

Impact of flavors and humectants on waterpipe tobacco smoking topography, subjective effects, toxicant exposure and intentions for continued use

Theodore L Wagener ^{1,2}, Eleanor L S Leavens,³ Toral Mehta,² Jessica Hale,² Alan Shihadeh,⁴ Thomas Eissenberg ⁵, Matthew Halquist,⁶ Marielle C Brinkman ^{2,7}, Amanda L Johnson,⁸ Evan L Floyd,⁹ Kai Ding,¹⁰ Rachel El Hage,¹¹ Rola Salman⁴

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For numbered affiliations see end of article.

Correspondence to

Dr Theodore L Wagener, Center for Tobacco Research, Ohio State University Comprehensive Cancer Center, Columbus, OH 43210, USA; Theodore.Wagener@osumc.edu

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ABSTRACT

Introduction The present study examined how the lack of characterising flavours and low levels of humectants may affect users' waterpipe tobacco (WT) smoking topography, subjective effects, toxicant exposure and intentions for continued use.

Methods 89 WT smokers completed four ad libitum smoking sessions (characterising flavor/high humectant (+F+H); characterising flavor/low humectant (+F-H); no characterising flavor/high humectant (-F+H); no characterising flavor/low humectant (-F-H)) in a randomised cross-over design. WT was commercially available; same brand but nicotine levels were not held constant. A subsample (n=50) completed a standardised, 10-puff session preceding ad libitum smoking. Participants completed questionnaires, exhaled carbon monoxide (eCO) testing and provided blood samples for plasma nicotine. Smoking topography was measured throughout the session. Post hoc analyses showed that -F+H and -F-H did not differ significantly in humectant levels. Therefore, these groups were collapsed in analyses (-F-H).

Results WT smokers reported significantly greater satisfaction, liking, enjoyment and greater intentions for continued use when smoking +F+H compared with other WT products, with -F-H receiving the lowest ratings. Significant differences in topography were observed during standardised and ad libitum sessions, with the -F-H preparation leading to greater total inhaled volume and eCO boost, but lower nicotine boost compared with +F+H (all $p < 0.05$).

Discussion The findings demonstrate the importance of flavours and humectants on improving WT smoking experience and increasing the likelihood that users will want to initiate and continue smoking. Moreover, it demonstrates that flavours and humectants influence smoking behaviour and toxicant exposure in some unexpected ways that are important for regulatory efforts.

present in combustible cigarette smoke, such as heavy metals, benzene, polycyclic aromatic hydrocarbons, semivolatile furans, tar, carbon monoxide (CO) and nicotine.^{3–6} As such, WT smoking is associated with many of the same negative health outcomes as combustible cigarette use such as cancer, cardiovascular and lung disease, and nicotine dependence.^{3,7}

A potential reason for the appeal of WT is that it is usually flavoured.⁸ The extant WT research examining flavours, while limited to a few studies, suggests that characterising flavours have played a role in the initiation and maintenance of WT smoking. Participants in qualitative research emphasise the importance of WT flavours on their reasons for trying WT and influencing their perceptions that WT is less harmful.^{9–11} These findings are supported by nationally representative samples, with 89% of adult ever WT smokers reporting the first WT they smoked was flavoured¹² and 59% reporting typically using flavoured tobacco, more than for any other tobacco product.¹³ Finally, two human laboratory studies examining the impact of WT flavours found that even a slight manipulation in flavours, such as using a non-preferred, tobacco-flavoured control, resulted in a poorer subjective smoking experience, decreased willingness to continue smoking and lower levels of nicotine exposure compared with using a preferred WT flavour.^{14,15} These studies provide initial evidence for the role of flavoured tobacco in the maintenance of WT smoking.

While the limited research has focused exclusively on the role of characterising flavours in WT smoking, WT also includes humectants, such as glycerol and propylene glycol. Both of these humectants are known to have a sweet taste,^{16,17} and in WT, shown to increase mainstream smoke particulate matter, resulting in greater smoke production and increased nicotine transfer efficiency.¹⁸ WT products sold in the US contain humectant levels of approximately 25%–50%; however, at least one country—Germany—has restricted the allowable amount ($\leq 5\%$) in WT.^{19,20} Unfortunately, Germany has not regulated the separate sale of bottles of WP-specific glycerol additive which are often sold alongside WT on German WT websites (eg, ²¹). The sale of these bottles anecdotally indicates the importance of glycerol to WT users.

