ORIGINAL ARTICLE

E-cigarette use is associated with other tobacco use among US adolescents

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Abstract

Objectives To examine whether tobacco initiation via e-cigarettes increases the likelihood of subsequent tobacco use among a large representative sample of US adolescents.

Methods This study is a retrospective longitudinal analysis from a representative sample of US middle and high school students ($n = 39,718$) who completed the 2014 and 2015 National Youth Tobacco Survey. The adjusted odds ratios of lifetime and current use of tobacco use were estimated by logistic regression analysis while controlling for important socio-ecological factors associated with tobacco use.

Results E-cigarette initiators were more likely to report current use of cigarettes (AOR 2.7; 1.9–4.0, $p < 0.001$), cigars (AOR 1.7; 1.2–2.4, $p < 0.01$), or smokeless tobacco (AOR 3.1; 2.2–5.4, $p < 0.001$), and lifetime use of the same products as well. Also, lifetime and current use of e-cigarettes significantly increased the likelihood of cigarettes, cigars, and smokeless tobacco use.

Conclusions Initiation of tobacco via e-cigarette, lifetime, and current use of e-cigarettes are associated with higher odds of lifetime and current use of cigarettes, cigars, and smokeless tobacco. Collectively this suggests e-cigarettes may lead to an increased use of tobacco among adolescents.

Keywords E-cigarette · Tobacco initiation · Cigarette · Cigar · Smokeless tobacco · Adolescents

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Introduction

Tobacco use continues to be the most preventable cause of premature death in the USA (United States Department of Health and Human Services—HHS 2014). Combating tobacco use among adolescents is key to reducing the global burden of tobacco for several reasons. First, tobacco initiation occurs most often among adolescents and young adults (HHS 2012). Second, some studies suggest that exposure to tobacco during adolescence may have adverse developmental effects on the brain (Smith et al. 2015). Finally, the earlier the age of tobacco initiation during adolescence, the higher the risk of nicotine dependence and failure of smoking cessation later in life (HHS 2012; HHS 2014). Therefore, reducing tobacco use among adolescents has been an important public health objective in the USA, which witnessed considerable success (Center for Disease Control and Prevention—CDC Healthy people 2020 nicotine use report).

Results of the latest National Youth Tobacco Survey (NYTS) indicated that the surge in alternative tobacco products in the USA, mainly electronic cigarettes (e-cigarettes), has offset the observed decline in combustible cigarette use among adolescents (Singh et al. 2016). In the 2011 NYTS, e-cigarettes were the least commonly reported tobacco product (ever use: 1.4% of high school students), but e-cigarette use doubled over the following two survey years. By the 2014 NYTS, e-cigarettes became the most reported tobacco product that was ever used (13.4% among high school students). In the 2015 NYTS, 16% of high school students reported current use of e-cigarettes, about double the reported rate for cigarette use (9.3%), which was also significantly higher than the reported rates for cigar (8.6%), hookah (7.2%), and smokeless tobacco (6.0%) use (Singh et al. 2016). Similar trends were reported in Monitoring the Future National Survey (Johnston et al. 2015).

E-cigarettes are battery-operated devices that people use to inhale an aerosol of nicotine mixed with other ingredients. Its glamourous designs and attractive advertisements might make it particularly attractive for adolescents (Auf et al. 2018). Generally, e-cigarettes have been promoted as a less harmful tobacco product due to the absence of many harmful chemicals that are typically emitted from combustible cigarettes (Patterson et al. 2016; de Andrade et al. 2013). However, some research has indicated that e-cigarettes also contain harmful substances, although at lower levels, that may lead to adverse health outcomes such as cancer and cardiovascular diseases (Jensen et al. 2015; Allen et al. 2016). Additionally, most e-cigarettes contain nicotine, which is the active substance responsible for dependence (Benowitz et al. 2017). Because of nicotine's addictive properties (DiFranza et al. 2002), there is a concern that adolescents using e-cigarettes may later use tobacco products (Dutra and Glantz 2014; Leventhal et al. 2015). Indeed, it has been shown that using one tobacco product is associated with a higher risk of using other tobacco products (Goniewicz et al. 2016; Kandel and Kandel 2014; Leventhal et al. 2015); thus, polytobacco use is becoming the more common form of tobacco use (Kowitt et al. 2015; Butler et al. 2016).

Few studies have investigated whether the use of e-cigarettes is associated with the subsequent increased risk of tobacco initiation among adolescents in the USA (e.g. Leventhal et al. 2015; Primack et al. 2015; Wills et al. 2015; Barrington-Trimis et al. 2016; Unger et al. 2016). In each of these studies, e-cigarettes were associated with a higher risk of initiating tobacco use among never smokers. Also, one study reported that e-cigarette use is associated with recent smoking initiation among US adolescents (Cardenas et al. 2016).

