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Original investigation

Public Understanding of Cigarette Smoke Chemicals: Longitudinal Study of US Adults and Adolescents

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Abstract

Introduction: The US Food and Drug Administration has increased communication efforts that aim to raise public awareness of the harmful constituents (ie, chemicals) in cigarette smoke. We sought to investigate whether the public's awareness of these chemicals has increased in light of such efforts.

Methods: Participants were national probability samples of 11 322 US adults and adolescents recruited in 2014–2015 (wave 1) and 2016–2017 (wave 2). Cross-sectional telephone surveys assessed awareness of 24 cigarette smoke chemicals at both timepoints.

Results: The proportion of US adults aware of cigarette smoke chemicals did not differ between waves 1 and 2 (25% and 26%, $p = .19$). In contrast, awareness of chemicals among adolescents fell from 28% to 22% ($p < .001$), mostly due to lower awareness of carbon monoxide, arsenic, benzene, and four other chemicals. Belief that most of the harmful chemicals in cigarette smoke come from burning the cigarette also fell from waves 1 to 2 (adults: 31% vs. 26%; adolescents: 47% vs. 41%, both ps $< .05$). Participants were more likely to be aware of cigarette smoke chemicals if they had been exposed to anti-smoking campaign advertisements ($p < .05$) or had previously sought chemical information ($p < .05$). Cigarette smoke chemical awareness did not differ between smokers and nonsmokers.

Conclusion: Awareness of cigarette smoke chemicals remains low and unchanged among adults and decreased somewhat among adolescents. The association of chemical awareness with information exposure via campaigns and information seeking behavior is promising. More concerted communication efforts may be needed to increase public awareness of cigarette smoke chemicals, which could potentially discourage smoking.

Implications: Awareness of the toxic chemicals in cigarette smoke may contribute to quitting. The US Food and Drug Administration is making efforts to increase public awareness of these chemicals. Two national surveys (2014–2017) found that chemical awareness was low among adults and adolescents. Although awareness did not change among adults, awareness among adolescents dropped over time. In addition, exposure to anti-smoking campaigns and chemical information seeking behavior were associated with higher awareness of chemicals in cigarette smoke. Campaigns and other efforts may be needed to increase awareness of cigarette smoke chemicals.

Introduction

Cigarette smoke contains harmful and potentially harmful constituents (ie, chemicals) that cause many smoking-related diseases.[1,2] Under the Family Smoking Prevention and Tobacco Control Act, tobacco manufacturers in the United States are required to report the quantity of certain chemicals in smoke from their cigarette products to the US Food and Drug Administration (FDA).[3,4] In turn, FDA is charged with publishing this information in a way that is understandable and not misleading to a layperson.[3] In 2012, FDA released a list of 93 harmful and potentially harmful chemicals in cigarette smoke[5] and an abbreviated list of 18 chemicals prioritized for industry reporting.[4] In 2017, FDA added a new web page about the harmful chemicals in tobacco plants, cigarettes, and cigarette smoke,[6] with videos and interactive tools to make the information more understandable to the general audience. FDA also sponsored a public communication campaign (ie, *The Real Cost*) since 2014, in which some campaign advertisements addressed the presence of toxic chemicals in cigarettes and cigarette smoke,[7–9] among other smoking-related themes. In light of such efforts, we sought to investigate whether awareness of cigarette smoke chemicals among US adults and adolescents changed over time.

The general public can become aware of cigarette smoke chemicals through two main routes—information scanning and seeking.[10] People can be exposed to information that they routinely encounter in their environment (ie, scanning) such as that presented in public health campaign advertisements. For instance, *The Real Cost* campaign aims to directly inform the public—most notably youth—of the negative consequences of smoking and cigarette chemicals. People can also actively look for cigarette smoke chemical information on various media platforms (ie, information seeking), such as online resources like the FDA web site where smokers as well as nonsmokers can find information about these chemicals.

Awareness of chemicals in cigarette smoke is linked to several important outcomes. A recent study showed that people in the United States were more discouraged from smoking by chemicals that they had heard were in cigarette smoke, compared to chemicals they were previously unaware of.[11] Similarly, a study of smokers in the United States, Canada, Australia, and the United Kingdom found that planning to quit was more common among those who were aware of more chemicals in cigarette smoke compared to those who were aware of fewer or none of the chemicals.[12] Thus, chemical awareness may play a significant role in tobacco prevention and cessation.

In our study, we sought to understand changes in awareness of harmful chemicals in cigarette smoke and antecedents of awareness. First, we hypothesized that messaging efforts on the part of FDA and others[13,14] would increase awareness of cigarette smoke chemicals over time (hypothesis 1). Our specific predictions included an increase in awareness over time; a decrease in misconceptions about the source of chemicals over time; an association between exposure to anti-smoking campaign advertisements and awareness of chemicals; and an association between chemical information seeking behavior and awareness of chemicals. Second, we examined other potential antecedents of cigarette smoke chemical awareness, including attributes of the chemical names that may affect familiarity and likelihood of recall. Specifically, we hypothesized that awareness would be higher for chemicals with shorter, nonnumerical names (hypothesis 2). We examined these hypotheses among several probability samples of US adults and adolescents.

