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School-level prevalence and predictors of e-cigarette use in 8th, 10th, and 12th grade U.S. youth: Results from a national survey (2015–2016)

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Abstract

Purpose: The aim of this study is to examine the school-level prevalence and predictors of e-cigarette use among U.S. adolescents.

Methods: The Monitoring the Future study is an annual national cross-sectional study of secondary (middle and high) school students. This study uses 2015 and 2016 survey data from 8th, 10th, and 12th grade students (n=38,926) attending 580 U.S. public and private secondary schools. E-cigarette use, binge drinking, cigarette smoking, marijuana use, and nonmedical prescription drug use were measured at the individual-level. School-level characteristics were measured with both aggregated student-level measures (e.g., school-level e-cigarette use, school-level racial/ethnic composition) and school characteristics (e.g., public/private, urbanicity).

Results: The prevalence of past-month e-cigarette use varied considerably across 580 U.S. middle and high schools, ranging from 0% to 60% at individual schools (Mean=10.2%,

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SD=8.9%). Multivariable regression analyses indicated that past-month e-cigarette use was significantly higher at schools with a higher proportion of White students, schools that were located in the U.S. Southern and Western regions, and schools with higher prevalence of past-month cigarette smoking, after controlling for relevant individual-level and school-level covariates.

Conclusions: E-cigarette use varies considerably across schools and this study suggests school context plays an important role in e-cigarette use. Cigarette smoking and e-cigarette use at the school level are closely linked and important risk factors for individual level e-cigarette use. The wide variation in prevalence of e-cigarette use highlights the need for schools to assess their own student body to guide prevention efforts rather than relying solely on state or national results.

Keywords

Epidemiology; E-cigarette; Cigarette Smoking; Adolescent; Schools; Socio-Environmental Context

Introduction

Cigarette smoking among adolescents in the U.S. has steadily decreased over the past four decades; however, U.S. adolescents are now using more e-cigarettes than traditional cigarettes [1], raising new public health concerns. More than one in every four U.S. high school students has used e-cigarettes in the past 30 days [1]. To date, the vast majority of research focused on e-cigarette use among adolescents has been at the individual-level and not at the school-level. Individual-level differences involved adolescents' ages, race/ethnicity, and sex [1–3]. White, male, and older adolescents have generally reported higher prevalence of e-cigarette use [1–3]. While individual-level differences are important when considering e-cigarette use among adolescents, the socio-contextual influences need further investigation. Prior research has shown significant school-level differences in cannabis, tobacco, and prescription drug misuse [4–7]. For instance, Morean and colleagues reported significant variation in the use of e-cigarettes to vaporize cannabis between six high schools in southeastern Connecticut [4]. The authors concluded that more research is needed to examine school-level characteristics that may account for e-cigarette variation between schools [4].

Despite several calls for more attention to school-level socio-contextual influences in adolescent substance use research [4,5,8–11], studies have largely neglected secondary school-level environments and their associations with e-cigarette use among U.S. students. At least one study has shown the importance of identifying correlates associated with secondary (middle and high) schools with high prevalence of e-cigarette use [12]. Expectations for future use were higher and perceived risk was lower among adolescent e-cigarette abstainers from medium- and high-use schools versus abstainers from low-use schools [12]. Moreover, regional differences in e-cigarette use have been documented among 8th and 10th graders [1,2,13], and more generally, researchers found that e-cigarette use decreases as population density increases [13].

There is a critical need to systematically examine socio-contextual level factors associated with e-cigarette use based on the rapid increase in this behavior among adolescents. Peer

influences are particularly important during adolescence and interventions must take into account both individual-level and school-level modifiable risk factors. The current study uses data from the Monitoring the Future (MTF) study, a multi-cohort survey of a nationally representative sample of secondary school students in the 8th, 10th, and 12th grades. The main objectives of this study were to: (1) examine school-level prevalence of e-cigarette use within a large national sample and (2) identify the risk factors of e-cigarette use in relation to school-level characteristics (e.g., public vs. private, urban vs. rural, school-level racial composition, and school-level prevalence of cigarette smoking).

Methods

Design

The MTF study is an annual self-administered survey with a nationally representative sample of 8th, 10th, and 12th grade students in U.S. secondary schools in the United States [1]. The 12th grade sample has been collected since 1975, and the 8th and 10th grade sample have been collected since 1991 [1]. The MTF study uses a three-stage sampling procedure which yields an overall cross-sectional sample of roughly 400 public and private schools (unique schools are sampled separately for 8th, 10th, and 12th grade respondents), with about 47,500 secondary school students each year. Roughly 350 students in each school (for the targeted grade) are selected to participate (either by randomly sampling entire classrooms or by some other unbiased, random method). In schools with a smaller number of students, the usual procedure is to include all of the students (for the targeted grade) to participate in the survey. The average response rates for the samples used for this study were 89.5% for 8th graders (i.e., 2015=89%, 2016=90%), 87.5% for 10th graders (i.e., 2015=87%, 2016=88%), and 81.5% for 12th graders (i.e., 2015=83%, 2016=80%). The MTF project design, protocol, and sampling methods are described in greater detail elsewhere [1].

Participants

The present study uses the 2015 and 2016 MTF samples; questions regarding past-month e-cigarette use were introduced in 2015. The 2015 and 2016 sample was composed of 90,365 students in 580 unique public and private schools. The breakdown of schools was 218 8th grade schools, 176 10th grade schools, and 186 12th grade schools. On average, there were 115 students (SD=87.9) per 8th grade school, 136 students (SD=84.1) per 10th grade school, and 109 students (SD=84.1) per 12th grade school. The analytic sample of students consisted of 10,899 8th graders, 10,438 10th graders, and 17,589 12th graders. Past-month e-cigarette use was only asked on two of four randomly assigned survey forms for 8th and 10th graders, and four of six randomly assigned survey forms for 12th graders. Thus, the total number of respondents for the analytic sample was 38,926.

Measures

Individual-level sociodemographic characteristics included several measures at the student-level such as sex (male/female); race/ethnicity (White, African-American, Hispanic, Asian, other); highest level of parental education (at least one parent has a college degree or higher versus both parents have less than a college degree); and grade point average (i.e., average grade of a C+ or lower versus has an average grade of a B- or higher).