Building on previous research (e.g. Leventhal et al. 2015; Primack et al. 2015; Wills et al. 2015; Barrington-Trimis et al. 2016; Unger et al. 2016), the aim of the present study is to retrospectively examine whether e-cigarette initiation among never tobacco users is associated with increased odds to use other tobacco products including cigarettes, cigars, and smokeless tobacco products from a large representative population of the National Youth Tobacco Survey (NYTS) for 2014 and 2015. Also, we examined the association between e-cigarette use and the use of tobacco products. This study is of public health significance because it examined the relationship between e-cigarettes and other tobacco use. Such potential association might disrupt the tobacco control efforts and warrants further research to inform policy. Also, reporting from the NYTS national representative sample of around 40 thousand US middle and high school students allows generalization of results.

Methods

Study population

The 2014 and 2015 National Youth Tobacco Survey (NYTS) obtained a nationally representative cross-sectional sample of middle and high school students (grades 6–12 with age ranging from 12 to 19 years) using a three-stage cluster probability sampling design without replacement. Non-Hispanic Black and Hispanic/Latino students were oversampled to offer a better opportunity to estimate tobacco use rates among minority populations. Parents or legal guardians consented for their children's participation. A total of 22,007 and 17,711 adolescents participated (91.4% and 87.4%. response rate) from 207 and 185 schools (80.2% and 72.6% response rate) in the 2014 and 2015 surveys, respectively, totalling 39,718 from the 2 years' surveys. All students responded to an anonymous self-administered 81-item, pencil-and-paper questionnaire. The NYTS was designed to inform national and state tobacco prevention and control programs (CDC 2014, 2015).

Ethics statement

The Institutional Review Board at Florida International University deemed the study non-human subjects research because non-identifiable publicly available data were used.

Measures

For simplicity, we will refer to "*cigars, cigarillos, or little cigars*" as "*cigars*" and "*chewing tobacco, snuff, or dip*"

as "smokeless tobacco" throughout this report. Consistent with reports from the Centers for Disease Control and Prevention [CDC], we list e-cigarettes as a tobacco product (Singh et al. 2016). To make the comparison uniform between different tobacco products' definition of use, we did not take into account the number of cigarettes smoked because no similar questions were available for the other included products (e-cigarettes, cigars, and smokeless tobacco). This is consistent with the published reports by the CDC (Singh et al. 2016) and facilitates the comparison of our results with other published research. Participants were asked about lifetime use (*ever*) and current use (*past 30 days*) of cigarettes, cigars, smokeless tobacco, and e-cigarettes. Lifetime and current use of the cigarettes, cigars, and smokeless tobacco was further grouped into at least one product use versus none.

E-cigarette tobacco initiation was defined by responding "*yes*" to a question inquiring whether "*e-cigarette was the first tried tobacco product*". This meant before using e-cigarettes those adolescents were never smokers. E-cigarette initiators were compared to the rest of the population as the comparison group, consistent with previous research (Leventhal et al. 2015). The newly introduced question about smoking initiation method in the 2014 and 2015 NYTS allowed the construction of a retrospective timeline of events within the cross-sectional design; similar methodology was used in the previous research of alcohol use (Sobell and Sobell 1992).

The peer influence on use of a tobacco product was measured by the question "*If one of your best friends were to offer you …. would you smoke it?*", which was available for cigarettes and cigars, but not for smokeless tobacco. Likert-type scale responses "*definitely yes, probably yes, probably no, and definitely no*" were reverse-coded, so higher scores indicated higher probability. Participants were asked to report all tobacco products used at home by household members. We classified any reported e-cigarette, cigarette, cigar, and smokeless tobacco use at home as "household tobacco use".

Covariates included age, race/ethnicity, and gender as detailed in Data Analysis section. We used the readily available recoded question for single race classification and collapsed all categories other than non-Hispanic Whites, non-Hispanic Blacks, and Hispanics/Latinos into "other".

Data analysis

The 2014 and 2015 NYTS data were pooled to examine the association of tobacco initiation via e-cigarettes and subsequent tobacco use by examining retrospective longitudinal events. PROC SURVEY procedure in SAS v9.4 was used to adjust for the survey's complex sampling design. Each survey year's weights and the survey procedures were

applied to account for the stratified clustered sampling design of the NYTS to adjust for nonresponse and the probability of selection and to match the sample's sociodemographic characteristics with those of US middle and high school students in 2014 (CDC 2014).