Methods

Participants

Wave 1

From September 2014 to May 2015, the Carolina Survey Research Laboratory (CSRL) at the University of North Carolina used random digit dialing of landline and cellular phones that covered approximately 98% of US households to recruit a wave 1 national probability sample of 5014 US adults. All English- or Spanish-speaking adults aged more than 18 years were eligible for the study. In addition, CSRL oversampled households in counties with higher prevalence of poverty and smoking. The American Association for Public Opinion Research (AAPOR) response rate 4 for adults was 42%. Further details on the approach used to sample adults can be found elsewhere.[15]

Simultaneously, CSRL recruited 1125 US adolescents (ages 13–17 years) using the adult frame of random digit dialing of landline and cellular phones that oversampled counties with higher prevalence of poverty and smoking. To ensure sufficient recruitment of adolescent participants, CSRL also used a nonoverlapping directory-listed sampling frame targeting households with teens, which used the same sampling approach as the random digit dial samples. All teens who spoke English and Spanish, lived in the United States, and had telephone access were eligible for the study. The AAPOR response rate 4 for adolescents was 66%.

Wave 2

From August 2016 to May 2017, CSRL recruited a new wave 2 national probability sample of 4208 US adults, using random digit dialing of landline and cellular phones with coverage of 96% of US households. Phone numbers from the wave 1 survey were excluded from the sampling frames for the wave 2 survey, meaning that the participant pools for the two waves were completely independent from one another. As with wave 1, in wave 2 CSRL oversampled counties with high smoking rates and low income levels. The AAPOR response rate 4 was 39%. Further details on adult sample recruitment are available elsewhere (R. P. Agans et al., unpublished data, 2018).

To enlist adolescents, CSRL recruited eligible adolescents from the random digit dial adult households, as well as from a

supplemental electronic white page frame that targeted households with 13–17 year olds. The final sample comprised 975 US adolescents. The AAPOR response rate 4 was 33%. Further details on adolescent sample recruitment appear in Supplementary Appendix 1.

Consent

Interviewers obtained verbal informed consent from adult participants. Prior to conducting adolescent surveys, interviewers obtained both verbal assent from adolescent participants and verbal consent from the adolescents' parents or guardians. The University of North Carolina Institutional Review Board approved all study procedures.

Measures

Awareness of Cigarette Smoke Chemicals

The survey software randomized participants to 1 of 6 panels (Supplementary Table 1). Each panel assessed awareness of four different chemicals in cigarette smoke for a total of 24 chemicals in the survey across all participants. These 24 chemicals were derived from either FDA's abbreviated list (n = 18) or complete list of harmful and potentially harmful chemicals.[5,16] To assess awareness, the survey asked separately for each chemical "Before today, had you ever heard that [chemical name] is in cigarette smoke?" We treated subjects who responded "Yes" as being aware of the chemical, and treated all other responses as not being aware. We then created an overall awareness measure that examined average awareness of the four chemicals in each panel.

Discouragement From Smoking

Using the same panels as described earlier, the survey assessed discouragement from wanting to smoke: "How much does [chemical name] being in cigarette smoke discourage you from wanting to smoke?" The response options ranged from "not at all" (coded as 1) to "a lot" (4).

Perceived Source of Cigarette Smoke Chemicals

The survey assessed participants' beliefs about the source of chemicals in cigarette smoke with the item: "Where do you think most of the harmful chemicals in cigarettes and cigarette smoke come from?" Response options were "tobacco before it is made into cigarettes," "tobacco additives," or "burning the cigarettes."

Chemical Name Characteristics

Following the methods of Brewer et al.,[11] we coded chemical names for three separate characteristics. First, we coded whether chemical names began with a number or not. Second, we coded whether chemical names ended in "ene"/"ine," "ide"/"yde," or "other" endings. Third, we coded the number of characters in a chemical name (ie, length).

Exposure to Anti-Smoking Campaigns and Chemical Information

The survey assessed participants' self-reported exposure to specific campaign advertisements as a proxy for overall awareness of anti-smoking campaigns. In the adult surveys, survey software randomized participants to a one-sentence description of 1 of 5 anti-smoking campaign advertisements. The majority were aired as part of FDA's *The Real Cost* campaign, and all advertisements were about the possible consequences of smoking; waves 1 and 2 asked about the advertisements airing at the respective time of the study (see Supplementary Table 2 for description of advertisements). As a form of aided recall, the survey asked whether the participant had "seen or heard" the ad that was described. We coded responses of "yes" as being aware of campaigns and coded other responses as being unaware. The adolescent survey asked participants whether they had seen or heard all five advertisements, in random order. For comparability of data interpretation across adults and adolescents, we coded respondents as being aware of campaigns if they had heard of one or more advertisements. In addition, the adult survey asked whether participants ever looked for information on chemicals in cigarettes and cigarette smoke.