INTRODUCTION

Approximately 2.6 million US adults¹ and 650 000 youth² are current users of waterpipe tobacco (WT). WT smoking involves inhaling through a hose, causing air to be pulled over burning charcoal, heating the tobacco and producing smoke that travels through the waterpipe, the water and finally the hose to the user. WT smokers are exposed to many of the same toxicants that are



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To date, no studies have examined the impact of both humectants and flavours on WT smoking. The current study fills this gap by examining the impact of humectants and characterising flavours in WT on subjective smoking experience, future intentions for WT smoking, smoking topography and resultant toxicant exposure (nicotine and CO). As WT smokers typically smoke WT with friends,²² participants completed sessions in self-identified dyads to increase ecological validity. We hypothesised that compared with WT with no characterising flavours and low levels of humectants, flavoured and high humectant WT would result in improved subjective smoking experience and increased smoking topography (eg, more frequent, longer and intense puffing) and toxicant exposure.

METHODS

Sample

Participants were 89 current WT smokers (44 dyads) recruited in the Oklahoma City, Oklahoma metropolitan area from the general community via internet advertisements as well as flyers and word-of-mouth advertising from May 2017 to January 2018. Potential participants were screened for eligibility via an online questionnaire and then over the telephone. Individuals were included if they (1) were a current WT smoker for at least the past 6 months; (2) smoke WT ≥ 3 times over the past 6 months; (3) were between 18 and 50 years old; and (4) able to abstain from tobacco, nicotine and marijuana use for at least 12 hours prior to each of the four sessions. Exclusion criteria were as follows: (1) self-reported diagnosis of lung disease including asthma, cystic fibrosis or chronic obstructive pulmonary disease; (2) history of cardiac event or distress within the past 3 months; (3) currently pregnant (determined with urine pregnancy test at every visit), planning to become pregnant or breastfeeding; and (4) any reported use of illicit drugs (other than marijuana) during the last 30 days. All participants provided informed consent.

Laboratory procedures

In this randomised cross-over design, WT smokers completed four, 1-hour WT smoking sessions. During each session, participants smoked ad libitum one of four different WT products, including a preferred characterising flavor/high humectant (+F+H); a preferred characterising flavor/low humectant (+F-H); no characterising flavor/high humectant (-F+H); and no characterising flavor/low humectant (-F-H) product. Sessions were separated by a minimum 48-hour washout period and completed in self-identified dyads. Consistent with past research,^{23 24} each member of the dyad met all inclusion criteria and each participant smoked a separate WT connected to a separate waterpipe smoking topography device. Participants were randomised as a dyad and were therefore in the same condition for all visits, although their preferred WT flavour could differ from one another. Each session was preceded by 12 hours of overnight smoking abstinence, confirmed via exhaled CO (eCO) <10 ppm, measured at the start of the visit.

A subsample (n=50, 25 dyads) also completed a standardised puffing session immediately preceding their ad libitum smoking session. Specifically, a research assistant with a stopwatch instructed participants to take a puff every 30s, resulting in 10 puffs over 5 min. Following the 10-puff bout, participants smoked ad libitum for the next hour; participants could stop puffing before the end of the ad libitum session, but were required to stay in the room for the full hour.

Sessions were completed in a controlled laboratory setting in a room under negative pressure. Participants completed the

session seated in a comfortable chair next to the other member of their dyad and listening to music. They were not allowed to eat, use their phone or other electronic devices, but were allowed to drink water during the session if requested. One piece of charcoal was lit and placed on top of the perforated foil. On request, participants were provided an additional preweighed, lit charcoal. WT puffing topography was measured continuously throughout the session. Venous blood samples were obtained at baseline and +5 min (immediately after the directed puffing segment—if a subsample participant), then at the completion of puffing during the ad libitum period (+60 min). eCO was collected immediately before smoking and following the completion of puffing during the ad libitum period. Participants were compensated \$50 for each visit and were provided a \$50 bonus for completing all sessions.

Materials

A one-hose Mya waterpipe was used during all study visits. The waterpipe had a stainless-steel stem attached to the glass base (58 cm total height), with 3 cm of the stem submerged in 500 mL of water. All features of the apparatus were kept constant across the smoking sessions, including water level, type of foil, disposable mouthpieces and hoses. In every session, the hose was tipped with a new, sterile, disposable mouthpiece. A glazed ceramic bowl was placed on the top of the waterpipe stem and filled with 10 g of WT and covered with a prepunched sheet of aluminium foil. Self-lighting charcoal briquettes were preweighed before being lit and placed on top of the foil. Traditional leather hoses interfaced with the topography machine were used for each session. For the two preferred flavour WT sessions (+F+H and +F-H), participants smoked one flavour from a selection of six Nakhla flavoured tobacco. During phone screening, participants were provided a list of these flavour options and asked to choose their favourite: double apple (35%), strawberry (35%), lemon (12%), mandarin (12%), apple (4%) or vanilla (2%). The same flavour was used in both the +F+H and +F-H session. WT with no characterising flavour (-F+H and -F-H) was Nakhla Zaghoul. All high humectant Nakhla WT (+F+H and -F+H) was purchased in the USA; low humectant Nakhla WT (+F-H and -F-H) was purchased from Germany.