All the presented percentages were weighted to represent the general population of adolescents from the USA. We used the Chi-square test for categorical variables and t-test for continuous variables, i.e. age at initiation of tobacco product use among different tobacco initiation groups. Comparison of different tobacco initiation groups is given in Table 1. Logistic regression models were used to estimate the odds ratio (OR) and corresponding 95% confidence interval (CI) of tobacco initiation via e-cigarettes, lifetime, and current e-cigarette use associated with lifetime and current use of cigarettes, cigars, and smokeless tobacco as the outcome variable in separate models. The OR and corresponding 95% CI were further adjusted by models that included age, gender, race/ethnicity, probability to smoke the specific tobacco product if offered by a friend, and home (i.e. household) tobacco use in separate models for lifetime and current use of each tobacco product. Using e-cigarettes at home was included to control for parents' (or other household members') influence and accessibility of e-cigarettes. The included covariates are known risk factors for tobacco use among adolescents (Wellman et al. 2018; Veeranki et al. 2017; Cardenas et al. 2015; Tyas and Pederson 1998), which were collected in the NYTS 2014 and 2015. Missing data accounted for $< 5\%$ and were excluded from the analysis, consistent with other published research from the same survey (Dutra and Glantz 2014). Statistical significance was set to 0.05. All tests were two-tailed, and Bonferroni–Holm correction for multiple tests was applied (Holm 1979).

Results

Descriptive analysis

A total of 39,718 adolescents participated in the 2014 and 2015 NYTS with 11,047 (28.3%) lifetime users and 4181 (10.6%) current users of either cigarettes, cigars, or smokeless tobacco (data not shown). A total of 2477 (6.2%), 5057 (12.7%), 1521 (15.0%), and 1055 (2.7%) reported e-cigarettes, cigarettes, cigars, and smokeless tobacco, respectively, as their method for tobacco initiation. E-cigarette initiators were more likely to be younger than other tobacco product initiators (15.1 years vs. 15.6, 16.1, and 15.8 years for cigarettes, cigars, and smokeless tobacco—$p < 0.05$, respectively). There was a higher percentage of Hispanics/Latino who initiated tobacco use

Table 1 Characteristics of adolescents who initiated tobacco via e-cigarettes, cigarettes, cigars, and smokeless tobacco among the participants of the 2014 and 2015 National Youth Tobacco Survey (NYTS), USA

Characteristics[a]	Tobacco use initiation method[b]				Overall[b]
	E-cigarettes	Cigarettes	Cigars	Smokeless	
Respondents, no. (%)[c]	2477 (24.5)	5057 (50.0)	1521 (15.4)	1055 (10.1)	10,110 (100)
Age, mean (SD), years**	15.1 (1.8)	15.6 (1.9)	16.1 (1.8)	15.8 (1.9)	15.5 (1.9)
Gender, no. (%)**					
Male	1319 (52.0)	2466 (46.9)	928 (60.1)	883 (84.7)	5596 (54.4)
Female	1131 (48.0)	2546 (53.1)	584 (39.9)	164 (15.3)	4425 (45.6)
Race, no. (%)**					
White	1153 (56.0)	2456 (57.1)	686 (55.0)	806 (82.3)	5101 (59.4)
Black	243 (9.5)	680 (11.7)	420 (24.2)	34 (2.8)	1377 (12.1)
Hispanic/Latino	859 (26.9)	1452 (23.1)	316 (15.8)	136 (8.7)	2763 (21.3)
Other	123 (3.7)	239 (4.0)	42 (1.8)	29 (2.0)	433 (3.4)
Unknown	99 (3.8)	230 (4.0)	57 (3.3)	50 (4.2)	436 (3.9)
Grade, no. (%)**					
Middle school	860 (31.1)	1210 (22.6)	230 (13.5)	236 (21.3)	2536 (23.1)
High school	1592 (68.9)	3812 (77.3)	1282 (86.2)	813 (78.7)	7499 (76.7)

Data are from the National Youth Tobacco Survey in the USA, 2014 and 2015

**$p < 0.001$

[a]Respondents with missing values were excluded

[b]Percentages (weighted) are by column

[c]Percentages are by row

via e-cigarettes (26.9%) compared to those who initiated via other tobacco products (23.1% of cigarettes, 15.8% of cigars, and 8.7% of smokeless tobacco), but this was not observed among Blacks or Whites. One-third of e-cigarette initiators were middle school students, which is higher than the proportions for cigarette (22.6%), cigars (13.5%), and smokeless tobacco (21.3%) initiators.