Participant Characteristics

Surveys assessed participants' age, sex, sexual orientation (or sexual interest, for adolescents), race, Hispanic ethnicity, college attendance (or college attendance of mothers, for adolescents), numeracy, state of residence, and smoking status. We defined current smoking status as smoking some days or every day and having smoked 100 or more cigarettes during one's lifetime (for adults),[17] or having smoked cigarettes at least one of the past 30 days (for adolescents).[18]

Data Analysis

We report unweighted frequencies and weighted proportions for all point estimates. Application of the survey weights results in nationally representative estimates; a detailed explanation of weighting procedures is available elsewhere.[15] To compare awareness of cigarette smoke chemicals and discouragement from smoking over time, we used two-sample proportion tests. We conducted chi-square tests to examine the overall difference in perceived source of cigarette smoke chemicals over time, and subsequently conducted post hoc tests to examine how each category of the variable differed over time. To account for the repeated measures design of the chemical panels, we used a generalized estimating equation model to examine correlates of chemical awareness across both waves, adjusting for survey weights.[19] We analyzed data separately for adults and for adolescents. Analyses were two-tailed, with critical alpha of .05, and conducted using Stata 15.0.

Results

Both the adult and adolescent samples were demographically diverse (Table 1). Survey samples also had high numeracy levels (69% among adults, 74% among adolescents) and more than half of the adult sample had attended at least some college (58%).

Changes in chemical understanding over time

Changes in Awareness of Cigarette Smoke Chemicals

In wave 1 (2014–2015), adults were most likely to report knowing that nicotine (89%), carbon monoxide (61%), and arsenic (50%) are present in cigarette smoke. In wave 2 (2016–2017), adults were most aware of nicotine (91%), formaldehyde (57%), and carbon monoxide (56%). Average awareness of cigarette smoke chemicals among adults did not differ between waves (25% vs. 26%, p = .19) (Supplementary Table 3). However, adults' awareness of *N*-nitrosonornicotine increased from 39% to 52% (p < .001) and their awareness decreased for benzene (39% to 35%, p < .001) and isoprene (13% to 10%, p < .05).

For both waves, adolescents were most likely to report being aware that nicotine, *N*-nitrosonornicotine, and carbon monoxide are in cigarette smoke (Table 2). In contrast to adults, adolescents' average awareness of cigarette smoke chemicals declined over time

Table 1. Participant Characteristics, Wave 1 (2014–2015) and Wave 2 (2016–2017)

	Adolescents (age 13–17 y)				Adults (age ≥18 y)			
	Wave 1 (n = 1125)		Wave 2 (n = 975)		Wave 1 (n = 5014)		Wave 2 (n = 4208)	
	n	%	n	%	n	%	n	%
Smoking status								
Nonsmoker	1085	97.0	948	97.2	3856	82.2	3234	85.0
Smoker	40	3.0	27	2.8	1151	17.8	973	15.0
Age (y)								
13–17	1124	100	975	100	—	—	—	—
18–25	—	—	—	—	809	14.9	545	15.4
26–64	—	—	—	—	3397	67.6	2990	67.0
≥65	—	—	—	—	789	17.5	655	17.6
Sex								
Female	564	48.7	491	49.9	2640	51.5	2276	51.4
Male	561	51.3	481	50.1	2372	48.5	1924	48.6
Gay, lesbian, or bisexual								
No	1041	96.1	880	92.1	4730	96.8	3943	95.6
Yes	42	3.9	55	7.9	192	3.3	192	4.4
Race								
African American	119	13.0	123	16.9	978	18.3	879	18.8
American Indian or Alaska Native	18	2.1	12	1.0	135	2.0	162	3.0
Asian or Pacific Islander	25	3.4	13	2.6	125	3.2	95	3.2
White	901	73.0	788	72.8	3473	68.3	2855	67.7
Other	62	8.4	39	6.7	270	8.2	189	7.3
Hispanic								
No	1040	90.1	913	89.9	4568	85.8	3838	85.5
Yes	85	9.9	61	10.1	432	14.2	353	14.5
Attended college								
No	218	20.9	208	22.4	1756	42.6	1489	41.6
Yes	731	79.1	681	77.6	3241	57.4	2602	58.4
Numeracy								
Low	307	27.0	223	24.8	1599	31.9	1302	29.4
High	818	73.0	752	75.2	3401	68.1	2901	70.6
Appalachia resident								
No	889	85.5	738	87.1	3987	91.2	3403	91.3
Yes	224	14.5	237	12.9	757	8.8	805	8.7
Chemical panel								
1	188	16.1	171	17.6	790	16.5	705	16.6
2	192	16.0	152	14.2	849	17.4	736	15.5
3	171	16.1	161	16.8	837	17.1	701	16.7
4	182	16.6	170	19.5	779	15.0	701	17.5
5	191	17.3	150	14.3	897	17.3	645	15.0
6	201	18.1	171	17.6	862	16.7	720	18.6

Percentages are weighted. Wave 1 = 2014–2015; wave 2 = 2016–2017. For adolescents, attended college is based on mother's highest level of education, smoking status is defined as having smoked during at least one of the past 30 days, and sexual orientation is sexual attraction to people of the same sex.

(28% vs. 22%, $p < .001$). Specifically, adolescents' awareness decreased for seven chemicals, most notably carbon monoxide (59% to 45%), arsenic (42% to 29%), and benzene (37% to 24%) (all $ps < .05$). Adolescents' awareness did not increase for any of the chemicals.

