

## RESEARCH ARTICLE

## Correlates of susceptibility to waterpipe tobacco smoking in young adults

Mahmood A. Alalwan<sup>1\*</sup>, Lauren Long<sup>1</sup>, Elise M. Stevens<sup>2</sup>, Brittney Keller-Hamilton<sup>1</sup>, Andrea C. Villanti<sup>3</sup>, Glenn Leshner<sup>4</sup>, Theodore L. Wagener<sup>1</sup>, Darren Mays<sup>1</sup>

**1** Department of Internal Medicine, The Ohio State University College of Medicine, Center for Tobacco Research, The Ohio State University Comprehensive Cancer Center, Columbus, Ohio, United States of America, **2** Division of Preventive and Behavioral Medicine, Department of Population and Quantitative Health Sciences, University of Massachusetts Chan Medical School, Worcester, Massachusetts, United States of America, **3** Department of Health, Behavior, Society, and Policy, Rutgers School of Public Health, Rutgers Institute for Nicotine & Tobacco Studies, New Brunswick, New Jersey, United States of America, **4** Gaylord College of Journalism and Mass Communication, University of Oklahoma, Norman, Oklahoma, United States of America

\* [mahmood.alalwan@osumc.edu](mailto:mahmood.alalwan@osumc.edu)



## OPEN ACCESS

**Citation:** Alalwan MA, Long L, Stevens EM, Keller-Hamilton B, Villanti AC, Leshner G, et al. (2024) Correlates of susceptibility to waterpipe tobacco smoking in young adults. PLoS ONE 19(7): e0307058. <https://doi.org/10.1371/journal.pone.0307058>

**Editor:** Niraj Babu, UT Austin: The University of Texas at Austin, UNITED STATES OF AMERICA

**Received:** January 8, 2024

**Accepted:** June 27, 2024

**Published:** July 16, 2024

**Copyright:** © 2024 Alalwan et al. This is an open access article distributed under the terms of the [Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

**Data Availability Statement:** "The data for this study comprise potentially identifying information about participants. To ensure participant confidentiality, researchers interested in accessing the study data must enter into a Data Use Agreement (DUA) with The Ohio State University. Data requests may be sent directly to the corresponding author ([Mahmood.Alalwan@osumc.edu](mailto:Mahmood.Alalwan@osumc.edu)) or to The Ohio State University Office of Innovation and Economic Development at [corporateengagement@osu.edu](mailto:corporateengagement@osu.edu) to establish a DUA. More information about the steps

## Abstract

## Introduction

Many US young adults are susceptible to waterpipe (i.e., hookah) tobacco smoking (WTS) initiation, but research on factors associated with WTS susceptibility is limited. We examined sociodemographic, other tobacco and substance use, and attitudes and perceptions correlates of WTS susceptibility among young adults.

## Methods

Baseline data from a randomized trial testing WTS risk messages was collected in US young adults aged 18 to 30 years who never used waterpipe tobacco but were susceptible to WTS ( $n = 294$ ). Extent of susceptibility to WTS was defined using the average score of a valid scale with higher scores indicating higher susceptibility. Correlates were sociodemographics, other tobacco and substance use, and attitudes and perceptions. Multiple linear regression models identified correlates of greater WTS susceptibility.

## Results

Participants averaged 25 (SD 3.2) years of age, 60% were male, 22% were Black non-Hispanic, 47% completed some college education, and 66% were employed. Our models consistently showed that more positive attitudes toward WTS ( $\beta = -0.08$ ,  $p < 0.01$ ), lower perceived addictiveness relative to cigarettes ( $\beta = -0.09$ ,  $p = 0.04$ ), and greater perceived social acceptability of WTS ( $\beta = 0.05$ ,  $p < 0.01$ ) were positively correlated with WTS susceptibility. Additionally, young adults who smoked cigarillos ( $\beta = 0.53$ ,  $p < 0.01$ ), used cannabis ( $\beta = 0.14$ ,  $p = 0.02$ ), and Black non-Hispanic versus White non-Hispanic young adults ( $\beta = 0.18$ ,  $p = 0.03$ ) also had higher WTS susceptibility.

to establish a DUA with The Ohio State University can also be found at <https://oied.osu.edu/cdas-mtas-and-duas>."

**Funding:** Research reported in this study was supported by the National Cancer Institute of the National Institutes of Health (NIH) and the U.S. Food and Drug Administration (FDA) Center for Tobacco Products (Award Number R01CA229082). Dr. Stevens' contributions were supported by the National Institute of Drug Abuse (NIDA) of the NIH and FDA Center for Tobacco Products (Award Number R00DA046563). Dr. Keller-Hamilton's contributions were supported by NIDA (Award Number K01DA055696). The funders were not involved in the design of the study, collection of data, analysis of data, or the decision to submit the results for publication. The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH or FDA.

**Competing interests:** The authors have declared that no competing interests exist.

## Conclusions

Findings suggest that WTS prevention efforts require multicomponent interventions including targeting subpopulations at greater risk based on race/ethnicity and other tobacco and substance use. These interventions should consider attitudes and social acceptability of WTS as modifiable targets to maximize public health benefits.

## Introduction

Waterpipe (also known as hookah, narghile, or shisha) tobacco smoking (WTS) exposes users to toxicants and poses similar health risks to cigarette smoking, including cancer and pulmonary and cardiac diseases [1, 2]. In the United States (U.S.), the prevalence of past 30-day of WTS is highest among young adults aged 18 to 30 years [3]. For instance, according to the latest data publicly available from the Population Assessment of Tobacco and Health (PATH) survey (Wave 5, 2019), past 30-day use of WTS was highest in young adults (5.1%), compared to youth (0.3%) and older adults (1.4%) [3]. Over time, many U.S. young adults continue to use waterpipe tobacco, albeit in use patterns that differ from other combustible tobacco products such as cigarettes (e.g., monthly rather than daily) [4].

