural, physiological (i.e. genetic), psychological, and individual (i.e. gender and age) factors. Few studies, with inconsistent results, have compared smoking topography between men and women during cigarette smoking (Nakajima et al., 2013; Chen et al., 2017; Kim and Yu, 2018). In one of these studies, the men demonstrated greater mean puff volume, mean puff duration, inter-puff interval, mean puff flow, peak puff flow, total daily puff volume, and puff volume per cigarette than women. Nonetheless, similar number of cigarettes per day, number of total puffs in a day and per cigarette were recorded in the women versus the men (Chen et al., 2017). However, among Koreans, the women smoked more puffs per cigarette, while recorded less puff volume and the women and men scored similar inter puff interval (Kim and Yu, 2018).

Studies comparing the topography profile between women and men smoking Wp are also a sparse (Soule et al., 2018). Similar to the current results, one study showed that the men recorded greater total puff volume, inhaled smoke volume, and post-smoking CO. The women, on the other hand, reported greater post-smoking nauseous, dizziness, nervousness, headache, and heart pounding without differences in inter puff intervals. Interestingly, the values and scores obtained in the current study (i.e. Jordanians) are comparable to previous findings from the US (Soule et al., 2018).

Table 4
Relationship of Physiological Responses with Puffing Topography.

	Number of Puffs	Average Puff Duration	Puff Duration	Average Puff Volume	Inter Puff Interval	Average Flow Rate	Max Flow Rate
Presmoking CO	**$r = 0.222$; $p = 0.016$**	$r = 0.112$; $p = 0.230$	$r = -0.023$; $p = 0.808$	$r = 0.056$; $p = 0.554$	**$r = -0.289$; $p = 0.002$**	$r = 0.003$; $p = 0.972$	$r = -0.030$; $p = 0.754$
Postsmoking CO	**$r = 0.194$; $p = 0.036$**	**$r = 0.323$; $p = 0.000$**	$r = -0.042$; $p = 0.651$	**$r = 0.415$; $p = 0.000$**	**$r = -0.375$; $p = 0.000$**	**$r = 0.338$; $p = 0.000$**	$r = 0.073$; $p = 0.439$
CO Boost	**$r = 0.186$; $p = 0.046$**	**$r = 0.323$; $p = 0.000$**	$r = -0.042$; $p = 0.654$	**$r = 0.420$; $p = 0.000$**	**$r = -0.366$; $p = 0.000$**	**$r = 0.344$; $p = 0.000$**	$r = 0.076$; $p = 0.420$
Inhaled smoke	**$r = 0.410$; $p = 0.000$**	**$r = 0.429$; $p = 0.000$**	$r = 0.024$; $p = 0.799$	**$r = 0.696$; $p = 0.000$**	**$r = -0.524$; $p = 0.000$**	**$r = 0.657$; $p = 0.000$**	**$r = 0.232$; $p = 0..013$**

Signficant relationships are indicated in bold.

According to the current results, greater number, total time, and volume of puff, and total smoked inhaled/session and lower inter puff interval were recorded in the men. This smoking behavior was reflected on the physiological measures, including greater blood CO content, CO boost, and smoke volume in the lungs in the men versus the women. Given no previous studies examined the relationship of gender and smoking dependence with Wp smoking topography, it is difficult to explain these differences. However, these differences can be attributed to physiological variations between genders. These variations include lower diffusion capacity for CO in women, body size, lung capacity, hormones, and blood volume and content (de Simone et al., 1991; Hopkins and Harms, 2004; Huang et al., 2017). Additionally, several physiological and behavioral measures were related to each other after controlling for confounding factors. Altogether, the smoking topography profile and the relationships indicate that the men are more exposed to Wp smoke, thus might be more affected by the toxicants. This might explain, at least partially, the gender discrepancies in smoking initiation (Elmore et al., 2017), behavior (Tsai et al., 2008; Weinberger et al., 2016), dependence (Minutillo et al., 2016; Becker et al., 2017), cessation (Weinberger et al., 2016), body system responses and alterations (Zhao et al., 2016), diseases (Nicolini et al., 2018; Lundberg et al., 2019), morbidity, and mortality (Allen et al., 2014; Sundberg et al., 2018). However, certainly more studies are needed to verify these findings. Additionally, studies are warranted to examine the relationships of Wp smoking topography and smoking behaviors and health effects of WP smoking.

The current study showed a relationship between dependence score and Wp smoking topography and physiological responses. This is unique as no previous studies examined the effect of smoking dependence on smoking topography or physiological responses to smoking, during Wp smoking or even otherwise. Therefore, it is difficult to compare or explain the current results. However, one might argue that individuals with greater dependence might have more desire for smoking; accordingly incline to consume more smoke. In the current study, individuals with greater dependence score tended to inhale at a slower puff flow rate, more frequently, and for longer time than individuals with a lower dependence score, especially men. This confirms recent study suggesting that individuals with greater dependence score would inhale slower to maximize exposure to nicotine (Eddingsaas et al., 2020). However, future studies are needed confirm the current findings.

The relationships between behavioral and physiological measures indicate that toxicant exposure are Wp smoking behavior-dependent. Additionally, men in the current study were exposed to Wp smoke, thus more toxicants than women. This might suggest that men are at greater risk of smoking-related dependence, cessation failure, adverse health effects, morbidity, and mortality. According to this, the women and men might require different Wp smoking dependence and cessation programs. Additionally, treatment plans and strategies from smoking-related diseases should be gender-selective, thus suitable to the amount of exposure to Wp smoke and toxicants. Therefore, future studies and treatment plan should be gender specific. Additionally, these studies and plans should consider Wp smoking topography profile and behavior.

The inherited limitations associated with the cross-sectional design might be inadequate for conclusive inferences. Additionally, the sample size, age, and race might also limit the generalizability of the results. Finally, in the current study, the topography measures were obtained during smoking in the lab. Smoking behaviors might differ when the participants smoke in natural environment (in natural setting). Therefore, longitudinal and intervention studies with larger sample size from a variety of population segments and races, and conducted in natural environment are needed to confirm the current findings.

5. Conclusions

The current study found differences in smoking topography among the men and women are suggestive of greater exposure to Wp smoke, thus toxicants, in men. Additionally, the physiological measures were related to the behavioral measures, suggesting that the extend of the Wp smoking depends on the smoking behavior during Wp consumption session.

Authors contribution

Mahmoud A. Alomari: participated in study design, data analysis, interpretation and manuscript drafting. Omar F. Khabour: participated in study design, samples collection, data analysis, interpretation, and manuscript drafting. Karem H. Alzoubi: participated in study design, subject's recruitment, statistical analysis and interpretation. Thomas Eissenberg: participated in study design, data analysis, and results interpretation. All authors participated in manuscript drafting and revisions.

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Declaration of Competing Interest

Dr. Eissenberg is a paid consultant in litigation against the tobacco and the electronic cigarette industry. The other authors declare that there is no conflict of interest.

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