Following study completion, each WT product was tested for nicotine and humectant content (see online supplementary table 1). +F+H had an average nicotine content of 0.18% (range 0.16%–0.22%) and humectant content of 23.9% (range 17.1%–37.0%). +F-H had an average nicotine content of 0.23% (range 0.19%–0.26%) and humectant content of 10.5% (1.9%–24.1%). -F+H had a nicotine content of 0.45% and a humectant content of 4.0%. -F-H had a nicotine content of 0.45% and a humectant content of 2.2%. These post hoc analyses suggested that Nakhla Zaghoul products (-F+H and -F-H) purchased in the USA were not different from those purchased in Germany, as both had the same level of nicotine and humectant content of $<5\%$. As such, for analysis, the session results for the -F+H and -F-H visits were collapsed for each participant and labelled as the -F-H visit. To account for the repeated condition, a main effect of time point (ie, visit number) was included in mixed model analyses.

Measures

Demographics

Participants completed demographic measures assessing age, gender, marital status, ethnicity, employment status, occupation, years of education and socioeconomic status.

WT and other tobacco and marijuana use history

Measures of self-reported WT use history included age of first use of WP, if the WT was flavoured/unflavoured the first time they tried it, average number of WT bowls and sessions per month, current use of flavoured/unflavoured WT.²⁵ Reported past 30-day use (even one time/one puff) of cigarettes, e-cigarettes and vapes, cigars (premium, little cigars and/or cigarillos), smokeless tobacco and cannabis were collected.

WT dependence

WT dependence was measured using the *Lebanese Water-pipe Dependence Scale (LWDS)-11*, an 11-item measure that comprises four subscales: physiological dependence, negative reinforcement, psychological craving and positive reinforcement. This validated scale is correlated significantly with nicotine exposure, eCO and WT smoking frequency. Total scores >10 are indicative of clinically relevant WT dependence.²⁶

Outcome measures

WT smoking topography

Measures of topography were collected throughout each session using a pressure transducer integrated into the water-pipe hose⁵ and included average puff duration, average inter-puff interval (IPI), total puffing time, total smoking time, total inhaled volume, average puff volume, average flow rate and total number of puffs.

Plasma nicotine

Venous blood was collected just before the onset of and immediately following the ad libitum smoking session (within 5 min of the last puff). The subset of participants who completed the standardised puffing session completed two additional blood draws, one immediately following the standardised puff session and then 5 min later, immediately preceding the ad libitum session. Analyses were completed according to validated methods using liquid chromatography tandem mass spectrometry.²⁷

eCO, a biomarker of smoke exposure, was collected at baseline immediately before the onset of smoking and at the end of the ad libitum session using a handheld monitor (Smokerlyzer Micro, Bedfont Scientific).

Subjective drug effects/liking

Subjective experience following each session was assessed across 10 measures of drug effects/liking: pleasantness, desire/urge, need to use for relief, want to smoke, like the product, enjoy the product, pleasurable to use, satisfaction, interest to use in the future and willingness to use.¹⁴ All items were presented on a Visual Analogue Scale (VAS) from 0 ('not at all') to 100 ('extremely').

Behavioural intentions

Behavioural intentions for continued WT use were evaluated at the end of the session using a 4-item, 7-point Likert scale ranging from 1 ('extremely unlikely') to 7 ('extremely likely'): 'If this was the only flavour available, how likely are you to': (1) 'try this product again,' (2) 'pay to smoke this product at a water-pipe lounge/bar,' (3) 'use this product regularly.' Answers were collapsed into 'unlikely' for users who responded 'extremely unlikely,' 'unlikely,' or 'somewhat unlikely,' 'neutral' for those who answered 'neutral,' and 'likely' for those who answered 'extremely likely,' 'likely,' or 'somewhat likely.'