This high prevalence of WTS among young adults is attributable to several factors, including demographic characteristics such as younger age and being male [4–7]. Additionally, other factors contributing the high prevalence of WTS in this population include potentially modifiable factors, which refer to elements or perceptions that can be influenced or shaped to reduce the risk of WTS, such as lower perceived risks of and more positive attitudes towards WTS [8–13]. WTS is also facilitated by permissive social norms surrounding WTS, use in social settings (e.g., lounges, bars), and availability of sweetened and flavored waterpipe tobacco [14, 15]. For these reasons, WTS has been characterized as a “starter product,” or a tobacco product that appeals to young people in particular [16]. Existing research has consistently described factors related to initiation and cessation of WTS [8–15, 17]. However, little is known about the factors that contribute to WTS susceptibility, which is an important upstream factor for behavioral interventions due to young adults' higher risk and susceptibility to WTS.

In young adults, unique psychological and biological factors set them apart from both adolescents and older adults, such as emotional distress and shifts in social and environmental factors associated with the transition to autonomy [18]. These factors increase the vulnerability of young adults to experimentation and persistence in tobacco use. Given their higher risk and susceptibility to WTS, young adults who do not smoke waterpipe are a key population to target preventive efforts. Susceptibility—a construct that relies on strong theoretical underpinnings (i.e., the association between intention and behavior)—to WTS is defined as the lack of a firm decision against use. Evidence from cross-sectional and longitudinal studies indicate that susceptibility to WTS is an important predictor of initiation among never-user young adults as well as continued use among ever-users [19–22]. For instance, a study among college students reported that 27% were susceptible to WTS. Among them, 20% had tried WTS a year later [21]. In another nationally representative sample of young adults aged 18 to 30 years, researchers reported 22% were susceptible to WTS. Those who were susceptible to WTS had nearly seven times greater odds of initiating WTS after 18 months compared to those who were not susceptible [12]. Several reviews show the scarcity of interventions to prevent WTS, with only a few interventions among young adult users and those who do not smoke waterpipe but are susceptible to WTS, a population at higher risk of WTS initiation [20, 23, 24]. These

interventions were mainly risk-based messages designed to counter misperceptions about health and addiction risks associated with WTS [9, 13, 25–29].

There is a limited number of interventions to date to prevent initiation of WTS, which may be due in part to lack of clarity on what populations or factors to target. For example, few studies examined demographic (e.g., race-ethnicity) and behavioral (e.g., substance use) factors to identify subgroups at greater susceptibility to WTS among young adults [20]. In particular, young adults are more susceptible to poly-tobacco use and experimentation with emerging tobacco products [30, 31]. They are likely to be concurrent users of waterpipe, cigarillos, little cigars, and electronic cigarettes (e-cigarettes) [32–34]. Additionally, there is little research on potentially modifiable factors, such as attitudes, perceptions, and social norms, associated with susceptibility to WTS [20, 35]. Identifying these factors can guide the development of new intervention strategies and refinement of available interventions to reduce the WTS burden among young adults. This study sought to address this gap and advance our understanding of young adults' susceptibility to WTS by examining sociodemographic, behavioral (other tobacco and substance use), and attitudes and perceptions associated with WTS susceptibility. To achieve this objective, we used a series of models that examined potentially modifiable factors with and without demographic and behavioral factors.

## Methods

### Participants and procedures

This is a secondary analysis of baseline data from a randomized controlled trial (NCT04252014) testing the effects of messages communicating health and addiction risks of WTS [35]. Participants for this analysis were young adults aged 18 to 30 years, able to complete study procedures online in English, and had never smoked waterpipe tobacco but were susceptible to initiating WTS based on responses to a valid, 4-item susceptibility measure [20]. Participants were recruited using a nationally representative consumer research panel (National Opinion Research Council (NORC) AmeriSpeak) between February 4, 2020 and March 3, 2020. Using probability-based sampling, NORC recruits AmeriSpeak panel members using the NORC National Frame and address-based sampling frames [36]. Participants completed a baseline assessment online with measures of WTS and baseline trial outcomes. All eligible participants provided online informed consent to complete enrollment, and the participating institutions' institutional review boards approved procedures (2020C0080).

### Measures

**Dependent variable.** *Extent of susceptibility to WTS.* We used the average score of four valid susceptibility items (Cronbach  $\alpha = 0.84$ ) [20]. These four items were: 1) Do you think that you will smoke tobacco from a waterpipe soon? 2) Do you think that you will smoke tobacco from a waterpipe in the next year? 3) Do you think that in the future you might experiment with waterpipe tobacco smoking? 4) If one of your best friends asked you to smoke tobacco from a waterpipe, would you? Response options were on a scale of 1 (Definitely Yes) to 4 (Definitely No). Those who responded "Definitely No" to all items were considered non-susceptible. We reversed the scale for these four items with higher scores indicating higher susceptibility to WTS.

**Independent variables.** *Sociodemographics.* Demographic characteristics from participants' AmeriSpeak profiles included age, sex (male/female), race (Black/Asian/Others), ethnicity (Hispanic/Non-Hispanic), household income (Range from 1 (Less than \$5,000) to 18 (\$200,000 or more)), educational attainment (High school or less/Some college/Bachelor's degree or higher), employment status (Yes/No), and marital status (Yes/No).

*Other tobacco and substance use.* We assessed other tobacco product and substance use including past-30-day (Yes/No) cigarette, cigar, cigarillo, smokeless tobacco, e-cigarette, alcohol, and cannabis use.

*Attitudes towards WTS.* We measured attitudes towards WTS by averaging responses to four pairs (Positive–Negative, Good–Bad, Like–Dislike, and Pleasant–Unpleasant) with a 1 to 9 bipolar scale with higher scores indicating increasingly negative attitudes (Cronbach's  $\alpha = 0.93$ ).

*Harm perceptions.* WTS harm perceptions (perceived harm of WTS relative to cigarettes, perceived likelihood of harm from WTS, and worry about harm from WTS) were assessed using three items: 1) Compared to regular cigarettes, how harmful do you think smoking hookah tobacco is to your health? Response options ranged from 1 (Much less harmful) to 5 (Much more harmful); 2) What do you think would be your chance of getting a serious smoking-related disease, such as cancer, lung disease, or heart disease, if you were to smoke hookah tobacco? Response options ranged from 1 (No chance) to 7 (Certain to happen); and 3) How worried are you about getting a serious smoking-related disease, such as cancer, lung disease, or heart disease, if you were to smoke hookah tobacco? Response options ranged from 1 (Not at all) to 7 (Very much) [23, 37, 38].