Of the 39,718 participants, 8887 (23.4%) and 3973 (10.3%) reported lifetime and current use of e-cigarettes, respectively. A higher percentage of Hispanics and Whites were lifetime and current e-cigarette users compared with other racial/ethnic groups. High school and male students were more likely to be lifetime and current e-cigarette users compared to middle school and female students ($p < 0.001$, Table 2).

Association between tobacco use initiation via e-cigarettes among never tobacco users and subsequent lifetime cigarette, cigar, and smokeless tobacco use

After controlling for age, gender and race/ethnicity and important tobacco product use factors (including peer influence, household use of the underlying tobacco products, and household use of e-cigarettes), e-cigarette initiators had a significantly higher adjusted odds of lifetime use of combustible cigarettes (adjusted OR (AOR); 3.7;

3.1–4.5, $p < 0.001$), cigars (AOR 2.5; 2.0–3.1, $p < 0.001$), smokeless tobacco (AOR 4.1; 2.9–5.7, $p < 0.001$), and any tobacco product (AOR 6.0; 5.1–7.2, $p < 0.001$) (Table 3), compared with never tobacco users.

Association between tobacco use initiation via e-cigarettes among never tobacco users and subsequent current cigarette, cigar, and smokeless tobacco use

There were significant associations between initiation of tobacco use via e-cigarettes and current use of cigarettes (AOR 2.7; 1.9–4.0, $p < 0.001$), cigars (AOR 1.7; 1.2–2.4, $p < 0.01$), smokeless tobacco (AOR 3.4; 2.2–5.4, $p < 0.001$), and any tobacco products (AOR 4.4; 3.5–5.6, $p < 0.001$) in comparison with never tobacco users (Table 4).

Association of important covariates with lifetime and current tobacco use in the adjusted model for those who initiated tobacco use via e-cigarettes

Peer influence was consistently associated with lifetime cigarette (AOR 4.5, $p < 0.001$), cigar use (AOR 6.5, $p < 0.001$) as well as current cigarette (AOR 7.7, $p < 0.001$) and cigar use (AOR 6.5, $p < 0.001$) (Tables 3

Table 2 Characteristics of lifetime and current e-cigarette users among the participants of the 2014 and 2015 National Youth Tobacco Survey (NYTS), USA

Characteristics	All[a, c]	E-cigarette use[b,c]	
		Lifetime	Current
Respondents, no. (%)	39,718 (100)	8887 (23.4)	3973 (10.3)
Age, mean (SD), years	14.5 (2.1)	15.6 (1.9)**	15.7 (1.8)**
Gender, no. (%)			
Male	20,108 (50.7)	4925 (25.4)**	2327 (11.8)**
Female	19,267 (49.3)	3888 (21.5)	1605 (8.7)
Race, no. (%)			
White	18,375 (54.7)	4305 (23.9)**	2022 (10.9)**
Black	5971 (14.0)	994 (17.6)	335 (5.8)
Hispanic/Latino	10,930 (21.7)	2828 (27.8)	1264 (12.1)**
Other	2421 (4.6)	410 (19.9)	191 (9.6)
Unknown	2021 (4.9)	350 (18.7)	161 (8.8)
Grade, no. (%)			
Middle school	18,589 (44.0)	2270 (11.8)**	958 (4.6)**
High school	20,832 (55.9)	6543 (32.5)	2974 (14.7)
Unknown	36 (0.1)	13 (51.9)	9 (39.5)
Lifetime use of cigarette, no. (%)			
Never	30,390 (77.9)	3262 (11.2)**	1161 (3.9)
Lifetime	8569 (22.1)	5409 (66.5)	2694 (32.8)
Current use cigarette, no. (%)			
Nonuser	36,374 (93.7)	6611 (19.2)**	2455 (7.0)**
Current	2473 (6.3)	1947 (81.8)	1327 (55.6)
Lifetime use of cigars, no. (%)			
Never	32,075 (82.6)	4336 (14.0)**	1557 (4.8)
Lifetime	6714 (17.4)	4309 (67.0)	2282 (35.2)
Current use of cigars, no. (%)			
Nonuser	36,254 (94,5)	6923 (19.9)**	2642 (7.4)
Current	2200 (5.5)	1567 (75.6)	1085 (52.7)
Lifetime use of smokeless tobacco, no. (%)			
Never	35,805 (91.7)	6674 (19.2)**	2693 (7.6)
Lifetime	3076 (8.3)	2057 (69.7)	1170 (39.3)**
Current use of smokeless tobacco, no. (%)			
Nonuser	37,613 (96.2)	7802 (21.4)**	3200 (8.6)**
Current	1401 (3.8)	998 (75.1)	710 (52.0)