Data analytical plan

For plasma nicotine and eCO measures, boost was calculated by subtracting the pre-session from the post-session measures. One-way analysis of variance was used to compare smoking topography and subjective smoking experience measures between WT flavours. For behavioural intentions, multinomial logistic regression was used to compare differences between WT flavours. Three-level linear mixed effects models were used to account for repeated measures within individuals and nesting of individuals within dyads (level 1: session, level 2: participant, level 3: dyad) adjusting for LWDS scores, gender and time point (visit number) in standard puff models and LWDS scores, gender, time point (visit number) and standard puff smoking status in ad libitum models. Topography measures were winsorised at the 1st and 99th percentiles to address outliers and maintain sample size. Post hoc comparisons were adjusted using the Bonferroni method. Data were analysed using SAS V.9.4 (SAS Institute). P values <0.05 were considered statistically significant. Two individuals were excluded from the analysis due to lack of consistent dyad partner. The analytic dataset consisted of 44 dyads of 88 individuals.

RESULTS

Participant demographics and WT smoking history

Participants had a mean age of 23.7 years (SD=4.9), were predominantly male (60.2%) and non-Hispanic white (54.5%). The majority completed at least some college or technical school (69.4%), were employed at least part time (57.9%) and earned less than \$40 000 annually (57.8%). Participants reported smoking hookah on average for 4.5 years, smoking an average of 6.6 days and 8.3 bowls per month, and a mean LWDS score of 9.4 (SD=0.5), indicating a moderate level of dependence. Over 93% reported that the WT was flavoured the first time they smoked and 94.3% reported currently smoking flavoured WT. Participants' reported past 30-day use of other tobacco products, including cigarettes (28.4%), e-cigarettes or nicotine vapes (34.1%), cigars (23.9%), and smokeless tobacco (5.7%), as well as cannabis (37.5%).

WT smoking topography

Table 1 shows the summary statistics and comparisons across the WTs for the topography and exposure measures. During the standardised puffing phase, participants took longer puffs, puffs of greater average and maximum volume, had a greater flow rate and larger total inhaled puff volume when smoking the -F-H compared with the +F+H (all, $p < 0.01$). No significant differences between the +F+H and +F-H were found for the standardised puffing phase. During the ad libitum phase, when participants smoked the +F-H and -F-H they had longer average puff duration, and greater average and maximum puff volume compared with +F+H (all $ps < 0.01$). In addition, when smoking -F-H, participants had greater flow rate, greater total inhaled volume, and longer total puffing time (all $ps < 0.01$). No significant differences were observed in average IPI, total smoking time or total number of puffs between +F+H and other products for the ad libitum phase.

Plasma nicotine and eCO boost

No statistically significant differences were found in plasma nicotine boost when comparing +F+H with other WT flavour products for the standardised puffing phase; however, smoking low humectant WT (+F-H and -F-H), regardless of flavour status, was associated with significantly lower plasma nicotine boost

Table 1 Waterpipe smoking topography measures by product (n=88)

	Ad libitum															
	Standard 10-puff sessions															
	+F+H M (SE)	+F+H M (SE)	+F+H versus -F-H t	+F+H versus -F-H P value	-F-H M (SE)	-F-H M (SE)	+F+H M (SE)	+F+H M (SE)	+F+H versus -F-H t	+F+H versus -F-H P value	-F-H M (SE)	-F-H M (SE)	+F+H versus -F-H t	+F+H versus -F-H P value	df	
Total smoke time (min)	5.48 (0.12)	5.62 (0.20)	1.47	0.43	5.40 (0.08)	5.40 (0.08)	5.40 (0.08)	5.40 (0.08)	-1.76	0.244	107	36.38 (1.97)	40.58 (1.37)	0.36	1.000	205
Cumulative puffing time (min)	0.17 (0.06)	0.17 (0.06)	0.11	1.00	0.27 (0.05)	0.27 (0.05)	0.27 (0.05)	0.27 (0.05)	5.44	0.000	107	3.28 (0.28)	4.16 (0.23)	3.24	0.004	204
Average puff duration (s)	4.06 (0.23)	4.21 (0.25)	0.38	1.00	4.94 (0.21)	4.94 (0.21)	4.94 (0.21)	4.94 (0.21)	5.06	0.000	107	3.26 (0.17)	3.42 (0.10)	6.34	0.000	205
Average flow rate (L/min)	17.70 (0.86)	19.53 (0.72)	1.76	0.24	20.87 (0.58)	20.87 (0.58)	20.87 (0.58)	20.87 (0.58)	3.47	0.002	107	15.85 (0.59)	17.22 (0.37)	4.97	0.000	205
Average interpuff interval (s)	1.63 (0.27)	1.69 (0.25)	-0.44	1.00	1.99 (0.25)	1.99 (0.25)	1.99 (0.25)	1.99 (0.25)	0.51	1.000	106	42.67 (3.06)	39.79 (2.33)	-0.74	0.459	205
Total puff number	10.07 (0.04)	10.05 (0.03)	-0.89	1.00	10.14 (0.05)	10.14 (0.05)	10.14 (0.05)	10.14 (0.05)	0.61	1.000	107	59.95 (4.96)	76.02 (4.83)	0.95	0.345	205
Total inhaled volume (L)	12.32 (0.93)	13.93 (1.02)	1.29	0.60	17.24 (0.80)	17.24 (0.80)	17.24 (0.80)	17.24 (0.80)	5.75	0.000	107	51.59 (4.63)	71.95 (4.33)	3.96	0.000	205
Average puff volume (L)	1.22 (0.09)	1.39 (0.10)	1.45	0.45	1.70 (0.08)	1.70 (0.08)	1.70 (0.08)	1.70 (0.08)	5.56	0.000	107	0.88 (0.06)	1.01 (0.04)	6.63	0.000	205
Maximum puff volume (L)	1.71 (0.12)	1.85 (0.12)	0.93	1.00	2.17 (0.09)	2.17 (0.09)	2.17 (0.09)	2.17 (0.09)	4.28	0.000	107	1.86 (0.20)	2.30 (0.15)	3.89	0.000	205
CO boost (ppm)*	-	-	-	-	-	-	-	-	-	-	-	41.85 (4.71)	55.57 (4.09)	4.91	0.000	202
Nicotine boost (ng/mL)	5.53 (1.09)	5.69 (0.94)	-0.15	1.00	5.48 (0.63)	5.48 (0.63)	5.48 (0.63)	5.48 (0.63)	0.86	1.000	83	10.33 (1.21)	6.71 (0.60)	-3.71	0.001	156