Changes in Perceived Source of and Discouragement From Cigarette Smoke Chemicals

In wave 2, fewer adults and adolescents believed that most of the harmful chemicals in cigarettes and cigarette smoke come from burning the cigarette, compared to wave 1 (adults: 31% [wave 1] vs. 26% [wave 2]; adolescents: 47% vs. 41%, both $ps < .05$) (Table 3). The number of adults and adolescents believing that most chemicals come from tobacco before it is made into cigarettes or that most chemicals come from tobacco additives, did not significantly change over time.

Discouragement from wanting to smoke after hearing about the presence of chemicals in cigarette smoke was high among both adults and adolescents. Adults' level of discouragement from wanting to smoke across the 24 constituents was slightly higher in wave 2 (71%), compared to wave 1 (69%, $p < .01$) (Table 3). However, the proportion of adolescents reporting a high level of discouragement from wanting to smoke did not change over time (76% vs. 74%, $p = .11$) (Table 3).

Correlates of Awareness

For both adults and adolescents, those who reported having seen or heard anti-smoking campaign advertisements were more likely to report awareness of cigarette smoke chemicals than those who reported no exposure to such advertisements (adults: 28% vs. 23%, aOR = 1.24, 95% CI = 1.11 to 1.39; adolescents: 26% vs. 15%,

Table 2. Awareness of Chemicals in Cigarette Smoke Among Adolescents

Chemical	Wave 1 2014–2015 (%)	Wave 2 2016–2017 (%)	Difference (95% CI)	*p*
1,3-Butadiene	7.8	12.3	4.5 (–3.4 to 12.4)	.263
1-Aminoaphthalene	13.6	11.4	–2.1 (–101 to 5.9)	.601
2-Aminonaphthalene	13.2	9.6	–3.6 (11.1 to 3.9)	.347
4-Aminobiphenyl	13.0	4.8	–8.2 (–14.1 to –2.4)	**.005**
Acetaldehyde	18.1	17.1	–1.1 (–11.2 to 9.0)	.837
Acrolein	5.9	7.9	2.0 (–4.0 to 7.9)	.519
Acrylonitrile	13.6	13.9	0.3 (–8.5 to 9.1)	.950
Ammonia	47.4	36.0	–11.4 (–23.4 to 0.6)	.062
Arsenic	41.9	29.0	–12.9 (–25.0 to –0.8)	**.036**
Benzene	37.2	24.4	–12.8 (-24.4 to –1.1)	**.032**
Benzo-*a*-pyrene	15.3	11.7	–3.6 (–12.8 to 5.7)	.450
Carbon monoxide	58.8	45.0	–13.8 (–27.5 to –0.0)	**.049**
Crotonaldehyde	19.8	19.6	–0.3 (–10.0 to 9.5)	.957
Formaldehyde	41.4	33.3	–8.1 (–20.7 to 4.4)	.203
Hydrogen cyanide	32.9	25.5	–7.4 (–18.6 to 3.8)	.192
Isoprene	18.0	13.7	–4.3 (–14.0 to 5.3)	.378
Lead	33.5	32.4	–1.0 (–12.9 to 10.9)	.866
Naphthalene	20.0	7.3	–12.6 (–20.8 to –4.5)	**.003**
Nicotine	92.4	90.3	–2.1 (–9.6 to 5.5)	.587
Nitrosamine	20.8	11.7	–9.1 (–17.2 to –1.0)	**.028**
N-nitrosonornicotine	61.8	55.6	–6.2 (–20.0 to 7.6)	.376
NNK	12.7	11.9	–0.8 (–9.8 to 8.3)	.866
Toluene	11.1	9.0	–2.1 (–10.0 to 5.9)	.605
Uranium	19.4	6.2	–13.2 (–21.2 to –5.2)	**.001**
Overall	27.9	21.7	–6.2 (–8.4 to –4.0)	**<.001**

2014–2015 n = 1125; 2016–2017 n = 975. The ns for each chemical differ slightly but are comparable. Percentages are weighted. NNK = nicotine-derived nitrosamine ketone. The threshold value of statistical significance is p = .05.

Table 3. Perceived Source of and Discouragement From Chemicals in Cigarette Smoke Among Adults and Adolescents

	Wave 1 2014–2015 (%)	Wave 2 2016–2017 (%)	Difference (95% CI)	*p*
Adults				
Tobacco before made into cigarettes	7.9	9.1	1.2 (–0.9 to 3.3)	.27
Tobacco additives	61.4	64.7	3.3 (–0.4 to 7.1)	.08
Burning the cigarette	30.7	26.2	–4.5 (–8.1 to –0.9)	.01
Discouragement	68.5	70.7	2.2 (0.5 to 3.9)	.01
Adolescents				
Tobacco before made into cigarettes	10.3	10.9	0.6 (–2.8 to 3.9)	.74
Tobacco additives	43.2	48.3	5.1 (–0.2 to 10.4)	.06
Burning the cigarette	46.5	40.8	–5.7 (–11.0 to –0.4)	.04
Discouragement	76.0	74.2	–1.8 (–4.1 to 0.4)	.11

Percentages are weighted. For perceived source of chemicals, data missing for <2% of adults and adolescents. For discouragement, data indicate the proportion of people who reported being "a lot" discouraged from wanting to smoke on a 4-point scale from "not at all" to "a lot."

aOR = 1.78, 95% CI = 1.08 to 2.93). Adults who reported having sought information about cigarette smoke chemicals were also more likely to report awareness of chemicals than those who did not seek information (36% vs. 20%, aOR = 2.12, 95% CI = 1.89 to 2.36).