*Addiction perceptions.* We assessed addiction perceptions using similar items (i.e., perceived addiction of WTS relative to cigarettes, perceived likelihood of addiction from WTS, and worry about addiction from WTS) with similar response options [23, 37, 38].

*Social aspects of WTS.* We also measured perceived harm of social WTS and flavored WTS using two items: 1) Smoking hookah tobacco for an hour or two in such settings as bars, cafes, and lounges is not harmful to my health and 2) Hookah tobacco that comes in flavors such as menthol or mint, clove, spice, candy, fruit, chocolate, or other sweets is less harmful to my health than unflavored hookah tobacco. Response options ranged from 1 (Strongly agree) to 5 (Strongly disagree). Finally, we measured social acceptability of WTS using the following item: How socially acceptable among your peers do you think each of the following products are? A list of substances followed, including "Hookah." Response options ranged from 1 (Not acceptable) to 7 (Acceptable).

## Statistical analysis

We used descriptive statistics to characterize the sample and bivariate analyses to assess associations between the extent of susceptibility to WTS and all other study measures using independent samples t-test/one-way ANOVA for categorical variables and Pearson's correlation for continuous variables. We used multivariable linear regression to examine the association between the extent of susceptibility to WTS and independent variables. For our model building strategy, we built two models, one examining attitudes towards, harms perceptions of, addiction perceptions of, social harm and acceptability of WTS only (Model 1) and another examining sociodemographics and other tobacco and substance use, in addition to all model 1 factors (Model 2). We reported model summary statistics including  $R^2$  and adjusted  $R^2$  values, F values, and  $\beta$ 's for each independent variable; significance level was set at  $p < 0.05$ . Missingness was minimal; therefore, we used complete case analysis. All model assumptions were checked and satisfied, including the linearity assumption using partial regression plots for each continuous predictor; the normality of the residuals assumption using the Q-Q plot; and homoskedasticity using the residuals versus fitted plot. We also assessed for multicollinearity using variance inflation factor ( $VIF < 10$ ) [39]. All analyses were conducted using SAS 9.4 (Cary, NC).

## Results

### Sample characteristics

A total of 315 participants had never smoked waterpipe and were susceptible with 21 (6.7%) individuals having missing data, leaving a final analytic sample of 294 (Table 1). The mean susceptibility score in our sample was 2.1 (SD 0.58, range 1–4). Among susceptible never waterpipe smokers, 59.5% were female, 78.2% attended some college or earned a bachelor's degree or higher, and 57.8% had an annual household income <\$50,000. Approximately two-thirds (68.7%) drank alcohol in the past 30 days, 45.6% used cannabis, 11.2% used e-cigarettes, and 7.5% used cigarillos.

### Bivariate and multivariable analyses

*Sociodemographics, other tobacco and substance use.* Consistently in bivariate analysis (Table 2) and multivariable analysis (Table 3 Model 2), young adults who smoked cigarillos ( $\beta = 0.53, p < 0.01$ ) and used cannabis ( $\beta = 0.14, p = 0.02$ ) in the past 30-days had higher WTS susceptibility. However, using e-cigarettes ( $p = 0.02$ ) in the past 30-days was correlated significantly with WTS susceptibility only in bivariate analysis (Table 2). Additionally, Black non-Hispanic race-ethnicity versus White non-Hispanic young adults ( $\beta = 0.19, p = 0.02$ ) was correlated significantly with WTS susceptibility in multivariable analysis (Table 3 Model 2).

*Attitudes, perceptions, and social aspects of WTS.* We examined the association of attitudes, perceptions, and social aspects of WTS with susceptibility to WTS using bivariate analysis (Table 2) and two multivariable models (Table 3). All these factors were significantly associated with susceptibility to WTS except for perceived harm of WTS relative to cigarettes, which was marginally significant ( $p = 0.05$ ). When we examined these factors only (i.e., excluding sociodemographics and other tobacco and substance use) in multivariable analysis (Table 3 Model 1), greater susceptibility to WTS was associated only with more positive attitudes towards WTS ( $\beta = -0.11, p < 0.01$ ) and greater perceived social acceptability of WTS ( $\beta = 0.06, p < 0.01$ ). However, in Model 2 (Table 3), lower perceived addictiveness of WTS relative to cigarettes ( $\beta = -0.08, p = 0.03$ ) was associated with greater susceptibility to WTS, in addition to the significant correlates found in Model 1 (Table 3). Model 2, which included sociodemographics, other tobacco and substance use, and attitudes, perceptions, and social aspects of WTS explained 36.32% of the variance in susceptibility to WTS ( $R^2 = 0.3632$ , Adjusted  $R^2 = 0.2932$ ,  $F = 5.19, p < 0.01$ ).

## Discussion

In this study, we examined factors associated with susceptibility to WTS among young adults who had never used waterpipe tobacco. Consistently across models, we found several factors associated with greater susceptibility to WTS uptake, including more positive attitudes towards WTS, lower perceived addictiveness of WTS relative to cigarettes, and greater perceived social acceptability of WTS. Also, our findings indicate that Black non-Hispanic young adults and those who used other tobacco products (cigarillos) or substances (cannabis) were more susceptible to WTS. Existent WTS prevention interventions are mainly risk-based messaging interventions [20, 23, 24]; however, our results indicate that effective WTS prevention interventions should target not only perceived risks of WTS, but also other tobacco and substance use, attitudes, and social acceptability of WTS. These findings can inform the refinement of existing interventions and development of novel interventions targeting young adults who are susceptible to WTS.