Individual-level e-cigarette use was assessed by asking respondents ‘During the last 30 days, on how many days have you used electronic cigarettes (e-cigarettes)?’ Response options ranged from ‘0 days’ to ‘20–30 days’. Binge drinking was measured by asking respondents to indicate, regarding the last two weeks, ‘How many times have you had five or more drinks in a row?’ Response options ranged from ‘None’ to ‘Ten or more times’. Cigarette smoking was measured by having respondents indicate how frequently they smoked cigarettes during the past 30 days. Response options ranged from ‘Not at all’ to ‘Two packs or more per day’. Marijuana use was measured by having respondents indicate on how many occasions they used marijuana (weed, pot) or hashish during the last 30 days?’ Response options ranged from ‘0 occasions’ to ‘40 or more occasions’. Nonmedical prescription drug use during the past 30 days was measured with a combination of four separate questions that asked respondents the number of occasions they used the following medications without a doctor’s orders: amphetamines, opioid analgesics, sedatives, and tranquilizers. The response categories for all four prescription drug classes ranged from ‘0 occasions’ to ‘40 or more occasions’. All substance use variables were recoded as binary (yes/no) variables.

School-level characteristics were assessed with a set of questions aimed at both the school-level and aggregated from measures at the student-level consistent with previous work [10,11,14]. The items at the school-level included public or private, urbanicity (i.e., rural, suburban, urban), region (i.e., Northeast, Midwest, South, West), and school size (based on the number of students sampled within schools: small school [62 or less sampled students], medium school [63 to 151 sampled students], and large school [152 or more sampled students]). Aggregated measures were created to equally divide the full sample of schools into tertiles in order to have adequate sample sizes at the school-level – note that the upper ranges (higher-end tertiles) represent the highest prevalence/percentage within the sample of schools (e.g., percent cigarette use at the school-level – the highest school prevalence rate in the sample was 48%). As shown in Table 1, the school-level characteristics that were aggregated from the student-level measures included: the percent of the student body with a C+ or lower (i.e., low [0%–11%], medium [12%–20%], high [21%–70%]), percent of the student body that was male (i.e., low [0%–46%], medium [47%–51%], high [52%–100%]), percent of the student body that had at least one parent with a college degree or higher (i.e., low [0%–44%], medium [45%–63%], high [64%–100%]), and the percent of the student body that was white (i.e., low [0%–55%], medium [56%–89%], high [90%–100%]).

School-level substance use was estimated from student-level variables and included the percent of the student body that used e-cigarettes during the past-month (this variable was treated as continuous at the school-level), the percent of the student body that engaged in binge drinking during the past two weeks (i.e., low [0%–5%], medium [6%–12%], high [13%–58%]), the percent of the student body that smoked cigarettes during the past-month (i.e., low [0%–2%], medium [3%–7%], high [8%–48%]), the percent of the student body that used marijuana during the past-month (i.e., low [0%–7%], medium [8%–16%], high [17%–75%]), and the percent of the student body that nonmedically used prescription drugs during the past-month (i.e., low [0%–2%], medium [3%–4%], high [5%–31%]). Similar to the aggregated school-level sociodemographic characteristics, the categorizations based on the aggregated measures were equally divided into tertiles. Two additional covariates included at both the student- and school-level were cohort year (i.e., survey conducted in

2015 or 2016) and grade-level of student (i.e., 8th, 10th, and 12th grade). Given that the schools for 8th, 10th, and 12th grade respondents were sampled separately, we accounted for grade-level at both the student- and school-level either by stratifying or including grade-level as a covariate.

Analyses

All analyses at the student-level fully accounted for the MTF sampling weights and complex sampling design when estimating parameters for the target MTF student-level population. As the study is designed to be nationally representative of students, not schools, we do not have school-level weights and the analyses assessing *only* school-level characteristics did not include student-level weights or the design variables.

First, we performed descriptive analyses assessing the prevalence of past 30 day e-cigarette use by assessing the mean prevalence rate across schools stratified by 8th, 10th, and 12th grade (Figure 1; these estimates were unweighted). Second, we assessed the association between the mean prevalence of past-month e-cigarette use across schools and the key school-level characteristics discussed above (see Table 1 for more information on the school-level characteristics). Given that we treat the mean prevalence (i.e., a proportion that ranges between 0 and 1) of e-cigarette use as continuous at the school-level, Wald Chi-Square tests (based on fractional outcome regression [probit]) were used to assess whether prevalence of e-cigarette use significantly varied by school-level characteristics. Moreover, an examination of the association between past-month e-cigarette use and student-level characteristics was assessed at the student-level (design-adjusted Rao-Scott Chi-square tests were used to assess these associations given that e-cigarette use was treated as a dichotomous variable at the student-level). Third, binary logistic and multivariable logistic regression models were fitted to estimate the association between past-month e-cigarette use (at the student-level) and the student- and school-level characteristics. Design-based approaches and robust standard errors were used when fitting these models to help correct for bias due to clustering within schools. Accordingly, the binary logistic regression models provide odds ratios (OR) and 95% confidence intervals, and the multivariable logistic regression model provides adjusted odds ratios (AOR) and 95% confidence intervals in order to assess the association between the covariates and the main outcome (i.e., past 30-day e-cigarette use at the student-level). It should be noted that all of the descriptive analyses (i.e., Tables 1 through 3) use Stata 15.0, while the binary logistic and multivariable logistic regression used Mplus version 8 (i.e., Table 4). Given that roughly 23.4% of the sample was excluded in the full multivariable models when assessing past-month e-cigarette use at the student-level due to missing data, Mplus was used to estimate missing data using full information maximum likelihood estimation. Results from the analyses using listwise deletion created similar results (results can be provided upon request).

Results

There was wide variation in the prevalence of past-month e-cigarette use across U.S. secondary schools (Figure 1). Across schools, the percent of the student body that used e-cigarettes in the past 30 days ranged from 0% to 60%, with an average prevalence across

schools of 10.8% (SD = .089). The mean school-level prevalence of past-month e-cigarette use reached higher levels among U.S. high schools (e.g., 14.3% based on 12th grade schools, SD = .09; values range between 0% and 50%) than U.S. middle schools (e.g., 6.7% based on 8th grade schools, SD = .07; values range between 0% and 40%) (Supplemental Figures 1–3).