Among adults, awareness was greater for cigarette smoke chemicals whose names ended in "ide" or "yde" compared to those that ended in "ene" or "ine" (36% vs. 25%, aOR = 1.35, 95% CI = 1.21 to 1.51) or other endings (Table 4). Adults' awareness was lower for chemicals that started with a number than for those that did not start with a number (10% vs. 28%, aOR = 0.28, 95% CI = 0.24 to 0.33). The length of the chemical name was not associated with adults' awareness. Similarly, adolescents were also less aware of chemicals that started with a number (11% vs. 28%, aOR = 0.27, 95% CI = 0.21 to 0.34). However, adolescents displayed no difference in awareness for chemicals whose names ended in "ide" or "yde" compared to those that ended in "ene" or "ine." Adolescents' awareness was slightly higher for chemicals with longer names (aOR = 1.03, 95% CI = 1.00 to 1.05).

With respect to adults' demographic characteristics, awareness of cigarette smoke chemicals was higher among men than women (aOR = 1.21, 95% CI = 1.09 to 1.36), and among whites compared to those with other racial backgrounds (aOR = 1.17, 95% CI = 1.03 to 1.32). Adults who attended college (aOR = 1.19, 95% CI = 1.04 to 1.36) and with high numeracy (aOR = 1.14, 95% CI = 1.01 to 1.29) were also more likely to be aware of chemicals in cigarette

Table 4. Correlates of Awareness of Chemicals in Cigarette Smoke (Adjusted Models, Wave 1 and 2 Combined)

	Adolescents (n = 1674)		Adults (n = 8379)	
	%	aOR (95% CI)	%	aOR (95% CI)
Chemical characteristics				
Chemical name starts with number				
No	28.0	Ref	28.2	Ref
Yes	10.7	0.27 (0.21 to 0.34)**	10.3	0.28 (0.24 to 0.33)**
Chemical name ends with				
"ene" or "ine"	25.3	Ref	25.2	Ref
"ide" or "yde"	31.1	0.96 (0.81 to 1.14)	36.0	1.35 (1.21 to 1.51)**
Other	21.1	0.74 (0.63 to 0.86)**	18.5	0.55 (0.49 to 0.61)**
Chemical name length		1.03 (1.00 to 1.05)*		1.00 (0.99 to 1.02)
Person characteristics				
Sought information about chemicals in cigarette smoke				
No	—	—	20.4	Ref
Yes	—	—	36.4	2.12 (1.89 to 2.36)**
Campaign awareness				
No	15.1	Ref	23.1	Ref
Yes	25.5	1.78 (1.08 to 2.93)*	28.2	1.24 (1.11 to 1.39)**
Smoking status				
Nonsmoker	25.0	Ref	25.2	Ref
Smoker	27.6	1.01 (0.72 to 1.43)	25.3	0.90 (0.78 to 1.03)
Age (y)		1.11 (1.06 to 1.18)**		0.99 (0.99-0.99)**
Sex				
Female	25.6	Ref	23.5	Ref
Male	24.7	0.93 (0.80 to 1.07)	27.0	1.21 (1.09 to 1.36)*
Gay, lesbian, or bisexual				
No	25.4	Ref	25.3	Ref
Yes	22.8	0.89 (0.62 to 1.27	26.6	0.93 (0.74 to 1.17)
Race				
Other	20.2	Ref	23.5	Ref
White	26.9	1.48 (1.22 to 1.79)*	25.9	1.17 (1.03 to 1.32)*
Hispanic				
No	25.3	Ref	25.7	Ref
Yes	22.6	0.95 (0.70 to 1.28)	22.7	0.83 (0.67 to 1.03)
Attended college				
No	25.2	Ref	22.0	Ref
Yes	26.5	1.04 (0.86 to 1.27)	27.2	1.19 (1.04 to 1.36)*
Numeracy				
Low	21.9	Ref	22.0	Ref
High	26.2	1.13 (0.95 to 1.35)	26.7	1.14 (1.01 to 1.29)*
Appalachia resident				
No	24.7	Ref	25.6	Ref
Yes	26.8	1.12 (0.91 to 1.37)	23.3	0.91 (0.77 to 1.08)
Time				
2014–2015 (wave 1)	27.9	Ref	24.9	Ref
2016–2017 (wave 2)	21.7	0.73 (0.63 to 0.86)*	25.7	0.96 (0.86 to 1.08)

Percentages are weighted and indicate the proportion of people who reported awareness of chemicals. Surveys did not assess seeking information about chemicals among adolescents. For adolescents, attended college is based on mother's highest level of education, smoking status is defined as having smoked during at least one of the past 30 days, and sexual orientation is sexual attraction to people of the same sex. Intraclass correlation for adolescents = 0.34, 95% CI = 0.27 to 0.41; Intraclass correlation for adults = 0.42, 95% CI = 0.33 to 0.49. aOR = adjusted odds ratio; Ref = reference group.
*$p < .05$, **$p < .001$.

smoke. Among adolescents, awareness was higher among whites compared to other races (aOR = 1.48, 95% CI = 1.22 to 1.79) and among those who were older (aOR = 1.11, 95% CI = 1.06 to 1.18).