**Table 1. Study sample characteristics (N = 294).**

	N	%	Mean	SD
<b>Sociodemographics</b>				
Age			25.0	3.16
Gender	175	59.5		
Female				
Male	119	40.5		
Race Ethnicity				
Non-Hispanic White	113	38.4		
Non-Hispanic Black	62	21.1		
Non-Hispanic Asian	40	13.6		
Non-Hispanic Other	23	7.8		
Hispanic	56	19.1		
Education				
High school or less	64	21.8		
Some college	137	46.6		
Bachelor's degree or above	93	31.6		
Marital Status				
No	243	82.7		
Yes	51	17.3		
Employment Status				
No	100	34.0		
Yes	194	66.0		
Household Income				
<\$50,000	170	57.8		
\$50,000 to \$99,999	79	26.9		
>\$100,000	45	15.3		
<b>Past-30-day tobacco and substance use</b>				
Cigarette Use				
No	263	89.5		
Yes	31	10.5		
Cigar Use				
No	278	94.6		
Yes	16	5.4		
Cigarillo Use				
No	272	92.5		
Yes	22	7.5		
Smokeless Tobacco Use				
No	289	98.3		
Yes	5	1.7		
E-cigarette Use				
No	261	88.8		
Yes	33	11.2		
Alcohol Use				
No	92	31.3		
Yes	202	68.7		
Cannabis Use				
No	160	54.4		
Yes	134	45.6		

*(Continued)*



**Table 1.** (Continued)

	N	%	Mean	SD
<b>Attitudes, perceptions, and social aspects of WTS</b>				
Susceptibility to WTS (range 1–4)			2.1	0.58
Attitude toward WTS (range 1–9)			6.4	1.81
Perceived harm of WTS relative to cigarettes (range 1–5)			2.9	0.84
Perceived likelihood of harm from WTS (range 1–7)			4.5	1.26
Worry about harm from WTS (range 1–7)			4.6	1.78
Perceived addictiveness of WTS relative to cigarettes (range 1–5)			2.8	0.81
Perceived likelihood of addiction to WTS (range 1–7)			4.1	1.46
Worry about addiction to WTS (range 1–7)			4.0	1.91
Perceived social acceptability of WTS (range 1–7)			3.8	1.66
Perceived social harm of WTS (range 1–5)			2.2	1.02
Perceived harm of flavored WTS (range 1–5)			2.0	0.97

<https://doi.org/10.1371/journal.pone.0307058.t001>

We found that Black non-Hispanic young adults appear to be more susceptible to WTS than White non-Hispanic young adults. Moreover, we found that young adults who reported cigarillo or cannabis had higher WTS susceptibility. One prior study examined characteristics of susceptibility to WTS among young adults [20], but it did not examine demographic and other tobacco product or substance use by susceptibility status. Consistent with our findings, another study that investigated openness to use non-cigarette tobacco products found that young adults who used non-cigarette products had higher odds of being open to use waterpipe [22]. Our findings suggests that additional efforts may be needed to prevent WTS in subpopulations at greater risk based on race-ethnicity and other tobacco and substance use. For instance, non-Hispanic Blacks appear to be at greater risk of using flavored tobacco (e.g., menthol cigarettes and cigars) in part due to the deliberate and pervasive targeting by the tobacco industry of black communities [40]. Further research is needed to identify how to target these subpopulations and what factors can be used to target interventions for these subpopulations.

In the two models examining attitudes and perceptions of WTS with and without demographic and behavioral factors, WTS susceptibility to WTS was consistently associated with attitudes towards WTS, perceived addictiveness of WTS relative to cigarettes, and perceived social acceptability of WTS. In line with our findings, Lipkus et. al. investigated characteristics of WTS susceptibility and found that attitudes towards WTS, perceived addictiveness of WTS, and perceived social acceptability of WTS were significantly associated with susceptibility to WTS [20]. However, unlike our findings, that study found additional characteristics that were significantly associated with WTS susceptibility, including relative harm of WTS and risk appraisals (perceived risk and worry about harm and addiction). These differences may be attributed to the varied measurement and study designs. For instance, we used individual measures for perceived harm and addictiveness and risk appraisals while Lipkus et. al. combined harm and addictiveness in a single measure. Although their target population was young adults, they included susceptible and non-susceptible participants who do not smoke waterpipe while we only included those who were susceptible. In a randomized controlled trial, intervention messages focused on targeting young adults' perceptions of WTS risks, addressing major factors contributing to the appeal of WTS such as flavors and social use [35]. The study indicated noteworthy effects, particularly decreasing initiation among susceptible young adults who do not smoke waterpipe at the highest exposure dose. Moreover, susceptible never smokers demonstrated an increased perception of the addictiveness of WTS two months after exposure to the intervention messages. Consistent with prior studies, our findings emphasize the

Table 2. Bivariate associations with susceptibility to waterpipe tobacco smoking (N = 294).

	Mean	SD	r	P-value
<b>Sociodemographics</b>				
Age			0.07	0.24
Gender				0.98
Female	2.10	0.57		
Male	2.08	0.58		
Race Ethnicity				0.08
Non-Hispanic White	2.04	0.51		
Non-Hispanic Black	2.23	0.65		
Non-Hispanic Asian	1.98	0.48		
Non-Hispanic Other	2.19	0.61		
Hispanic	2.08	0.62		
Education				0.90
High school or less	2.12	0.65		
Some college	2.08	0.60		
Bachelor's degree or above	2.09	0.47		
Marital Status				0.83
No	2.10	0.57		
Yes	2.06	0.58		
Employment Status				0.35
No	2.06	0.56		
Yes	2.11	0.58		
Household Income				0.11
<\$50,000	2.13	0.57		
\$50,000 to \$99,999	1.99	0.57		
>\$100,000	2.12	0.58		
<b>Past-30-day tobacco and substance use</b>				
Cigarette Use				<b>0.02</b>
No	2.07	0.55		
Yes	2.31	0.70		
Cigar Use				0.10
No	2.08	0.56		
Yes	2.31	0.68		
Cigarillo Use				<b>&lt; 0.01</b>
No	2.04	0.54		
Yes	2.66	0.62		
Smokeless Tobacco Use				0.42
No	2.09	0.57		
Yes	2.30	0.74		
E-cigarette Use				<b>&lt; 0.01</b>
No	2.04	0.54		
Yes	2.50	0.67		
Alcohol Use				<b>&lt; 0.01</b>
No	1.93	0.57		
Yes	2.17	0.56		
Cannabis Use				<b>&lt; 0.01</b>
No	1.97	0.53		
Yes	2.24	0.59		

(Continued)



Table 2. (Continued)

	Mean	SD	r	P-value
<b>Attitudes, perceptions, and social aspects of WTS</b>				
Attitude toward WTS (range 1–9)			-0.44	< <b>0.01</b>
Perceived harm of WTS relative to cigarettes (range 1–5)			-0.11	0.05
Perceived likelihood of harm from WTS (range 1–7)			-0.22	< <b>0.01</b>
Worry about harm from WTS (range 1–7)			-0.17	< <b>0.01</b>
Perceived addictiveness of WTS relative to cigarettes (range 1–5)			-0.18	< <b>0.01</b>
Perceived likelihood of addiction to WTS (range 1–7)			-0.16	< <b>0.01</b>
Worry about addiction to WTS (range 1–7)			-0.17	< <b>0.01</b>
Perceived social acceptability of WTS (range 1–7)			0.29	< <b>0.01</b>
Perceived social harm of WTS (range 1–5)			0.15	< <b>0.01</b>
Perceived harm of flavored WTS (range 1–5)			0.17	< <b>0.01</b>

Bold values indicate significant results at  $p < 0.05$ .