Ever use indicates lifetime trial and current use indicates past 30 days use

Data are from the National Youth Tobacco Survey in the USA, 2014 and 2015

**$p < 0.001$

[a]Percentages are by column

[b]Percentages are by row

[c]All percentages are weighted

and 4). Notably, household e-cigarette use was associated with lifetime (AOR 1.8, $p < 0.01$) and current (AOR 2.2, $p < 0.001$) cigarette use, and lifetime (AOR 1.5, $p < 0.01$) and current cigar use (AOR 1.7, $p < 0.01$). As expected, household use of cigarettes was associated with lifetime (AOR 1.7, $p < 0.001$) and current use (AOR 2.1, $p < 0.001$) of cigarettes among adolescents. Household use

of cigars was associated with lifetime (AOR 2.2, $p < 0.001$) and current use (AOR 2.7, $p < 0.001$) of cigars. Likewise, household use of smokeless tobacco was associated with lifetime (AOR 2.7, $p < 0.001$) and current use (AOR 3.5, $p < 0.001$) of smokeless tobacco (Tables 3 and 4—tobacco initiation model).

Table 3 Association of smoking initiation via e-cigarettes and e-cigarette use (main covariate) with lifetime use of cigarettes, cigars, and smokeless tobacco (outcomes) from the participants of the 2014 and 2015 National Youth Tobacco Survey (NYTS), USA

Lifetime use	At least one OR (95% CI)	Cigarettes OR (95% CI)	Cigars OR (95% CI)	Smokeless tobacco OR (95% CI)
Adjusted models[a]				
Initiation via e-cigarette model[a]				
Initiation via e-cigarette	6.0 (5.1–7.2)**	3.7 (3.1–4.5)**	2.5 (2.0–3.1)**	4.1 (2.9–5.7)**
Age (per year)	1.4 (1.3–1.4)**	1.3 (1.3–1.4)**	1.5 (1.4–1.6)**	1.3 (1.2–1.4)**
Male (ref = female)	1.3 (1.1–1.5)**	1.3 (1.1–1.5)**	1.2 (1.0–1.4)	3.0 (2.2–4.2)**
Race				
White	1	1	1	1
Black	2.5 (2.0–3.1)**	2.1 (1.7–2.7)**	3.2 (2.5–4.2)**	1.1 (0.7–1.8)
Hispanic/Latino	2.0 (1.7–2.3)**	2.0 (1.7–2.4)**	1.6 (1.4–2.0)**	1.3 (1.0–1.6)*
Peer influence	–	4.5 (4.0–5.2)**	6.2 (5.4–7.1)**	–
Household e-cigarette use	1.7 (1.4–2.0)**	1.8 (1.4–2.2)**	1.5 (1.2–1.8)*	1.9 (1.3–2.8)*
Household use of outcome product[b]	1.7 (1.5–1.9)**	1.7 (1.4–2.0)**	2.2 (1.7–2.8)**	2.7 (2.0–3.7)**
Lifetime e-cigarette use model[a]				
Lifetime e-cigarette use	12.9 (11.8–14.1)**	7.3 (6.6–8.0)**	5.7 (5.1–6.3)**	7.8 (6.5–9.4)**
Age (per year)	1.39 (1.36–1.44)**	1.3 (1.3–1.4)**	1.5 (1.4–1.5)**	1.3 (1.2–1.3)**
Male (ref = female)	1.3 (1.2–1.4)**	1.1 (1.0–1.2)*	1.4 (1.2–1.5)**	4.5 (3.8–5.3)**
Race				
White	1	1	1	1
Black	1.6 (1.3–1.9)**	1.5 (1.3–1.8)**	2.3 (2.0–2.8)**	0.3 (0.2–0.4)**
Hispanic/Latino	1.1 (1.0–1.2)	1.2 (1.1–1.4)**	1.0 (0.9–1.1)	0.5 (0.4–0.6)**
Peer influence	–	4.5 (4.2–4.9)**	5.5 (5.0–6.1)**	–
Household e-cigarette use	1.1 (0.9–1.2)	1.2 (1.0–1.3)*	0.9 (0.8–1.1)	0.9 (0.8–1.1)
Household use of the outcome product[b]	2.4 (2.2–2.6)**	2.2 (2.0–2.4)**	2.7 (2.3 –3.1)**	4.9 (4.0–6.1)**
Current e-cigarette use adjusted model[a]				
Current e-cigarette use	11.4 (10.1–13.0)**	4.6 (4.1–5.3)**	4.1 (3.6–4.7)**	6.2 (5.3–7.2)
Age (in years)	1.5 (1.4–1.5)**	1.4 (1.35–1.44)**	1.5 (1.5–1.6)**	1.3 (1.3–1.4)**
Male (Ref = female)	1.3 (1.2–1.4)**	1.1 (1.0–1.3)*	1.4 (1.2–1.5)**	4.4 (3.6–5.3)**
Race				
White	1	1	1	1
Black	1.4 (1.2–1.7)**	1.5 (1.2–1.7)**	2.1 (1.8–2.5)**	0.3 (0.2–0.4)**
Hispanic/Latino	1.2 (1.1–1.3)**	1.3 (1.2–1.5)**	1.1 (1.0–1.2)	0.6 (0.5–0.7)**
Peer influence	–	5.4 (5.0–5.9)**	6.4 (5.8–7.2)**	–
Household e-cigarette use	1.4 (1.2–1.5)**	1.4 (1.3–1.6)**	1.1 (0.9–1.2)	1.0 (0.8–1.2)
Household use of the outcome product[b]	2.6 (2.4–2.8)**	2.3 (2.1–2.6)**	2.6 (2.3–3.0)**	5.2 (4.3–6.4)**