Discussion

The US Tobacco Control Act requires the collection and dissemination of detailed information on cigarette smoke chemicals in order to inform the public. Our large national surveys conducted from 2014 to 2017 found low awareness of cigarette smoke chemicals among US adults, with no change over time. Awareness was also quite low among US adolescents, and it decreased somewhat. The low awareness mirrors findings from previous focus group studies[20,21] and some cross-sectional surveys.[22] This low awareness suggests that many Americans are not adequately informed of the harms of smoking, a gap in understanding that may undermine quitting. Furthermore, a decline in awareness of these chemicals among adolescents is especially concerning, as youths' awareness of cigarette smoke chemicals is linked to their discouragement from smoking,[11] and tobacco use typically begins during adolescence.[23]

Adolescents' awareness decreased for particular harmful chemicals in cigarette smoke. A possible explanation for this decline is that some advertisements from *The Real Cost* that were explicitly about chemicals in cigarette smoke (ie, "7000 Chemicals") ran during 2014–2015 while our wave 1 survey was in the field.[9,24] It may be that the campaign increased awareness of some cigarette smoke chemicals among adolescents, but by 2016–2017, awareness among the new cohort of adolescents declined to pre-campaign levels, suggesting the need to disseminate chemical-specific advertisements for a prolonged period of time and to refresh these advertisements. Another possible explanation for the low cigarette smoke chemical awareness is that most of the relevant advertisements simply convey the generic message that cigarettes contain many toxic chemicals, rather than naming individual chemicals. Future efforts may wish to consider messaging about specific chemicals to help youth become truly aware of the chemicals in cigarette smoke. In addition, the tobacco industry has continued efforts to downplay the potential harms of cigarette smoke chemicals and to resist providing reliable chemical information, thereby undermining enactment of disclosures.[25,26]

Perhaps as a consequence of the general lack of awareness of cigarette smoke chemicals, we found that fewer than half of both adolescents and adults correctly attributed the source of most chemicals to the tobacco combustion process, pointing to the need for increased efforts to promote accurate understanding of the source of greatest harm from chemicals in cigarette smoke. It is also troubling that accurate perceptions of chemical source actually *decreased* for both adults and adolescents. Raising awareness of the source of harms in cigarettes may be more important in the future if FDA requires manufacturers to remove nearly all of the nicotine from combustible products.[27] Having this awareness may encourage smokers to ideally quit or switch to less harmful, noncombustible products instead of seeking out illicit combustible products.

Among both adults and adolescents, nicotine and carbon monoxide consistently ranked highest on awareness over time. This high level of awareness may partly be because carbon monoxide is the only chemical explicitly mentioned in Surgeon General's warnings currently on US cigarette packs and advertisements. Our results are in line with findings from other studies that have shown nicotine and carbon monoxide rank consistently high on public awareness not only in the United States, but also in other countries such as Australia, Canada, and the United Kingdom.[12,20,21,28]

Our finding that cigarette smoke chemical awareness is positively associated with information seeking behavior and information scanning (as measured by exposure to campaign advertisements) is promising. Prior studies have found that both adults and adolescents are interested in learning more about the chemicals in cigarette smoke,[20–22] suggesting that exposure to the right information could help them become more aware of these chemicals.[22] It is especially encouraging that we found an association between campaign exposure and chemical awareness among both adults and adolescents, given that most of the advertisements assessed in our surveys were targeting youth and were not necessarily about chemicals in cigarette smoke. Although some of our participants may have learned about cigarette smoke chemicals directly from the advertisements, for others this may be a marker for other exposures they have had to information about chemicals through other venues (eg, on FDA's web page about cigarette smoke chemicals). In light of these findings, a feasible campaign approach would be for various information sources to act in synergy to promote a media environment in which people are encouraged to seek chemical information and are led to accurate, informative resources when they do. This would increase the chances of repeated exposure to information that will further help the public understand the toxic sources that lead to harms of smoking.

Awareness was lower for cigarette smoke chemicals with names that started with a number than for those that did not start with a number. The former names may be more difficult to remember even if people had previously seen them in a list of chemicals. In a prior study, we found that discouragement was also lower for chemicals with names that started with a number.[11] As most people are more discouraged from smoking by chemicals that they had heard are in cigarette smoke,[11,29] it is important that people are regularly exposed to cigarette smoke chemical information. Next steps could entail familiarizing the public with chemicals that have unfamiliar names, so as to raise awareness of those chemicals and subsequently, discouragement from wanting to smoke.