The percent of the student body that reported past-month e-cigarette use across schools differed significantly as a function of several school-level socio-contextual characteristics (Table 2). Among the sample of 8th grade schools, school-level prevalence of e-cigarette use was highest among public schools (8.1%), schools located in rural areas (8.0%), schools with a higher number of students (8.5%), schools located in the Southern region of the U.S. (8.4%), schools with a high percentage of students who indicated having poor grades (8.8%), and schools with a low percentage of students who have at least one parent who obtained a university degree (9.0%). Among the sample of 10th grade schools and 12th grade schools, schools with a higher percentage of white students had the highest prevalence of e-cigarette use at the school-level (14.4% and 17.1%, respectively). Moreover, 12th grade schools with a moderately higher percentage of students who had at least one parent who obtained a college degree had a higher prevalence of e-cigarette use at the school-level (17.0%).

With respect to school-level substance use characteristics, schools with a high mean prevalence of binge drinking and cigarette smoking had a higher mean school-level prevalence of past-month e-cigarette use than schools with a lower mean prevalence of binge drinking and cigarette smoking (see Table 2). For instance, the average school-level prevalence for e-cigarette use was 17% for 10th grade schools with a high proportion of cigarette smoking relative to 7% for schools with a low proportion of cigarette smoking. These patterns were less consistent across schools with respect to marijuana and nonmedical prescription drug use at the school-level.

As shown in Table 3, the prevalence of past-month e-cigarette use differed significantly as a function of several student-level characteristics. Prevalence of past-month e-cigarette use was higher for secondary school students who were male, White, had grade point averages of C+ or below, binge drank in the past two weeks, smoked cigarettes in the past-month, used marijuana in the past-month, and reported nonmedical prescription drug use in the past-month.

As illustrated in Table 4, multivariable logistic regression analyses confirmed many of the bivariate associations at the student-level (refer to bivariate models and Full Model 1 in Table 4). Only parental level of education failed to reach statistical significance. In particular, substance use at the student-level was strongly associated with past-month e-cigarette use. For instance, the odds of past-month e-cigarette use was 4.8 times greater (AOR=4.83; 95% CI=4.24, 5.42, $p<0.001$) among students who reported past-month cigarette smoking when compared to their peers who did not smoke cigarettes.

With respect to the school-level characteristics, there were several consistent associations with e-cigarette use, with and without controlling for student- and school-level

characteristics (refer to bivariate models and Full Model 1 in Table 4). First, students who attended schools with a higher percentage of White students (AOR=1.25; 95% CI=1.04, 1.46, $p<0.05$) had higher odds of past-month e-cigarette use when compared to students who attended schools with the lowest percentage of White students. Second, students who attended schools with the highest prevalence of past-month cigarette smoking had higher odds of past-month e-cigarette use (High prevalence of cigarette smoking, AOR=1.54; 95% CI=1.24, 1.84, $p<0.001$; Medium prevalence of cigarette smoking, AOR=1.35; 95% CI=1.12, 1.58, $p<0.001$) than students who attended school with the lowest prevalence of past-month cigarette smoking.

Additional models also assessed the association between school-level e-cigarette use and student-level e-cigarette use (refer to bivariate models and Full Model 2 in Table 4). Accordingly, students who attended schools with the highest prevalence of past-month e-cigarette use had higher odds of past-month e-cigarette use (High prevalence of e-cigarette use, AOR=6.82; 95% CI=5.68, 7.96, $p<0.001$; Medium prevalence of e-cigarette use, AOR=3.03; 95% CI=2.60, 3.45, $p<0.001$) than students who attended schools with the lowest prevalence of past-month e-cigarette use. It should be noted that the multivariable model that included school-level e-cigarette use was estimated separately given that this covariate (i.e. school-level e-cigarette use) was derived (i.e., aggregated) from the outcome being assessed (i.e., student-level e-cigarette use) and should be interpreted with caution given the high degree of overlap between these two measures.

Finally, we performed additional analyses and found that school-level e-cigarette use was not associated with individual-level cigarette smoking, adjusting for individual-level e-cigarette use and other factors (see Supplemental Table 1). Post-hoc analyses (results not shown) also explored how sex moderated each of the covariates in the full multivariable models (i.e., interaction effects were estimated separately for sex and each covariate – 22 additional models). Given the number of interaction effects being estimated, we only focus on statistically significant interaction effects at the .01 alpha level in order to avoid a Type I error. Accordingly, three statistically significant interaction effects were found in these exploratory models. First, the interaction effect between males and 12th grade (AOR=2.02; 95% CI=1.53, 2.68, $p<0.001$) found that 12th grade males had higher odds of past-month e-cigarette use when compared to 12th grade females (i.e., the risk for e-cigarette use became larger for males at this higher grade level). Moreover, the analyses also found that males who attended schools with higher prevalence of binge drinking (male X high-binge school: AOR=1.53; 95% CI=1.13, 2.06, $p<0.01$) and with high prevalence of marijuana use (male X high-marijuana use school: AOR=1.69; 95% CI=1.22, 2.35, $p<0.01$) also had higher odds of past-month e-cigarette use when compared to females who attended these same higher prevalence schools.

Discussion

To our knowledge, this is the first national investigation to identify school-level prevalence and predictors associated with e-cigarette use among U.S. secondary (middle and high) schools. The prevalence of past-month e-cigarette use across 580 public and private secondary schools in the U.S. varied considerably, ranging from 0% to 60%. The wide

variation in the prevalence of e-cigarette use highlights the need for schools to assess their own student body to guide their prevention efforts rather than relying solely on regional, state, or national results. The findings indicate large differences in environments that U.S. adolescents encounter each day as a function of which grade and school they attend. Previous regional and national research has found variation in tobacco and other substance use across schools [4,5,8,15], and this study extends this work to e-cigarette use.