Mean (M) and SE data for topography measures. Bold font indicates statistical significance ($p < 0.05$).

*CO boost was not collected in the standardised puffing phase.

(all, $p < 0.001$) compared with +F+H during the ad libitum phase. For eCO boost, smoking -F-H WT was associated with significantly higher boost ($p < 0.001$) compared with +F+H.

Subjective smoking experience and behavioural intentions

During the ad libitum phase, when participants smoked -F-H, they reported significantly lower levels for all smoking experiences (Need, $p = 0.013$, all others, $p < 0.001$) compared with +F+H. For +F-H, only finding the experience satisfying was significant, with participants reporting lower levels ($p = 0.039$) compared with +F+H (see figure 1). Regardless of flavour status, when participants smoked low humectant WT, they were significantly less likely to want to try the product again (+F-H, AOR: 0.36; 95% CI 0.15 to 0.86; -F-H, AOR: 0.19; 95% CI 0.08 to 0.40), pay to use this product at a WT lounge or bar (+F-H, AOR: 0.26; 95% CI 0.10 to 0.66; -F-H, AOR: 0.16; 95% CI 0.07 to 0.37), or use the product regularly (+F-H, AOR: 0.24; 95% CI 0.09 to 0.65; -F-H, AOR: 0.17; 95% CI 0.07 to 0.39) compared with +F+H (see figure 2).

DISCUSSION

The present study is the first to examine the unique and combined contribution of WT flavours and humectants on WT smoking patterns, toxicant exposure and subjective effects. Overall, the findings demonstrate an interesting pattern of results—some unexpected. Current WT smokers reported significantly greater satisfaction, liking and enjoyment when smoking the +F+H compared with the other WT products. Likewise, the +F+H garnered significantly greater reported intentions for continued use if it were the only WT available. Intentions for continued use were lowest for -F-H, with only 32%, 23% and 9% of participants reporting that they were 'likely' to 'try this product again', 'pay to smoke this product at a WT lounge' or 'use this product regularly', respectively. Moreover, greater than 93% of participants reported that the WT was flavoured the first time they smoked WT and almost 95% reported currently smoking flavoured WT. These findings, in conjunction with previous studies demonstrating the importance of characterising flavours,^{14 15} indicate that a WT product standard restricting the use of characterising flavours and humectants may have a significant impact on the initiation and continued use of WT use.