Interestingly, smokers did not report more awareness of cigarette smoke chemicals compared to nonsmokers. Given that smokers are less likely to be discouraged from tobacco use than nonsmokers,[11] it may be necessary to expend more effort toward raising smokers' awareness of the toxicity of chemicals in cigarette smoke, thereby dissuading them from smoking. One possible solution is to build on the ongoing efforts being made to display chemical information on cigarette packs,[3] as smokers regularly interact with these packs and would have the opportunity to be frequently exposed to cigarette smoke chemical information.[30,31] Previous studies have found that exposure to health warnings on cigarette packs in countries such as the United Kingdom, Australia, Canada, and Mexico were associated with greater awareness of cigarette smoke chemicals[12,28,32] and a recent randomized clinical trial of US smokers showed that exposure to chemical labels on cigarette packs led to higher awareness of the chemicals mentioned on those labels compared to those who were not exposed.[33] Prior studies have shown an additive effect of exposure to mass media campaigns and pictorial pack warnings on knowledge of chemicals[34] and on health consequences of smoking,[35] further pointing to potential benefits of synergistic efforts to communicate chemical information across multiple platforms.

Strengths of our study include the use of two large national probability surveys with mostly identical measures that allowed us to examine changes over time. We surveyed both adults and adolescents, allowing us to compare findings among different age groups. Limitations of our study included the use of cross-sectional surveys over time, which prevented us from making strong causal inferences. Although our study examined awareness of 24 chemicals in cigarette smoke, 18 of which were on FDA's abbreviated list of harmful and potentially harmful chemicals, we did not measure awareness for the full list of 93 chemicals. To gain a more comprehensive understanding of the public's understanding of different chemicals in cigarette smoke, future studies may wish to replicate the current findings with a more expansive list of chemicals. Similarly, our measure of awareness of anti-smoking campaign advertisements was limited in that the individual items asking about exposure to specific advertisements differed between the two surveys, due to our efforts to reflect the advertisements that were airing at the time of survey rollout. Relatedly, only one advertisement assessed in the survey was explicitly about cigarette smoke chemicals; the remaining advertisements were about the health and addictive consequences of smoking. Despite this limitation, we were able to treat our measure as a proxy for campaign exposure and offer preliminary conclusions that could form a basis for future research.

Conclusions

Our study shows that, among other factors, seeking or scanning relevant information is associated with higher awareness of chemicals in cigarette smoke. However, overall awareness of cigarette smoke chemicals did not increase among either the adult or the adolescent US populations, pointing to the need for strengthened efforts to disseminate chemical information to the public that would raise cigarette smoke chemical awareness and discourage tobacco use. Specifically, tobacco prevention programs may wish to implement more concerted communication strategies to increase awareness of cigarette smoke chemicals among the public using multiple communication platforms.

Supplementary Material

Supplementary data are available at *Nicotine and Tobacco Research* online.

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Declaration of Interests

KMR and NTB have served as paid expert consultants in litigation against tobacco companies. The other authors declare no conflicts of interest.