We found that U.S. public and private secondary schools with higher proportions of White students were more likely to have a higher prevalence of e-cigarette use. These findings are in line with a study that found U.S. secondary schools with a majority of Black students typically had the lowest prevalence of substance use at all grades [11]. Furthermore, at least one prior study found a positive association between attending secondary schools with high prevalence of e-cigarette use and students' lifetime use of e-cigarettes [16]. Notably, this association was stronger for White students attending schools with a high prevalence of e-cigarette use, and a weaker association for Black students [16]. Taken together, these findings reinforce the importance of understanding both school-level racial composition and other school-level contextual factors when examining e-cigarette use among adolescents at the population level.

One of the most robust findings in the present study was the significant association between school-level cigarette smoking and e-cigarette use, after controlling for relevant individual-level and school-level covariates. We found that a student who attends a secondary school with a high proportion of cigarette smokers had roughly one-and-a-half times greater odds of past-month e-cigarette use. Existing evidence indicates e-cigarette use in adolescents who have never smoked is associated with an increased risk of transitioning to cigarette smoking [17–19], and the vast majority of e-cigarette use among adolescents who are dual users is not motivated by a desire to stop smoking [20,21]. The strong connection of school-level cigarette smoking and e-cigarette risk could place (1) non-users at greater risk for initiating nicotine during a time period when nicotine can have adverse effects on the developing brain [18] and (2) e-cigarette users at increased risk for transitioning to cigarette smoking because peers and school-level socio-contextual influences play such an integral role [5,8,22,23]. Indeed, e-cigarette use often involves adolescents associating with other friends who also use e-cigarettes or smoke cigarettes [24,25]. These findings also indicate that school-level interventions to reduce cigarette smoking may have an impact on e-cigarette use and vice versa. Future research should account for the growing evidence that associations between school-level factors and e-cigarette use change over time as the policy and culture surrounding e-cigarette use shifts [26].

Although the long-term health effects of e-cigarettes remain unknown, early nicotine exposure and long-term e-cigarette use may have adverse health consequences such as the initiation of combustible tobacco products and tobacco use disorder [18,19,27,28]. While e-cigarettes have shown some promise for tobacco cessation in certain sub-populations, more efforts are needed to reduce e-cigarette use among young people if e-cigarettes are to confer a net population-level benefit in the future. Based on the high prevalence of e-cigarette use among adolescents, more longitudinal research is needed regarding the impact of e-cigarette use on physical health, other drug use, and efficacy in smoking cessation [18].

There was evidence for sex interactions and the risk for e-cigarette use widened between females and males at higher grade levels. Additionally, males in schools with high levels of binge drinking and marijuana use were at greater risk for e-cigarette use when compared to females who attended these same schools. Geographical region was significantly associated with e-cigarette use. Students who attended U.S. schools located in the Southern region were the most likely to report past-month e-cigarette use. These findings are consistent with prior research indicating that e-cigarette use is higher among adolescents from the Southern region [1,2,13]. Although the present study did not find significant differences in e-cigarette use between urban and rural schools, there was some indication that differences based on population density differences may exist for younger students. We found that students in suburban schools had greater odds of e-cigarette use than students attending schools in rural areas. In addition, recent research suggests the importance of distinguishing between vaping nicotine and marijuana when examining population density [1]. Vaping nicotine decreases as population density increases. Inversely, vaping marijuana increases as population density increases.

The main strength of the present study is the large national sample of 8th, 10th, and 12th graders attending public and private schools in the U.S. with large enough samples to derive school-level estimates. However, large-scale studies such as MTF also carry limitations. For example, the MTF study does not include students who were home-schooled, dropped out, or were absent on the day of data collection [1]. School-level estimates were unweighted based on selected grade levels and schools were not sampled to be representative at the school-level, thus these results are meant to describe this sample not US schools as a whole. Additionally, there are some measures that are not assessed in the MTF study that are associated with initiation of nicotine and tobacco (e.g., family history of substance use disorder). Although the MTF study has been reported to be reliable and valid, there is some evidence that adolescents may misclassify or under-report sensitive substance use behaviors [29,30]. Finally, the 2015–2016 data were cross-sectional and do not capture more recent products (e.g., Juul® and Suorin®) and recent spikes in vaping [1]. The MTF measures used in the present study did not distinguish between vaping nicotine and vaping THC/cannabis. Thus, there is a need for future research to examine school-level factors associated with vaping nicotine separately from vaping marijuana.

In conclusion, the findings of the present study highlight the wide range in prevalence of e-cigarette use at U.S. middle and high schools (0%–60%) and differences in socio-environmental contexts. These findings suggest that school environments are closely linked to cigarette and e-cigarette use and serve as important risk factors for individual level e-cigarette use, a factor to be considered in school-level prevention interventions. Middle and high schools are strongly encouraged to assess their own student body to guide their prevention efforts.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Implication and Contribution

There is a wide variation in current e-cigarette use across U.S. secondary (middle and high) schools (0% to 60%); schools with a higher proportion of White students, schools located in the Southern and Western U.S. regions, and schools with a higher cigarette smoking prevalence had increased odds of e-cigarette use.

Figure 1:
Distribution of past-month e-cigarette use across U.S. middle and high schools, 2015–2016
(unweighted frequencies)

Table 1:

Demographics for both student-level and school-level characteristics

Student-Level n = 38,926	%(n)	School-Level (aggregated) n = 580	% ^a (n)	School-Level (measured at the school-level) n= 580	% ^a (n)
<u>Sex</u>		<u>Percent male</u>		<u>Private status</u>	
Female	51.3% (18493)	Low (0% to 46%)	33.0% (162)	Public school (n= 177)	82.6% (484)
Male	48.7% (17841)	Medium (47% to 51%)	33.3% (181)	Private school (n = 41)	17.4% (96)
		High (52% to 100%)	33.7% (237)		
<u>Grade-Level</u>		<u>Percent White</u>		<u>Grade-Level</u>	
8 th grade	28.0% (10899)	Low (0% to 55%)	33.1% (196)	8 th grade	37.5% (218)
10 th grade	26.8% (10438)	Medium (56% to 89%)	33.0% (179)	10 th grade	30.5% (176)
12 th grade	45.2% (17589)	High (90% to 100%)	33.9% (205)	12 th grade	32.0% (186)
<u>Race/ethnicity</u>		<u>Parental education (% with a BA or higher)</u>		<u>Urbanicity of School</u>	30.9% (176)
White	48.4% (18923)	Low (0% to 44%)	33.0% (190)	Rural (n = 64)	38.1% (219)
Black	13.0% (4885)	Medium (45% to 63%)	33.3% (186)	Suburban (n= 81)	31.0% (185)
Hispanic	18.1% (6988)	High (64% to 100%)	33.7% (204)	Urban (n = 73)	
Other	20.5% (8130)	<u>Percent with low grades</u>			
		Low (0% to 11%)	33.0% (173)	<u>U.S. Census region</u>	
		Medium (12% to 20%)	33.0% (185)	Northeast (n = 48)	21.1% (123)
<u>Highest parental education</u>		High (21% to 70%)	34.0% (222)	Midwest (n = 57)	25.3% (146)
Less than a BA	47.6% (17414)			South (n = 74)	35.9% (206)
BA or higher	52.4% (19725)	<u>Percent Binge Drinking</u>		West (n = 39)	17.7% (105)
		Low (0% to 5%)	34.0% (180)		
		Medium (6% to 12%)	36.6% (207)		
<u>Grade point average</u>		High (13% to 58%)	29.4% (193)		
B- or higher	82.1% (30106)				
C+ or lower	17.9% (6366)	<u>Percent Cigarette Use</u>			
		Low (0% to 2%)	33.9% (175)		
<u>Binge Drinking</u>		Medium (3% to 7%)	32.1% (189)		
No	88.8% (31582)	High (8% to 48%)	33.9% (216)		
Yes	11.2% (4205)				
<u>Cigarette Use</u>		<u>Percent E-Cigarette Use</u>			
No	92.8% (34651)	Low (0% to 6%)	24.3% (164)		
Yes	7.2% (2720)	Medium (7% to 12%)	37.7% (187)		
		High (13% to 60%)	38.0% (229)		
<u>E-Cigarette Use</u>		<u>Percent Marijuana Use</u>			
No	88.0% (31009)	Low (0% to 7%)	33.4% (174)		
Yes	11.9% (4261)	Medium (8% to 16%)	32.8% (190)		

Student-Level n = 38,926	%(n)	School-Level (aggregated) n = 580	% ^a (n)	School-Level (measured at the school-level) n= 580	% ^a (n)
<u>Marijuana Use</u>		High (17% to 75%)	33.8% (216)		
No	84.6% (31212)	<u>Percent Nonmedical Rx Use</u>			
Yes	15.4% (5764)	Low (0% to 2%)	33.6% (160)		
<u>Nonmedical Rx Use</u>		Medium (3% to 4%)	32.8% (193)		
No	95.6% (35833)	High (5% to 31%)	33.6% (227)		
Yes	4.4% (1667)	<u>School Size</u>			
<u>Cohort Year</u>		Small (1 to 62 students)	33.6% (182)		
2015	50.3% (19571)	Medium (63 to 151 students)	32.4% (190)		
2016	49.7% (19355)	High (152 or more)	34.0% (208)		

Notes: % = weighted percent; %^a = unweighted percent; n = unweighted sample size. Additional school-level information: Percent male Mean = 49.2%, SD = .102; Percent White Mean = 64.0%, SD = .337; Parental education Mean = 54.6%, SD = .211; Percent with low grades Mean = 17.4%, SD = .116; Percent Binge Drinking Mean = 10.1%, SD = .088; Percent Cigarette Use Mean = 7.0%, SD = .070; Percent E-Cigarette Use Mean = 10.8%, SD = .089; Percent Marijuana Use Mean = 13.4%, SD = .109; Percent Nonmedical Rx Drug Use Mean = 4.1%, SD = .033

Table 2.

Prevalence e-cigarette use by school-level characteristics, 2015–2016

School characteristics (8 th grade)	Past-month e-cigarette % (95% CI)	χ^2 p-value ^a	School characteristics (10 th grade)	Past-month e-cigarette % (95% CI)	χ^2 p-value ^a	School characteristics (12 th grade)	Past-month e-cigarette % (95% CI)	χ^2 p-value ^a
<u>Private status</u>			<u>Private status</u>			<u>Private status</u>		
Public school	8.1% (7.2%, 8.9%)	<.001	Public school	12.3% (11.0%, 13.6%)	.604	Public school	14.6% (13.3%, 15.8%)	.404
Private school	1.1% (0.3%, 1.9%)		Private school	11.4% (8.4%, 14.5%)		Private school	13.3% (10.5%, 16.0%)	
<u>Urbanicity of School</u>			<u>Urbanicity of School</u>			<u>Urbanicity of School</u>		
Rural	8.0% (6.3%, 9.7%)	<.001	Rural	13.7% (11.2%, 16.3%)		Rural	15.4% (13.1%, 17.8%)	.061
Suburban	7.4% (6.2%, 8.6%)		Suburban	11.4% (9.7%, 13.0%)		Suburban	15.0% (13.2%, 16.7%)	
Urban	4.6% (3.5%, 5.7%)		Urban	11.7% (9.5%, 13.9%)		Urban	12.4% (10.7%, 14.2%)	
<u>School Size</u>			<u>School Size</u>			<u>School Size</u>		
Small	4.3% (2.9%, 5.8%)	<.001	Small	11.8% (8.5%, 15.0%)		Small	14.4% (12.2%, 16.6%)	.947
Medium	7.6% (6.1%, 9.1%)		Medium	12.1% (10.3%, 13.9%)		Medium	14.5% (12.5%, 16.4%)	
High	8.5% (7.6%, 9.5%)		High	12.5% (10.9%, 14.1%)		High	14.1% (12.7%, 15.5%)	
<u>U.S. Census region</u>			<u>U.S. Census region</u>			<u>U.S. Census region</u>		
Northeast	5.3% (4.0%, 6.7%)	<.001	Northeast	11.1% (8.9%, 13.4%)		Northeast	13.9% (11.2%, 16.7%)	
Midwest	5.6% (4.0%, 7.3%)		Midwest	11.0% (8.6%, 13.3%)		Midwest	15.0% (12.6%, 17.3%)	
South	8.4% (7.1%, 9.8%)		South	13.9% (11.7%, 16.1%)		South	13.2% (11.8%, 14.5%)	
West	6.7% (4.9%, 8.4%)		West	11.6% (8.9%, 14.3%)		West	16.6% (13.1%, 20.0%)	
<u>Percent with low grades</u>			<u>Percent with low grades</u>			<u>Percent with low grades</u>		
Low	3.9% (2.9%, 4.9%)	<.01	Low	12.5% (9.9%, 15.0%)		Low	14.1% (12.3%, 15.8%)	.707
Medium	7.9% (6.4%, 9.3%)		Medium	12.6% (10.4%, 14.8%)		Medium	14.9% (13.3%, 16.5%)	