Unexpectedly, smoking topography results, which were confirmed by eCO, indicated that participants smoked the products lacking characterising flavour (-F-H) more intensely, taking larger and longer puffs, resulting in inhaling a greater amount of CO than the +F+H tobacco. More intense puffing of -F-H did not, however, yield greater plasma nicotine boost. The +F+H product yielded approximately 1.5-fold more nicotine during the ad libitum session. This finding is further surprising given that the unflavoured product contained two to three times more nicotine by weight than the flavoured products. Observed during the sessions by both staff and participants was that +F+H produced substantially more visible smoke per puff than the other products, with -F-H producing the least amount of visible smoke. Waterpipe machine smoking measurements according to a standardised puffing regimen made by Brinkman *et al* showed that the same low flavour, low humectant-containing WT, when fortified with humectant (30% glycerol and 1% propylene glycol), produced four times as much mainstream total particulate matter, but the same nicotine yield, despite the fact that the fortification involves replacing 3.1 g of the nicotine-containing tobacco with glycerol and propylene glycol.¹⁸ Results showed that these additives increased nicotine transfer efficiency,

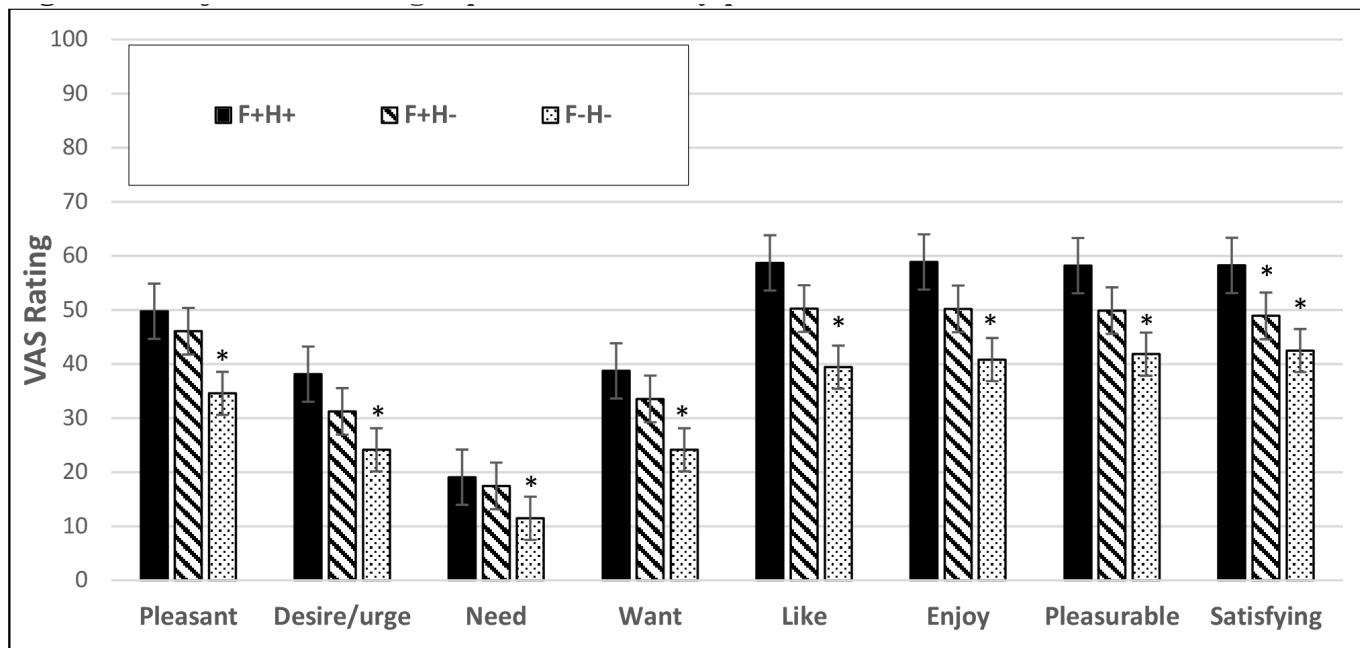


Figure 1 Subjective smoking experience items by product. Notes: Mean (\pm SEM) data for subjective smoking experience items. VAS, Visual Analogue Scale. VAS ranges from 0 to 100 for each item. * indicates significant differences for that item/product compared with the F+H+ product.