<https://doi.org/10.1371/journal.pone.0307058.t002>

importance of influencing attitudes towards, perceived addictiveness of, and perceived social acceptability of WTS to reduce the susceptibility to WTS among young adults who do not smoke waterpipe, and, potentially, reduce WTS uptake.

Many young adults are unaware of WTS risks and misperceive it as a less harmful product than other tobacco products, such as cigarettes [41–43]. Our bivariate analysis indicated the importance of WTS health harm perceptions among susceptible young adults who do not smoke waterpipe. However, this association was attenuated in the multivariable models. Extant interventions targeting WTS prevention are mainly risk-based messages, which were successful in raising harm beliefs and reducing susceptibility to future WTS [20, 23, 24, 35]. In one recent study, researchers examined the effect of WTS risk messages on WTS risk appraisals, attitudes towards WTS, ambivalence about WTS, and willingness to smoke waterpipe in young adults aged 18–30 years [37]. The study revealed that the risk messaging intervention heightened risk appraisals, which in turn induced more negative attitudes towards WTS, leading to reduced willingness to WTS. This mediation analysis aligns with our results by indicating that attitudes may be a significant mechanism through which risk messaging impacts susceptibility to WTS, and in turn waterpipe use behavior.

Our findings—in line with successful interventions that have effectively heightened the perceived addictiveness of WTS among young adults [35]—also extend our understanding of young adults' susceptibility to WTS, underscoring the importance of addressing perceived addictiveness in interventions to prevent WTS. The belief that WTS is less addictive than cigarettes—a common misperception among young adults—represents an opportunity for interventions to potentially decrease susceptibility [8, 9, 25, 44, 45]. However, little information exists regarding addiction beliefs relevant to WTS among susceptible young adults who do not smoke waterpipe to reduce susceptibility to WTS uptake. This information is crucial for the development of targeted interventions with the goal of diminishing susceptibility and preventing the initiation of WTS among this population. Expanding our understanding of specific beliefs associated with addiction in the context of WTS among susceptible young adults who do not smoke waterpipe will contribute valuable insights to the design and implementation of more effective prevention strategies.

Our study had notable strengths, such as using a sample from a nationally representative consumer research panel and using literature to guide our variable selection and analysis. Also, the measures we used in our study were validated in young adults. However, there were

Table 3. Multivariable analysis of correlates of susceptibility to waterpipe tobacco smoking.

	$\beta$	Model 1*		Model 2†			
		95% CI	P-value	$\beta$	95% CI	P-value	
<b>Sociodemographics</b>							
Age				0.005	-0.016	0.025	0.66
Gender							
Female				Ref.			
Male				-0.004	-0.118	0.109	0.94
Race Ethnicity							
Non-Hispanic White				Ref.			
Non-Hispanic Black				0.189	0.028	0.350	<b>0.02</b>
Non-Hispanic Asian				0.075	-0.107	0.256	0.42
Non-Hispanic Other				0.060	-0.155	0.275	0.58
Hispanic				0.054	-0.103	0.211	0.50
Education							
High school or less				Ref.			
Some college				-0.072	-0.221	0.077	0.35
Bachelor's degree or above				-0.029	-0.215	0.156	0.76
Marital Status							
No				Ref.			
Yes				-0.044	-0.195	0.107	0.57
Employment Status							
No				Ref.			
Yes				0.043	-0.081	0.168	0.49
Household Income							
<\$50,000				Ref.			
\$50,000 to \$99,999				-0.083	-0.212	0.045	0.20
>\$100,000				0.012	-0.161	0.185	0.89
<b>Past-30-day tobacco and substance use</b>							
Cigarette Use							
No				Ref.			
Yes				0.088	-0.111	0.286	0.39
Cigar Use							
No				Ref.			
Yes				-0.042	-0.308	0.225	0.76
Cigarillo Use							
No				Ref.			
Yes				0.527	0.303	0.750	<b>&lt;0.01</b>
Smokeless Tobacco Use							
No				Ref.			
Yes				0.004	-0.434	0.443	0.98
E-cigarette Use							
No				Ref.			
Yes				0.176	-0.014	0.366	0.07
Alcohol Use							
No				Ref.			
Yes				0.099	-0.025	0.222	0.12
Cannabis Use							
No				Ref.			

(Continued)

Table 3. (Continued)

	Model 1*				Model 2†			
	$\beta$	95% CI		P-value	$\beta$	95% CI		P-value
Yes					0.136	0.020	0.252	<b>0.02</b>
<b>Attitudes, perceptions, and social aspects of WTS</b>								
Attitude toward WTS	-0.114	-0.154	-0.074	< <b>0.01</b>	-0.080	-0.119	-0.041	< <b>0.01</b>
Perceived harm of WTS relative to cigarettes	0.034	-0.048	0.115	0.42	-0.002	-0.076	0.072	0.95
Perceived likelihood of harm from WTS	-0.044	-0.108	0.019	0.17	-0.049	-0.107	0.009	0.10
Worry about harm from WTS	0.026	-0.017	0.070	0.23	0.011	-0.028	0.051	0.58
Perceived addictiveness of WTS relative to cigarettes	-0.067	-0.149	0.016	0.11	-0.084	-0.161	-0.007	<b>0.03</b>
Perceived likelihood of addiction to WTS	0.028	-0.028	0.083	0.33	0.026	-0.025	0.077	0.32
Worry about addiction to WTS	-0.028	-0.071	0.014	0.19	-0.011	-0.051	0.028	0.57
Perceived social acceptability of WTS	0.060	0.023	0.097	< <b>0.01</b>	0.050	0.015	0.084	< <b>0.01</b>
Perceived social harm of WTS	0.005	-0.064	0.074	0.89	0.015	-0.049	0.080	0.64
Perceived harm of flavored WTS	0.013	-0.061	0.087	0.73	0.000	-0.069	0.069	1.00