School characteristics (8 th grade)	Past-month e-cigarette % (95% CI)	χ^2 p-value ^a	School characteristics (10 th grade)	Past-month e-cigarette % (95% CI)	χ^2 p-value ^a	School characteristics (12 th grade)	Past-month e-cigarette % (95% CI)	χ^2 p-value ^a
High	8.8% (7.4%, 10.3%)		High	11.8% (10.1%, 13.6%)		High	13.7% (10.5%, 17.0%)	
<u>Percent male</u>			<u>Percent male</u>			<u>Percent male</u>		
Low	7.1% (5.4%, 8.7%)	.857	Low	11.8% (9.5%, 14.1%)	.145	Low	14.1% (12.2%, 16.1%)	.303
Medium	6.6% (5.4%, 7.8%)		Medium	13.7% (11.9%, 15.6%)		Medium	13.4% (11.8%, 15.0%)	
High	6.5% (5.3%, 7.7%)		High	11.1% (9.1%, 13.2%)		High	15.5% (13.2%, 17.9%)	
<u>Parental education</u>			<u>Parental education</u>			<u>Parental education</u>		
Low	9.0% (7.5%, 10.5%)	<.001	Low	10.7% (8.5%, 12.9%)	.206	Low	11.9% (10.1%, 13.7%)	<.01
Medium	7.5% (6.0%, 8.9%)		Medium	13.4% (11.3%, 15.5%)		Medium	17.0% (14.9%, 19.2%)	
High	4.0% (3.0%, 4.9%)		High	11.9% (10.1%, 13.8%)		High	14.1% (12.4%, 15.9%)	
<u>Percent White</u>			<u>Percent White</u>			<u>Percent White</u>		
Low	7.3% (5.9%, 8.6%)	.262	Low	8.1% (6.5%, 9.8%)	<.001	Low	10.6% (9.0%, 12.1%)	<.001
Medium	7.1% (5.6%, 8.5%)		Medium	13.7% (11.7%, 15.6%)		Medium	14.6% (13.0%, 16.1%)	
High	5.8% (4.5%, 7.1%)		High	14.4% (12.1%, 16.7%)		High	17.1% (14.9%, 19.4%)	
<u>Percent Cigarette Use</u>			<u>Percent Cigarette Use</u>			<u>Percent Cigarette Use</u>		
Low	4.4% (3.7%, 5.2%)	<.001	Low	7.1% (5.6%, 8.7%)	<.001	Low	6.9% (4.3%, 9.5%)	<.001
Medium	9.1% (7.8%, 10.3%)		Medium	12.7% (11.1%, 14.2%)		Medium	10.6% (9.3%, 11.9%)	
High	13.0% (9.6%, 16.5%)		High	16.9% (14.2%, 19.5%)		High	16.7% (15.2%, 18.2%)	
<u>Percent Binge Drinking</u>			<u>Percent Binge Drinking</u>			<u>Percent Binge Drinking</u>		
Low	5.2% (4.5%, 6.0%)	<.001	Low	6.5% (4.7%, 8.3%)	<.001	Low	10.9% (8.0%, 13.9%)	<.01
Medium	10.1% (8.3%, 11.9%)		Medium	11.2% (9.7%, 12.8%)		Medium	12.6% (10.8%, 14.4%)	
High	16.4% (13.7%, 19.2%)		High	17.2% (14.9%, 19.6%)		High	15.6% (14.0%, 17.1%)	

School characteristics (8 th grade)	Past-month e-cigarette % (95% CI)	χ^2 p-value ^a	School characteristics (10 th grade)	Past-month e-cigarette % (95% CI)	χ^2 p-value ^a	School characteristics (12 th grade)	Past-month e-cigarette % (95% CI)	χ^2 p-value ^a
<u>Percent Marijuana Use</u>			<u>Percent Marijuana Use</u>			<u>Percent Marijuana Use</u>		
Low	5.5% (4.6%, 6.3%)	<.001	Low	9.9% (6.2%, 13.6%)	.085	Low	11.3% (8.5%, 14.0%)	.078
Medium	9.7% (8.2%, 11.2%)		Medium	11.6% (10.1%, 13.1%)		Medium	13.6% (11.3%, 15.9%)	
High	9.9% (2.7%, 17.0%)		High	14.0% (11.9%, 16.1%)		High	14.9% (13.5%, 16.3%)	
<u>Nonmedical Rx Use</u>			<u>Nonmedical Rx Use</u>			<u>Nonmedical Rx Use</u>		
Low	5.9% (4.9%, 6.9%)	.107	Low	11.1% (8.2%, 14.0%)	<.01	Low	13.3% (10.6%, 16.1%)	<.05
Medium	7.3% (6.0%, 8.6%)		Medium	10.4% (8.8%, 11.9%)		Medium	12.4% (10.9%, 14.0%)	
High	8.1% (5.6%, 10.6%)		High	14.5% (12.6%, 16.4%)		High	15.9% (14.2%, 17.7%)	

^a p-values based on Wald Chi-Square-tests were used to indicate whether rates of e-cigarette use are significantly vary by school-level characteristics (based on fractional outcome regression [probit]). All analyses at the school-level only were unweighted.

Table 3.