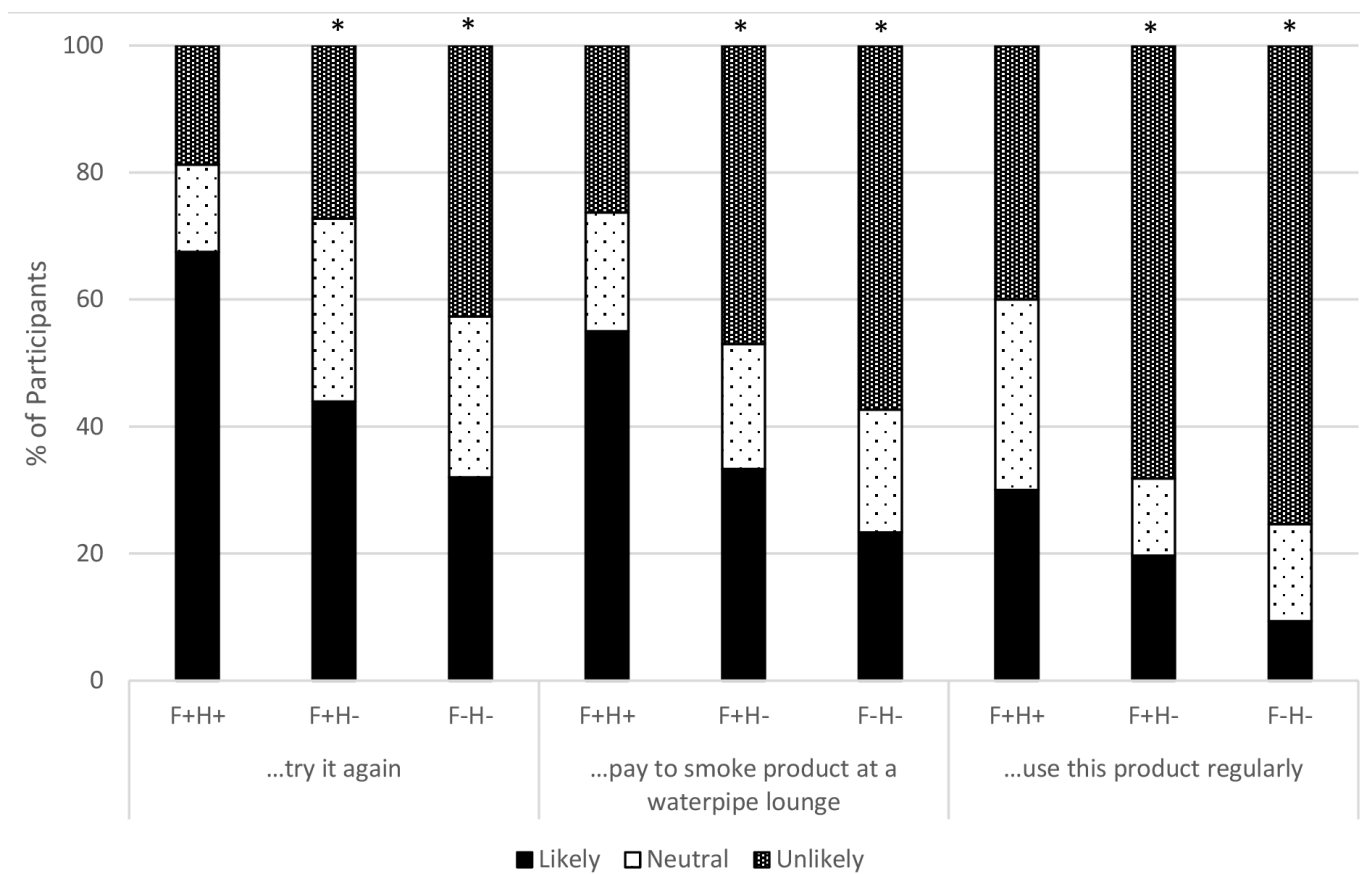


Figure 2 Behavioural intentions by waterpipe tobacco (WT) product. Note: Percentage of likelihood reported for behavioural intentions items. Participants responded to each item on a 7-point Likert scale (1 ('extremely unlikely') to 7 ('extremely likely')) and responses collapsed into three categories for analysis. * indicates significant differences for that item/product compared with the F+H+ product.

meaning a greater fraction of the nicotine in the fortified tobacco was transferred to the mainstream smoke.¹⁸ For our study, we hypothesise that decreased levels of glycerol resulted in lower production of smoke and a smaller fraction of nicotine transferred to the smoke, thus users puffed harder and longer to achieve satisfactory sensory levels of nicotine and smoke inhalation. Taken as a whole, these results suggest that the additives propylene glycol and glycerol are important to the delivery of nicotine when smoking WT, and the amounts in which manufacturers add them may affect their addiction potential.