Data are from the National Youth Tobacco Survey in the USA, 2014 and 2015

*$p < 0.05$ **$p < 0.001$

[a]All OR are weighted. Columns represent the outcome of the three logistic regression models with titles in bold italic text

[b]The variable "Household use of the outcome product" refers to the outcome tobacco products in the columns

Association between e-cigarette use and smoking cigarettes, cigars, and smokeless tobacco (lifetime and current)

Lifetime and current e-cigarette users (irrespective of their method of initiation) were consistently more likely to be lifetime or current users of cigarettes, cigars, smokeless tobacco, or at least one of the three products compared to non-e-cigarette users (Tables 3 and 4). The association of ever and current e-cigarette use with lifetime and current use of the examined tobacco products was significant after adjusting for other risk factors (Tables 3 and 4).

Table 4 Association of initiation via e-cigarettes and e-cigarette use (main covariate) with current use of cigarettes, cigars, and/or smokeless tobacco (outcomes) from the participants of the 2014 and 2015 National Youth Tobacco Survey (NYTS), USA

Current use	At least one OR (95% CI)	Cigarettes OR (95% CI)	Cigars OR (95% CI)	Smokeless tobacco OR (95% CI)
Adjusted models[a]				
Initiation via e-cigarette model[a]				
Initiation via e-cigarette	4.4 (3.5–5.6)**	2.7 (1.9–4.0)**	1.7 (1.2–2.4)*	3.4 (2.2–5.4)**
Age (per year)	1.4 (1.4–1.5)**	1.3 (1.2–1.5)**	1.4 (1.3–1.6)**	1.3 (1.3–1.5)**
Male (ref = female)	1.8 (1.4–2.3)**	1.6 (1.2–2.2)*	1.7 (1.2–2.2)*	3.6 (2.3–5.6)**
Race				
White	1	1	1	1
Black	1.7 (1.3–2.4)**	1.5 (1.0–2.4)	2.7 (1.8–3.9)**	1.4 (0.8–2.5)
Hispanic/Latino	1.9 (1.5–2.3)**	2.1 (1.5–2.9)**	1.8 (1.2–2.6)**	1.7 (1.3–2.4)*
Peer influence	–	7.7 (6.6–8.9)**	6.5 (5.7–7.4)**	–
Household e-cigarette use	2.0 (1.5–2.5)**	2.2 (1.5–3.4)**	1.7 (1.0–2.8)*	1.5 (0.9–2.3)
Household use of the outcome product	2.1 (1.7–2.5)**	2.1 (1.5–2.8)**	2.7 (1.8–4.0)**	3.5 (2.3–5.5)**
Lifetime e-cigarette use model[a]				
Lifetime e-cigarette use	9.4 (8.2–10.8)**	5.4 (4.4–6.5)**	3.9 (3.3–4.7)**	8.2 (6.4–10.5)**
Age (per year)	1.4 (1.3–1.4)**	1.3 (1.2–1.3)**	1.3 (1.3–1.4)**	1.2 (1.2–1.3)
Male (ref = female)	1.9 (1.7–2.2)**	1.4 (1.2–1.6)**	1.5 (1.3–1.7)*	5.5 (4.3–7.0)**
Race				
White	1	1	1	1
Black	1.0 (0.8–1.2)	0.9 (0.7–1.3)	2.3 (1.8–3.1)**	0.3 (0.2–0.5)**
Hispanic/Latino	0.8 (0.7–0.9)**	1.0 (0.8–1.3)	1.3 (1.1–1.5)*	0.6 (0.5–0.7)**
Peer influence	–	6.7 (6.1–7.3)**	4.0 (3.7–4.4)**	–
Household e-cigarette use	1.1 (0.9–1.2)	1.2 (1.0–1.4)	1.0 (0.8–1.3)	0.8 (0.6–0.99)*
Household use of the outcome product	2.3 (2.0–2.6)	2.4 (2.0–2.8)**	3.2 (2.5–4.0)	5.5 (4.4–7.0)**
Current e-cigarette use model[a]				
Current e-cigarette use	11.0 (9.7–12.5)**	5.2 (4.4–6.2)**	5.0 (4.2–6.0)**	9.4 (7.4–11.9)**
Age	1.4 (1.4–1.5)**	1.3 (1.3–1.4)**	1.4 (1.3–1.4)**	1.3 (1.2–1.4)**
Male (ref = female)	1.9 (1.7–2.2)**	1.3 (1.1–1.6)**	1.5 (1.2–1.7)**	5.5 (4.2–7.2)**
Race				
White	1	1	1	1
Black	(0.8–1.2)	0.9 (0.7–1.2)	2.4 (1.8–3.0)**	0.4 (0.3–0.6)**
Hispanic/Latino	0.9 (0.8–1.0)	1.1 (0.9–1.3)	1.3 (1.1–1.6)**	0.6 (0.5–0.8)**
Peer influence	–	7.0 (6.4–7.6)**	4.1 (3.8–4.4)**	–
Household e-cigarette use	1.0 (0.8–1.1)	1.1 (0.9–1.4)	0.9 (0.7–1.2)	0.7 (0.5–0.9)*
Household use of the outcome product	2.7 (2.4–3.0)**	2.6 (2.2–3.1)**	3.4 (2.7–4.2)**	6.7 (5.3–8.6)**