Bold values indicate significant results at  $p < 0.05$ . \*Model 1 included attitudes, perceptions, and social aspects of WTS only. †Model 2 included sociodemographics, other tobacco and substance use, and attitudes, perceptions, and social aspects of WTS

<https://doi.org/10.1371/journal.pone.0307058.t003>

some limitations to our study results. Our analysis was cross-sectional, so we cannot establish the temporality between correlates and susceptibility to WTS among young adults. Although we recruited participants from a nationally representative consumer research panel, restricting our sample to susceptible young adults who do not smoke waterpipe may limit the generalizability of our findings to other populations. Larger, more representative, longitudinal studies are needed to replicate our findings. Additionally, several factors were unmeasured, including exposure to marketing strategies and advertising targeting young adults, exposure to second-hand smoke at home and social settings, parental smoking history, and perceived social benefits of smoking, which may influence susceptibility to WTS.

## Conclusion

This study identified several potentially modifiable correlates of susceptibility to WTS, which can inform which factors may be best to target in WTS prevention intervention among young adult susceptible to WTS. Consistently across models, our analyses indicated that several factors were associated with susceptibility to WTS uptake, including attitudes towards WTS, perceived addictiveness of WTS relative to cigarettes, and perceived social acceptability of WTS. Additionally, our findings suggested demographic and behavioral differences, including racial and ethnic (Black non-Hispanic) and other substance use (cigarillo, cannabis) differences. These results could assist in improving current interventions and creating new interventions for young adults who do not smoke waterpipe susceptible to WTS, and subsequently reduce WTS uptake in this population. Longitudinal studies are also needed to better understand the role of attitudes and perceptions in WTS susceptibility and what specific beliefs are relevant to those factors that contribute to WTS susceptibility.

## Author Contributions

**Conceptualization:** Mahmood A. Alalwan, Lauren Long, Brittney Keller-Hamilton, Andrea C. Villanti, Glenn Leshner, Theodore L. Wagener, Darren Mays.

**Data curation:** Elise M. Stevens, Andrea C. Villanti, Glenn Leshner, Theodore L. Wagener, Darren Mays.

**Formal analysis:** Mahmood A. Alalwan, Darren Mays.

**Funding acquisition:** Andrea C. Villanti, Glenn Leshner, Theodore L. Wagener.

**Investigation:** Elise M. Stevens, Darren Mays.

**Methodology:** Darren Mays.

**Project administration:** Darren Mays.

**Resources:** Darren Mays.

**Supervision:** Darren Mays.

**Writing – original draft:** Mahmood A. Alalwan, Lauren Long, Elise M. Stevens, Brittney Keller-Hamilton, Andrea C. Villanti, Glenn Leshner, Theodore L. Wagener, Darren Mays.

**Writing – review & editing:** Mahmood A. Alalwan, Lauren Long, Elise M. Stevens, Brittney Keller-Hamilton, Andrea C. Villanti, Glenn Leshner, Theodore L. Wagener, Darren Mays.

## References

1. American Lung Association. Facts About Hookah. [cited 17 Apr 2024]. Available: <https://www.lung.org/quit-smoking/smoking-facts/health-effects/facts-about-hookah>
2. CDCTobaccoFree. Hookahs. In: Centers for Disease Control and Prevention [Internet]. 20 Oct 2023 [cited 17 Apr 2024]. Available: [https://www.cdc.gov/tobacco/data\\_statistics/fact\\_sheets/tobacco\\_industry/hookahs/index.htm](https://www.cdc.gov/tobacco/data_statistics/fact_sheets/tobacco_industry/hookahs/index.htm)
3. United States Department of Health and Human Services, National Institutes of Health, National Institute on Drug Abuse, and United States Department of Health and Human Services, Food and Drug Administration, Center for Tobacco Products. Youth, young adult, and older adult past 30-day hookah use. in PATH study data tables and figures. Inter-university Consortium for Political and Social Research [distributor]; 2021. Available: <https://www.icpsr.umich.edu/files/nahdap/pathstudy/YoungAdult-30Day-Hookah.pdf>
4. Robinson JN, Wang B, Jackson KJ, Donaldson EA, Ryant CA. Characteristics of Hookah Tobacco Smoking Sessions and Correlates of Use Frequency Among US Adults: Findings From Wave 1 of the Population Assessment of Tobacco and Health (PATH) Study. *Nicotine Tob Res Off J Soc Res Nicotine Tob*. 2018; 20: 731–740. <https://doi.org/10.1093/ntr/ntx060> PMID: 28340148
5. Grekin ER, Ayna D. Waterpipe smoking among college students in the United States: a review of the literature. *J Am Coll Health J ACH*. 2012; 60: 244–249. <https://doi.org/10.1080/07448481.2011.589419> PMID: 22420702
6. Jarrett T, Blosnich J, Tworek C, Horn K. Hookah use among U.S. college students: results from the National College Health Assessment II. *Nicotine Tob Res Off J Soc Res Nicotine Tob*. 2012; 14: 1145–1153. <https://doi.org/10.1093/ntr/nts003> PMID: 22318687
7. Park SH, Duncan DT, Shahawy OE, Shearston JA, Lee L, Tamura K, et al. Analysis of State-Specific Prevalence, Regional Differences, and Correlates of Hookah Use in U.S. Adults, 2012–2013. *Nicotine Tob Res Off J Soc Res Nicotine Tob*. 2017; 19: 1365–1374. <https://doi.org/10.1093/ntr/ntw229> PMID: 27613949
8. Akl EA, Jawad M, Lam WY, Co CN, Obeid R, Irani J. Motives, beliefs and attitudes towards waterpipe tobacco smoking: a systematic review. *Harm Reduct J*. 2013; 10: 12. <https://doi.org/10.1186/1477-7517-10-12> PMID: 23816366
9. Akl EA, Ward KD, Bteddini D, Khaliel R, Alexander AC, Lotfi T, et al. The allure of the waterpipe: a narrative review of factors affecting the epidemic rise in waterpipe smoking among young persons globally. *Tob Control*. 2015; 24 Suppl 1: i13–i21. <https://doi.org/10.1136/tobaccocontrol-2014-051906> PMID: 25618895
10. Elton-Marshall T, Driezen P, Fong GT, Cummings KM, Persoskie A, Wackowski O, et al. Adult perceptions of the relative harm of tobacco products and subsequent tobacco product use: Longitudinal findings from waves 1 and 2 of the population assessment of tobacco and health (PATH) study. *Addict Behav*. 2020; 106: 106337. <https://doi.org/10.1016/j.addbeh.2020.106337> PMID: 32145496