Prevalence of e-cigarette use by student-level characteristics, 2015–2016

Student characteristics (8 th grade)	Past-month e-cigarette % (95% CI)	χ^2 p-value ^a	Student characteristics (10 th grade)	Past-month e-cigarette % (95% CI)	χ^2 p-value ^a	Student characteristics (12 th grade)	Past-month e-cigarette % (95% CI)	χ^2 p-value ^a
<u>Sex</u>			<u>Sex</u>			<u>Sex</u>		
Female	7.0% (6.0%, 8.0%)	<.05	Female	10.7% (9.4%, 12.2%)	<.001	Female	9.7% (8.9%, 10.6%)	<.001
Male	8.5% (7.4%, 9.7%)		Male	13.4% (11.8%, 15.3%)		Male	19.1% (17.4%, 20.9%)	
<u>Race/ethnicity</u>			<u>Race/ethnicity</u>			<u>Race/ethnicity</u>		
White	7.7% (6.6%, 9.0%)	<.05	White	14.1% (12.4%, 16.0%)	<.001	White	17.0% (15.5%, 18.7%)	<.001
Black	5.0% (3.6%, 6.9%)		Black	6.9% (5.1%, 9.2%)		Black	6.5% (5.4%, 7.8%)	
Hispanic	8.8% (7.4%, 10.6%)		Hispanic	10.4% (8.3%, 13.0%)		Hispanic	13.0% (11.4%, 14.9%)	
Other	8.4% (7.0%, 10.0%)		Other	11.3% (9.4%, 13.5%)		Other	13.8% (11.9%, 16.1%)	
<u>Highest parental education</u>			<u>Highest parental education</u>			<u>Highest parental education</u>		
Less than a BA	8.9% (7.9%, 10.1%)	<.01	Less than a BA	13.1% (11.5%, 14.8%)	0.07	Less than a BA	14.1% (12.8%, 15.5%)	0.55
BA or higher	6.6% (5.7%, 7.7%)		BA or higher	11.5% (10.0%, 13.1%)		BA or higher	14.5% (13.2%, 15.9%)	
<u>Grade point average</u>			<u>Grade point average</u>			<u>Grade point average</u>		
B– or higher	6.3% (5.6%, 7.1%)	<.001	B– or higher	10.2% (8.9%, 11.7%)	<.001	B– or higher	13.2% (12.2%, 14.3%)	<.001
C+ or lower	14.4% (12.5%, 16.5%)		C+ or lower	19.2% (16.9%, 21.7%)		C+ or lower	20.5% (17.8%, 23.6%)	
<u>Binge Drinking</u>			<u>Binge Drinking</u>			<u>Binge Drinking</u>		
No	5.8% (5.2%, 6.5%)	<.001	No	8.1% (7.2%, 9.2%)	<.001	No	10.3% (9.4%, 11.3%)	<.001
Yes	41.0% (35.8%, 46.5%)		Yes	42.9% (38.4%, 47.6%)		Yes	33.5% (30.2%, 37.1%)	
<u>Cigarette Use</u>			<u>Cigarette Use</u>			<u>Cigarette Use</u>		
No	5.9% (5.2%, 6.6%)	<.001	No	9.5% (8.5%, 10.6%)	<.001	No	10.1% (9.2%, 11.1%)	<.001

Student characteristics (8 th grade)	Past-month e-cigarette % (95% CI)	χ^2 p-value ^a	Student characteristics (10 th grade)	Past-month e-cigarette % (95% CI)	χ^2 p-value ^a	Student characteristics (12 th grade)	Past-month e-cigarette % (95% CI)	χ^2 p-value ^a
Yes	58.6% (52.8%, 64.2%)		Yes	60.6% (54.5%, 66.3%)		Yes	50.5% (47.0%, 53.9%)	
<u>Marijuana Use</u>			<u>Marijuana Use</u>			<u>Marijuana Use</u>		
No	5.5% (4.8%, 6.2%)	<.001	No	7.4% (6.5%, 8.4%)	<.001	No	9.4% (8.5%, 10.4%)	<.001
Yes	39.5% (34.4%, 44.8%)		Yes	41.0% (36.5%, 45.5%)		Yes	31.2% (28.2%, 34.4%)	
<u>Nonmedical Rx Drug Use</u>			<u>Nonmedical Rx Drug Use</u>			<u>Nonmedical Rx Drug Use</u>		
No	7.0% (6.3%, 7.8%)	<.001	No	10.9% (9.8%, 12.2%)	<.001	No	12.8% (11.8%, 13.8%)	<.001
Yes	34.0% (27.5%, 41.3%)		Yes	39.5% (32.9%, 46.6%)		Yes	41.3% (36.0%, 46.9%)	
<u>Cohort Year</u>			<u>Cohort Year</u>			<u>Cohort Year</u>		
2015	9.4% (8.4%, 10.6%)	<.001	2015	13.9% (12.2%, 15.8%)	<.01	2015	16.2% (14.7%, 17.8%)	<.001
2016	6.3% (5.4%, 7.2%)		2016	10.4% (8.9%, 12.1%)		2016	12.3% (11.0%, 13.7%)	

^a Chi-square p-values indicate differences in prevalence rates of past 30 day e-cigarette use by individual-level characteristics. All analyses at the student-level were unweighted and accounted for the complex sampling design.

Table 4.Predictors of e-cigarette use by school-level and student-level factors^a