Data are from the National Youth Tobacco Survey in the USA, 2014 and 2015

*p < 0.05, **p < 0.001

[a] All OR are weighted. Columns represent the outcome of the three logistic regression models with titles in bold italic text

[b] The variable "Household use of the outcome product" refers to the outcome tobacco products in the columns

Discussion

Using a nationally representative sample, our results indicate that e-cigarette initiation among never tobacco users is associated with an increased likelihood of tobacco initiation among US adolescents. Our findings are consistent with other published studies (Leventhal et al. 2015; Primack et al. 2015; Wills et al. 2015; Barrington-Trimis et al.

2016; Unger et al. 2016) and a larger representative sample that allows the generalization of the results.

One study reported that adolescents who initiated tobacco use via cigarettes were more likely to be lifetime and current users of e-cigarettes as reported elsewhere (Leventhal et al. 2015). Therefore, a bidirectional relationship between cigarette and e-cigarette use is possible. The bidirectional association of e-cigarette and other

tobacco products can be explained by having common socio-ecological risk factors (Leventhal et al. 2015). Some putative direct and indirect mechanisms might be contributing to the shift from e-cigarette to the use of tobacco products or dual use (Auf et al. 2016). Directly, this can be attributed to the nicotine gateway mechanism given nicotine is the active substance in all tobacco products, leading users to shift between different products (Kandel and Kandel 2014). However, given that the relationship between e-cigarettes and other tobacco products might be bidirectional (i.e. no specific order is required) and can be attributed to other factors beyond nicotine (detailed later) such as socioeconomic background (Wellman et al. 2018), the common liability theory (i.e. common risk factors are shared between e-cigarette and other tobacco use that would lead to switching between them in a non-specific order) might be a good fit to describe the observed association (Vanyukov et al. 2012; Mayet et al. 2016; Van Leeuwen et al. 2011). Also, this might explain that dual use of e-cigarettes and cigarettes was reported to be the most common form compared to the single use of the two products (Goniewicz et al. 2016).

Our results indicate that, on average, adolescents who reported initiation via e-cigarettes were significantly younger compared with those who reported initiating tobacco use via cigarettes, cigars, and smokeless tobacco products. One possible explanation is that e-cigarettes were not as highly regulated as a tobacco product when the underlying survey was conducted. Therefore, adolescents could more easily access them at an earlier age compared to regulated tobacco products. It will be important to reexamine this observation for the time period after the FDA began regulating e-cigarettes as tobacco products. Nevertheless, the younger age of e-cigarette initiators combined with the increasing prevalence of e-cigarettes among adolescents (Singh et al. 2016; CDC 2015) warns of e-cigarettes potentially becoming a gateway for initiating other tobacco products, and possibly substance use, based on the direct nicotine pathway and common liability theory. Such mechanisms lend themselves as a support to the observed increasingly common polytobacco use reported in several studies (Kowitt et al. 2015; Butler et al. 2016). In other words, the commonly observed polytobacco use supports the hypothesis that using one tobacco product is a gateway to using other tobacco products, which provides plausibility and coherence to our findings.