References

1. Hecht SS. Research opportunities related to establishing standards for tobacco products under the Family Smoking Prevention and Tobacco Control Act. *Nicotine Tob Res*. 2012;14(1):18–28.
2. Rodgman A, Perfetti TA. *The Chemical Components of Tobacco and Tobacco Smoke*. 2nd ed. New York, NY: CRC Press; 2013.
3. Family Smoking Prevention and Tobacco Control Act. *Public Law* 111–31. 2009. https://www.gpo.gov/fdsys/pkg/PLAW-111publ31/pdf/PLAW-111publ31.pdf. Accessed February 20, 2018.
4. US Food and Drug Administration. *Reporting Harmful and Potentially Harmful Constituents in Tobacco Products and Tobacco Smoke Under Section 904(a)(3) of the Federal Food, Drug, and Cosmetic Act*. Rockville, MD: US Department of Health and Human Services, Food and Drug Administration, Center for Tobacco Products; 2012.
5. US Food and Drug Administration. Harmful and potentially harmful constituents in tobacco products and tobacco smoke; established list. *Fed Regist*. 2012;77(64):20034–20037.
6. US Food and Drug Administration. *Chemicals in Cigarettes: From Plant to Product to Puff*. https://www.fda.gov/TobaccoProducts/Labeling/ProductsIngredientsComponents/ucm535235.htm. Accessed February 20, 2018.
7. Duke JC, Alexander TN, Zhao X, et al. Youth's awareness of and reactions to The Real Cost national tobacco public education campaign. *PLoS One*. 2015;10(12):e0144827.
8. Farrelly MC, Duke JC, Nonnemaker J, et al. Association between The Real Cost media campaign and smoking initiation among youths—United States, 2014–2016. *MMWR Morb Mortal Wkly Rep*. 2017;66(2):47–50.
9. Huang L-L, Lazard AJ, Pepper JK, Noar SM, Ranney LM, Goldstein AO. Impact of The Real Cost campaign on adolescents' recall, attitudes, and risk perceptions about tobacco use: a national study. *Int J Environ Res Public Health*. 2017;14(1):42.
10. Kelly B, Hornik R, Romantan A, et al. Cancer information scanning and seeking in the general population. *J Health Commun*. 2010;15(7):734–753.
11. Brewer NT, Morgan JC, Baig SA, et al. Public understanding of cigarette smoke constituents: three US surveys. *Tob Control*. 2016;26(5):592–599.
12. Hammond D, Fong GT, McNeill A, Borland R, Cummings KM. Effectiveness of cigarette warning labels in informing smokers about the risks of smoking: findings from the International Tobacco Control (ITC) Four Country Survey. *Tob Control*. 2006;15(suppl 3):iii19–25.
13. Davis KC, Patel D, Shafer P, et al. Association between media doses of the tips from former smokers campaign and cessation behaviors and intentions to quit among cigarette smokers, 2012–2015. *Health Educ Behav*. 2018;45(1):52–60.
14. Farrelly MC, Nonnemaker J, Davis KC, Hussin A. The Influence of the National truth campaign on smoking initiation. *Am J Prev Med*. 2009;36(5):379–384.
15. Boynton MH, Agans RP, Bowling JM, et al. Understanding how perceptions of tobacco constituents and the FDA relate to effective and credible tobacco risk messaging: a national phone survey of US adults, 2014–2015. *BMC Public Health*. 2016;16:516.
16. US Food and Drug Administration. *Guidance for Industry and FDA Staff: "Harmful and Potentially Harmful Constituents" in Tobacco Products as Used in Section 904(e) of the Federal Food, Drug, and Cosmetic Act*. Rockville, MD: US Department of Health and Human Services, Food and Drug Administration, Center for Tobacco Products; 2011.
17. Davis S, Malarcher A, Thorne S, Maurice E, Trosclair A, Mowery P. State-specific prevalence and trends in adult cigarette smoking—United States, 1998–2007. *JAMA*. 2009;302(3):250–252.
18. Arrazola RA, Singh T, Corey CG, et al.; Centers for Disease Control and Prevention (CDC). Tobacco use among middle and high school students—United States, 2011–2014. *MMWR Morb Mortal Wkly Rep*. 2015;64(14):381–385.
19. Zorn CJW. Generalized estimating equation models for correlated data: a review with applications. *Am J Polit Sci*. 2001;45(2):470–490.
20. Moracco KE, Morgan JC, Mendel J, et al. "My first thought was croutons": perceptions of cigarettes and cigarette smoke constituents among adult smokers and nonsmokers. *Nicotine Tob Res*. 2016;18(7):1566–1574.
21. Wiseman KD, Cornacchione J, Wagoner KG, et al. Adolescents' and young adults' knowledge and beliefs about constituents in novel tobacco products. *Nicotine Tob Res*. 2016;18(7):1581–1587.
22. Morgan JC, Byron MJ, Baig SA, Stepanov I, Brewer NT. How people think about the chemicals in cigarette smoke: a systematic review. *J Behav Med*. 2017;40(4):553–564.
23. US Department of Health and Human Services. *Preventing Tobacco Use Among Youth and Young Adults: A Report of the Surgeon General*. Atlanta, GA: Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion; 2012.
24. Duke JC, Farrelly MC, Alexander TN, et al. Effect of a national tobacco public education campaign on youth's risk perceptions and beliefs about smoking. *Am J Health Promot*. 2018;32(5):1248–1256.
25. Velicer C, Aguinaga-Bialous S, Glantz S. Tobacco companies' efforts to undermine ingredient disclosure: the Massachusetts benchmark study. *Tob Control*. 2016;25(5):575–583.
26. Gray N, Borland R. Research required for the effective implementation of the framework convention on tobacco control, articles 9 and 10. *Nicotine Tob Res*. 2013;15(4):777–788.
27. Gottlieb S, Zeller M. A nicotine-focused framework for public health. *N Engl J Med*. 2017;377(12):1111–1114.
28. Borland R, Hill D. Initial impact of the new Australian tobacco health warnings on knowledge and beliefs. *Tob Control*. 1997;6(4):317–325.
29. Hall MG, Ribisl KM, Brewer NT. Smokers' and nonsmokers' beliefs about harmful tobacco constituents: implications for FDA communication efforts. *Nicotine Tob Res*. 2014;16(3):343–350.
30. Centers for Disease Control and Prevention. Health warnings on tobacco products—worldwide, 2007. *MMWR Morb Mortal Wkly Rep*. 2009;58(19):528–529.
31. Noar SM, Francis DB, Bridges C, Sontag JM, Brewer NT, Ribisl KM. Effects of strengthening cigarette pack warnings on attention and

message processing: a systematic review. *Journal Mass Commun Q*. 2017;94(2):416–442.
32. Swayampakala K, Thrasher JF, Hammond D, et al. Pictorial health warning label content and smokers' understanding of smoking-related risks—a cross-country comparison. *Health Educ Res*. 2015;30(1):35–45.
33. Brewer NT, Jeong M, Mendel JR, et al. Cigarette pack messages about toxic chemicals: a randomized clinical trial. *Tob Control*. 2019;28(1):74–80. doi: 10.1136/tobaccocontrol-2017–054112
34. Thrasher JF, Murukutla N, Pérez-Hernández R, et al. Linking mass media campaigns to pictorial warning labels on cigarette packages: a cross-sectional study to evaluate effects among Mexican smokers. *Tob Control*. 2013;22(e1):e57–e65.
35. Brennan E, Durkin SJ, Cotter T, Harper T, Wakefield MA. Mass media campaigns designed to support new pictorial health warnings on cigarette packets: evidence of a complementary relationship. *Tob Control*. 2011;20(6):412–418.