11. Hair E, Rath JM, Pitzer L, Emelle B, Ganz O, Halenar MJ, et al. Trajectories of Hookah Use: Harm Perceptions from Youth to Young Adulthood. *Am J Health Behav.* 2017; 41: 240–247. <https://doi.org/10.5993/AJHB.41.3.3> PMID: 28376968
12. Sidani JE, Shensa A, Naidu MR, Yabes JG, Primack BA. Initiation, Progression, and Sustained Waterpipe Use: A Nationally Representative Longitudinal Study of U.S. Young Adults. *Cancer Epidemiol Biomark Prev Publ Am Assoc Cancer Res Cosponsored Am Soc Prev Oncol.* 2017; 26: 748–755. <https://doi.org/10.1158/1055-9965.EPI-16-0687-T> PMID: 28082346
13. Villanti AC, Cobb CO, Cohn AM, Williams VF, Rath JM. Correlates of hookah use and predictors of hookah trial in U.S. young adults. *Am J Prev Med.* 2015; 48: 742–746. <https://doi.org/10.1016/j.amepre.2015.01.010> PMID: 25890683
14. Kates FR, Salloum RG, Thrasher JF, Islam F, Fleischer NL, Maziak W. Geographic Proximity of Waterpipe Smoking Establishments to Colleges in the U.S. *Am J Prev Med.* 2016; 50: e9–e14. <https://doi.org/10.1016/j.amepre.2015.07.006> PMID: 26346294
15. Shepardson RL, Hustad JTP. Hookah Tobacco Smoking During the Transition to College: Prevalence of Other Substance Use and Predictors of Initiation. *Nicotine Tob Res Off J Soc Res Nicotine Tob.* 2016; 18: 763–769. <https://doi.org/10.1093/ntr/ntv170> PMID: 26259986
16. Brinkman MC, Teferre AA, Kassem NO, Kassem NO. Effect of electric heating and ice added to the bowl on mainstream waterpipe semivolatile furan and other toxicant yields. *Tob Control.* 2020; 29: s110–s116. <https://doi.org/10.1136/tobaccocontrol-2019-054961> PMID: 31542776
17. Alalwan MA, Keller-Hamilton B, Long L, Lipkus I, Wagener TL, Mays D. Correlates of motivation to quit waterpipe tobacco smoking among US young adults: implications for cessation interventions. *Health Educ Res.* 2023; cyad010. <https://doi.org/10.1093/her/cyad010> PMID: 36880171
18. Committee on Improving the Health, Safety, and Well-Being of Young Adults, Board on Children, Youth, and Families, Institute of Medicine, National Research Council. *Investing in the Health and Well-Being of Young Adults.* Bonnie RJ, Stroud C, Breiner H, editors. Washington (DC): National Academies Press (US); 2015. Available: <http://www.ncbi.nlm.nih.gov/books/NBK284787/>
19. Roberts ME, Ferketich AK. Hookah Susceptibility and Transitions Over the First Year of College. *J Stud Alcohol Drugs.* 2020; 81: 195–202. <https://doi.org/10.15288/jsad.2020.81.195> PMID: 32359049
20. Lipkus IM, Mays D, P. Tercyak K. Characterizing Young Adults' Susceptibility to Waterpipe Tobacco Use and Their Reactions to Messages About Product Harms and Addictiveness. *Nicotine Tob Res.* 2017; 19: 1216–1223. <https://doi.org/10.1093/ntr/ntw251> PMID: 27799355
21. Lipkus IM, Reboussin BA, Wolfson M, Sutfin EL. Assessing and Predicting Susceptibility to Waterpipe Tobacco Use Among College Students. *Nicotine Tob Res Off J Soc Res Nicotine Tob.* 2015; 17: 1120–1125. <https://doi.org/10.1093/ntr/ntu336> PMID: 25542922
22. Mays D, Arrazola RA, Tworek C, Rolle IV, Neff LJ, Portnoy DB. Openness to Using Non-cigarette Tobacco Products Among U.S. Young Adults. *Am J Prev Med.* 2016; 50: 528–534. <https://doi.org/10.1016/j.amepre.2015.08.015> PMID: 26549502
23. Mays D, Tercyak KP, Lipkus IM. The Effects of Brief Waterpipe Tobacco Use Harm and Addiction Education Messages Among Young Adult Waterpipe Tobacco Users. *Nicotine Tob Res Off J Soc Res Nicotine Tob.* 2016; 18: 777–784. <https://doi.org/10.1093/ntr/ntv223> PMID: 26438650
24. Lipkus I, Sanders C. A Pilot Study Assessing Reactions to Educational Videos on Harm of Waterpipe among Young Adults Susceptible to Waterpipe Tobacco Smoking. *J Health Commun.* 2021; 26: 743–752. <https://doi.org/10.1080/10810730.2021.2000522> PMID: 34758698
25. Cornacchione J, Wagoner KG, Wiseman KD, Kelley D, Noar SM, Smith MH, et al. Adolescent and Young Adult Perceptions of Hookah and Little Cigars/Cigarillos: Implications for Risk Messages. *J Health Commun.* 2016; 21: 818–825. <https://doi.org/10.1080/10810730.2016.1177141> PMID: 27337629
26. Eissenberg T, Ward KD, Smith-Simone S, Maziak W. Waterpipe tobacco smoking on a U.S. College campus: prevalence and correlates. *J Adolesc Health Off Publ Soc Adolesc Med.* 2008; 42: 526–529. <https://doi.org/10.1016/j.jadohealth.2007.10.004> PMID: 18407049
27. Heinz AJ, Giedgowd GE, Crane NA, Veilleux JC, Conrad M, Braun AR, et al. A comprehensive examination of hookah smoking in college students: use patterns and contexts, social norms and attitudes, harm perception, psychological correlates and co-occurring substance use. *Addict Behav.* 2013; 38: 2751–2760. <https://doi.org/10.1016/j.addbeh.2013.07.009> PMID: 23934006
28. Sidani JE, Shensa A, Barnett TE, Cook RL, Primack BA. Knowledge, attitudes, and normative beliefs as predictors of hookah smoking initiation: a longitudinal study of university students. *Nicotine Tob Res Off J Soc Res Nicotine Tob.* 2014; 16: 647–654. <https://doi.org/10.1093/ntr/ntt201> PMID: 24323574
29. Sutfin EL, McCoy TP, Reboussin BA, Wagoner KG, Spangler J, Wolfson M. Prevalence and correlates of waterpipe tobacco smoking by college students in North Carolina. *Drug Alcohol Depend.* 2011; 115: 131–136. <https://doi.org/10.1016/j.drugalcdep.2011.01.018> PMID: 21353750