The indirect mechanisms, contributing to the shift from e-cigarettes to other tobacco products or dual use, may include tobacco marketing messages (Padon et al. 2017; Auf et al. 2018), renormalization of tobacco use within public spaces, and societies (Fairchild et al. 2014), while sale restrictions have proven to be not fully effective in controlling adolescents' tobacco use (Utah Department Of Health—UDOH—2013; Simons-Morton and Farhat 2010; Ahmad and Billimek 2007). Therefore, a rebound increase in tobacco use might be observed over the coming years if the prevalence of e-cigarettes continues to escalate (Auf et al. 2016) among adolescents in the USA (CDC 2015; Singh et al. 2016) and other parts of the globe (e.g. South Korea) (Lee et al. 2014). If this were to occur, it could potentially reverse decades of tobacco control and increase the prevalence of tobacco use.

The younger age of e-cigarette initiators compared to those who initiated tobacco use via cigarettes, cigars, or smokeless tobacco is problematic for several considerations. Exposure to nicotine during the period of adolescence leads to structural changes in the brain enhancing the vulnerability to nicotine dependence (Dwyer et al. 2009). In developed countries, nicotine dependence manifests early among adolescents (DiFranza et al. 2011). Therefore, the younger age of initiation among e-cigarette users would increase their risk of nicotine dependence. Nicotine dependence at an early age may hinder the opportunity to quit tobacco products later on in life (DiFranza et al. 2002, 2011). Also, adolescence is a critical period in brain development. Exposure to nicotine during this period might lead to brain structural changes increasing the vulnerability to nicotine dependence and disrupt the dopamine and serotonin transporter leading to mood disorders and subsequently lower likelihood of quitting smoking and transition into heavier smoking (Dwyer et al. 2009).

Interestingly, in the adjusted model testing for the effect of initiation via e-cigarettes on subsequent tobacco use, we reported a new association between household e-cigarette use and tobacco initiation, but it was not consistently found in the models testing for lifetime and current e-cigarette use. One possible explanation is that household use of e-cigarettes may increase the likelihood of an adolescent initiating tobacco use via e-cigarette and then shifting to other tobacco products. This suggests that promoting e-cigarettes for adults as a smoking cessation tool might increase the likelihood of adolescent tobacco use. It was reported that second-hand smoking mediates the increase in e-cigarette uptake (Zhang and Pu 2016); therefore, it can be said that household use of any tobacco product might increase the likelihood of use of various tobacco products among adolescents (Veeranki et al. 2017). Consistent with published research (Veeranki et al. 2017; Cardenas et al. 2015; Tyas and Pederson 1998), peer influence and smoking practice at home are significant factors associated with tobacco use. This underscores the interplay between known risk factors of tobacco use and e-cigarettes, which further complicates tobacco control efforts.

The adjusted models included possible socio-ecological factors (e.g. gender, age, race/ethnicity, peer influence, and household tobacco use) that might influence tobacco use

(Veeranki et al. 2017; Cardenas et al. 2015; Tyas and Pederson 1998), yielding robust statistically significant associations. Due to the representative nature of the sample, the reported odds ratio provides a national estimate of the odds of tobacco initiation among never tobacco users who were first exposed to e-cigarettes. E-cigarette use among adolescents was not as prevalent in the previous studies as in the NYTS 2014 and 2015; therefore, this study is important.

The current study has some limitations. The analysis was bound by the available variables in NYTS; therefore, it did not allow including other variables. Those who initiated cigarettes, cigars, and smokeless tobacco later on might have done so with or without the preceding e-cigarette initiation (i.e. adolescence is the time when most smokers initiate smoking). However, the referred to five published cohort studies suffered from similar limitations. Also, despite the limitations of causal inference from cross-sectional design, our estimated adjusted odds ratio for cigarette, cigar, and smokeless tobacco initiation was within the range of previously published research, which underscores the consistency of our results with similar research supporting a possible causal relationship. Recall bias is possible, and the exact age of initiation could not be ascertained for all products.

In conclusion, the results suggest that initiation of tobacco via e-cigarettes, its lifetime, and current use are associated with higher odds to use cigarettes, cigars, and smokeless tobacco. Such findings suggest that e-cigarettes might disrupt tobacco control efforts among adolescents. Future studies should focus on progression to current tobacco use, intensity to smoke, and difficulty of quitting among e-cigarette initiators and e-cigarette users.

Compliance with ethical standards

The study was approved by Florida International University Institutional Review Board (see methods sections for details).

Conflict of interest The authors report no conflict of interest.

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