	E-cigarette Use Bivariate Models n = 38,926	E-cigarette Use Full Model 1 n = 38,926	E-Cigarette Use Full Model 2 n = 38,926
Student-Level	OR (95% CI)	AOR (95% CI)	AOR (95% CI)
<u>Sex</u>			
Female	Reference	Reference	Reference
Male	1.68(1.51,1.85) ***	1.59(1.42,1.76) ***	1.59(1.41,1.77) ***
<u>Grade-Level of Student/School</u>			
8 th grade	Reference	Reference	Reference
10 th grade	1.65(1.36,1.94) ***	1.00 (.810, 1.19)	1.01 (.881,1.14)
12 th grade	1.99(1.70,2.28) ***	.786 (.612, .960) *	.873 (.730,1.02)
<u>Race/ethnicity</u>			
White	Reference	Reference	Reference
Black	.410(343, .477) ***	.484 (.388, .580) ***	.532 (.430, .634) ***
Hispanic	.762 (.658, .866) ***	.894 (.747, 1.04)	.886 (.745,1.03)
Other	.817 (.707, .927) ***	.883 (.744, 1.02)	.908 (.769,1.05)
<u>Highest parental education</u>			
Less than a BA	Reference	Reference	Reference
BA or higher	.914 (.828, 1.00) *	.938 (.838, 1.04)	.949 (.849, 1.05)
<u>Grade point average</u>			
B- or higher	Reference	Reference	Reference
C+ or lower	1.93(1.73,2.13) ***	1.44(1.25,1.63) ***	1.44(1.25,1.63) ***
<u>Binge Drinking</u>			
No	Reference	Reference	Reference
Yes	6.27(5.52,7.02) ***	2.46(2.12,2.80) ***	2.49(2.15,2.83) ***
<u>Cigarette Use</u>			
No	Reference	Reference	Reference
Yes	11.9(10.5,13.3) ***	4.83 (4.24, 5.42) ***	4.94 (4.32, 5.56) ***
<u>Marijuana Use</u>			
No	Reference	Reference	Reference
Yes	6.33(5.64,7.02) ***	3.08(2.68,3.48) ***	3.15(2.75,3.55) ***
<u>Nonmedical Rx Use</u>			
No	Reference	Reference	Reference
Yes	5.51 (4.62,6.40) ***	1.63(1.28,1.98) ***	1.66(1.29,2.03) ***
<u>Cohort Year (Student/School)</u>			
2015	Reference	Reference	Reference
2016	.689 (.616, .762) ***	.727 (.643, .811) ***	.900 (.824, .976) *
School-Level			

	E-cigarette Use Bivariate Models n = 38,926	E-cigarette Use Full Model 1 n = 38,926	E-Cigarette Use Full Model 2 n = 38,926
<u>Private status</u>			
Public school	Reference	Reference	Reference
Private school	.737 (.563, .911) **	.792 (.571, 1.01)	.919 (.739, 1.10)
<u>Urbanicity of School</u>			
Rural	Reference	Reference	Reference
Suburban	.929 (.788, 1.07)	1.18 (.964, 1.40)	1.10 (.981, 1.22)
Urban	.836 (.691, .981) *	1.14 (.915, 1.37)	1.03 (.889, 1.17)
<u>School Size</u>			
vSmall	Reference	Reference	Reference
Medium	1.01 (.804, 1.22)	1.01 (.783, 1.24)	.982 (.815, 1.15)
High	1.07 (.868, 1.27)	1.04 (.775, 1.30)	.950 (.766, 1.13)
<u>U.S. Census region</u>			
Northeast	Reference	Reference	Reference
Midwest	1.09 (.839, 1.34)	1.18 (.921, 1.44)	1.08 (.919, 1.24)
South	1.19 (.949, 1.43)	1.36(1.07, 1.65) *	1.09 (.947, 1.24)
West	1.13 (.860, 1.40)	1.36(1.02, 1.70) *	1.16 (.960, 1.35)
<u>Percent with low grades</u>			
Low	Reference	Reference	Reference
Medium	1.11 (.934, 1.29)	.927 (.790, 1.06)	.948 (.854, 1.04)
High	.952 (.797, 1.11)	.780 (.617, .943) **	.859 (.741, .977) *
<u>Percent male</u>			
Low	Reference	Reference	Reference
Medium	1.04 (.875, 1.20)	.942 (.809, 1.08)	.977 (.893, 1.06)
High	1.06 (.872, 1.25)	.996 (.943, 1.22)	.999 (.893, 1.10)
<u>Parental education</u>			
Low	Reference	Reference	Reference
Medium	1.33(1.14, 1.52) ***	1.10 (.935, 1.26)	1.12 (.987, 1.25)
High	1.12 (.944, 1.30)	1.06 (.819, 1.30)	1.03 (.860, 1.19)
<u>Percent White</u>			
Low	Reference	Reference	Reference
Medium	1.51 (1.30, 1.72) ***	1.25(1.04, 1.46) *	1.03 (.884, 1.17)
High	1.49(1.25, 1.74) ***	1.21 (.930, 1.49)	.949 (.771, 1.13)
<u>Percent Binge Drinking</u>			
Low	Reference	Reference	Reference
Medium	1.79(1.52, 2.06) ***	1.17 (.949, 1.39)	1.02 (.910, 1.13)
High	2.60(2.20, 3.00) ***	1.19 (.886, 1.49)	.929 (.780, 1.08)
<u>Percent Cigarette Use</u>			
Low	Reference	Reference	Reference
Medium	1.92(1.58, 2.26) ***	1.35(1.12, 1.58) **	.953 (.845, 1.06)

	E-cigarette Use Bivariate Models n = 38,926	E-cigarette Use Full Model 1 n = 38,926	E-Cigarette Use Full Model 2 n = 38,926
High	2.85(2.40,3.30) ***	1.54(1.24,1.84) ***	.907(.762,1.05)
<u>Percent E-Cigarette Use</u>			
Low	Reference		Reference
Medium	3.33(2.96,3.69) ***	—	3.03(2.60,3.45) ***
High	7.61 (6.68, 8.53) ***	—	6.82 (5.68, 7.96) ***
<u>Percent Marijuana Use</u>			
Low	Reference	Reference	Reference
Medium	1.71 (1.42,2.00) ***	1.08 (.862, 1.30)	.829 (.727, .931) ***
High	2.22(1.86,2.58) ***	.946 (.705, 1.19)	.780 (.660, .900) ***
<u>Percent Nonmedical Rx Use</u>			
Low	Reference	Reference	Reference
Medium	1.28(1.07, 1.49) **	1.02 (.846, 1.19)	.928 (.822, 1.03)
High	1.83(1.51,2.15) ***	1.05 (.862, 1.24)	.914 (.791, 1.04)
		R2 = .199; VIF = 3.42	R2 = .228; VIF = 3.49

*
p < .05,

**
p < 0.01,

p < 0.001

'Reference' refers to the reference category. '--' refers to variable not included due to overlap with outcome variable. OR refers to odds ratio (bivariate association). AOR refers to adjusted odds ratio (estimate when controlling for all of the other variables presented in table 4). R² refers to McFadden's Pseudo R². VIF refers to the average variance inflation factor. All analyses presented use weights provided by the MTF and account for the complex sampling design. All analyses presented in Table 4 use full information maximum likelihood estimation in order to retain the full sample (all analyses in Table 4 were performed in Mplus version 8). Analyses using listwise deletion can be provided upon request.