Despite these important and novel findings, the study has several limitations. First, while participants were offered their preferred flavour of WT, this was only from one brand and from a selection of only six flavours. While the flavours were selected based on reported popularity and availability, it is likely that at least some of the current WT users in this study would have selected a different brand or flavour, as only 67% reported that would even want to try their preferred +F+H WT they selected again. However, flavour was controlled across conditions, within participant, making us confident in the pattern of results described in this study. Second, the study was conducted in a controlled laboratory setting under negative pressure and may not generalise to WT smoking in more natural settings (eg, WT lounges). As this was an anticipated weakness of the study, we attempted to improve ecological validity a priori by having participants complete the smoking sessions in dyads, as most WT smokers report smoking WT in groups.²⁸ While completion of study procedures in dyads could impact smoking behaviours due to the presence of a peer, concerns are lessened due to the cross-over design and emphasis on within subject comparisons, making us confident in the pattern of results observed. Third, while we used commercially available WT from the same manufacturer, there was some variability in the level of nicotine between the flavoured versus the unflavoured WT and humectant content within the +F-H and -F-H WT. Findings regarding nicotine delivery should be interpreted with this confound in mind. While sacrificing some external validity, future human studies could use a -F-H WT as a base and then add different controlled amounts of flavouring and humectants to address this limitation. Finally, the current study used a convenience sample of WT smokers recruited from one state. While there was significant variability in participant demographics and level of WT dependence, future research should increase the representativeness of the sample to further improve the applicability of the results.

CONCLUSION

The present study contributes significantly to our understanding of the impact of WT flavours and humectants across a variety of important outcomes. The findings support past research demonstrating the importance of flavours and humectants on improving the overall smoking experience and increasing the likelihood that users will want to initiate and continue smoking WT. Moreover, it demonstrates that flavours and humectants influence smoking behaviour and toxicant exposure in some unexpected ways. It also presents additional questions that need to be further examined outside of the laboratory, including, what would be the likely impact of a WT flavour and humectant tobacco product standard? In one country that restricted WT glycerol levels, the market adjusted and manufactures began selling flavoured bottles of flavoured syrups (largely containing propylene glycol and glycerol) alongside the low-humectant WT so that users could simply mix them together before smoking. Under US law, any product used with the human consumption

of a tobacco product that alters or affects a tobacco product's performance is considered a tobacco product.²⁹ Therefore, if WT humectants enhance nicotine transfer efficiency, they would be subject to the Food and Drug Administration regulation. Also, if a WT flavouring and humectant standard were established, what would be the population level health benefit in terms of reduced initiation and continued use, balanced by a product that now causes increased puffing and greater exposure to harmful toxicants among smokers that choose to continue smoking despite regulations?

What this paper adds

- ▶ Waterpipe tobacco (WT) smoking is associated with many of the same negative health outcomes as cigarette use such as cancer, cardiovascular and lung disease, and nicotine dependence.
- ▶ A potential reason for the appeal of WT is that it is usually flavoured and contains humectants.
- ▶ No study has examined what effect the removal or reduction of flavours and humectants in WT would have on WT smoking.
- ▶ This study is the first to investigate the impact of removing flavours and humectants from WT on subjective smoking experience, smoking topography and toxicant exposure.
- ▶ The findings demonstrate the importance of flavours and humectants on improving the overall smoking experience and increasing the likelihood that users will want to initiate and continue smoking WT.
- ▶ It demonstrates that flavours and humectants influence smoking behaviour and toxicant exposure in some unexpected ways that are important for regulatory efforts.

Author affiliations

¹Department of Internal Medicine, Ohio State University Wexner Medical Center, Columbus, Ohio, USA

²Center for Tobacco Research, The Ohio State University Comprehensive Cancer Center, Columbus, Ohio, United States

³Department of Population Health, University of Kansas School of Medicine, Kansas City, Kansas, United States

⁴Department of Mechanical Engineering, American University of Beirut, Beirut, Lebanon

⁵Center for the Study of Tobacco Products, Department of Psychology, Virginia Commonwealth University, Richmond, Virginia, USA

⁶Department of Pharmaceutics, School of Pharmacy, Virginia Commonwealth University, Richmond, Virginia, USA

⁷Department of Epidemiology, College of Public Health, The Ohio State University, Columbus, Ohio, USA

⁸Oklahoma Tobacco Research Center, Stephenson Cancer Center, Oklahoma City, Oklahoma, USA

⁹Department of Occupational and Environmental Health, University of Oklahoma - Health Sciences Center, Oklahoma City, Oklahoma, USA

¹⁰Department of Biostatistics and Epidemiology, Hudson College of Public Health, University of Oklahoma Health Sciences Center, Oklahoma City, Oklahoma, USA

¹¹Department of Chemistry, American University of Beirut, Beirut, Lebanon

Twitter Theodore L Wagener @TheodoreWagener

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Competing interests TE is a paid consultant in litigation against the tobacco industry and the electronic cigarette industry, and is named on a patent for a device that measures the puffing behaviour of electronic cigarette users.

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ORCID iDs

Theodore L Wagener <http://orcid.org/0000-0002-9072-228X>

Thomas Eissenberg <http://orcid.org/0000-0002-8277-5437>

Marielle C Brinkman <http://orcid.org/0000-0002-4315-649X>

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