30. Harrell PT, Naqvi SMH, Plunk AD, Ji M, Martins SS. Patterns of youth tobacco and polytobacco usage: The shift to alternative tobacco products. *Am J Drug Alcohol Abuse*. 2017; 43: 694–702. <https://doi.org/10.1080/00952990.2016.1225072> PMID: 27668320
31. Richardson A, Williams V, Rath J, Villanti AC, Vallone D. The next generation of users: prevalence and longitudinal patterns of tobacco use among US young adults. *Am J Public Health*. 2014; 104: 1429–1436. <https://doi.org/10.2105/AJPH.2013.301802> PMID: 24922152
32. Soneji S, Sargent J, Tanski S. Multiple tobacco product use among US adolescents and young adults. *Tob Control*. 2016; 25: 174–180. <https://doi.org/10.1136/tobaccocontrol-2014-051638> PMID: 25361744
33. Lee YO, Hebert CJ, Nonnemaker JM, Kim AE. Multiple tobacco product use among adults in the United States: cigarettes, cigars, electronic cigarettes, hookah, smokeless tobacco, and snus. *Prev Med*. 2014; 62: 14–19. <https://doi.org/10.1016/j.ypmed.2014.01.014> PMID: 24440684
34. Kasza KA, Ambrose BK, Conway KP, Borek N, Taylor K, Goniewicz ML, et al. Tobacco-Product Use by Adults and Youths in the United States in 2013 and 2014. *N Engl J Med*. 2017; 376: 342–353. <https://doi.org/10.1056/NEJMsa1607538> PMID: 28121512
35. Keller-Hamilton B, Stevens EM, Villanti AC, Leshner G, Wagener TL, Mays D. Messaging to prevent and reduce young adults' waterpipe tobacco smoking: A randomized trial. *Addict Behav*. 2023; 138: 107546. <https://doi.org/10.1016/j.addbeh.2022.107546> PMID: 36455379
36. National Opinion Research Council. AmeriSpeak Panel Design. NORC. 2021 [cited 3 Nov 2023]. Available: <https://amerispeak.norc.org/us/en/amerispeak/about-amerispeak/panel-design.html>
37. Mays D, Johnson AC, Phan L, Tercyak KP, Rehberg K, Lipkus I. Effect of risk messages on risk appraisals, attitudes, ambivalence, and willingness to smoke hookah in young adults. *Health Psychol Behav Med*. 2020; 8: 96–109. <https://doi.org/10.1080/21642850.2020.1730844> PMID: 33033657
38. Lipkus IM, Eissenberg T, Schwartz-Bloom RD, Prokhorov AV, Levy J. Affecting perceptions of harm and addiction among college waterpipe tobacco smokers. *Nicotine Tob Res Off J Soc Res Nicotine Tob*. 2011; 13: 599–610. <https://doi.org/10.1093/ntr/ntr049> PMID: 21471304
39. Shrestha N. Detecting Multicollinearity in Regression Analysis. *Am J Appl Math Stat*. 2020; 8: 39–42. <https://doi.org/10.12691/ajams-8-2-1>
40. Stopping Menthol, Saving Lives. In: Campaign for Tobacco-Free Kids [Internet]. [cited 17 Apr 2024]. Available: <https://www.tobaccofreekids.org/what-we-do/industry-watch/menthol-report>
41. Maziak W, Sharma E. Building the evidence base for waterpipe regulation and policy. *Tob Control*. 2020; 29: s59–s61. <https://doi.org/10.1136/tobaccocontrol-2019-055391> PMID: 31767787
42. Arshad A, Matharoo J, Arshad E, Sadhra SS, Norton-Wangford R, Jawad M. Knowledge, attitudes, and perceptions towards waterpipe tobacco smoking amongst college or university students: a systematic review. *BMC Public Health*. 2019; 19: 439. <https://doi.org/10.1186/s12889-019-6680-x> PMID: 31029118
43. Dhillon AZ, Doran T, Aggarwal VR. Perceptions of Waterpipe Smoking among Young Adults: A Phenomenological Study. *Dent J*. 2020; 8: 134. <https://doi.org/10.3390/dj8040134> PMID: 33321834
44. Lipkus IM, Mays D. Comparing harm beliefs and risk perceptions among young adult waterpipe tobacco smokers and nonsmokers: Implications for cessation and prevention. *Addict Behav Rep*. 2018; 7: 103–110. <https://doi.org/10.1016/j.abrep.2018.03.003> PMID: 29892704
45. Mays D, Tercyak KP, Rehberg K, Crane M-K, Lipkus IM. Young adult waterpipe tobacco users' perceived addictiveness of waterpipe tobacco. *Tob Prev Cessat*. 2017; 3. <https://doi.org/10.18332/tpc/80133> PMID: 32432207