Association between e-cigarette use and abstinence from cigarette smoking among adolescent established smokers who initiated cigarette smoking first: a cross-sectional study in the United States

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ABSTRACT

Background:

The popularity of electronic cigarettes (e-cigarettes) among adolescents in the United States (US) has been increasing. Evidence on their role in the continuation of or abstinence from cigarette smoking among young smokers remains scarce.

Objective:

To examine the relationship between e-cigarette use and abstinence from cigarette smoking among US adolescent established smokers who initiated cigarette smoking first.

Methods:

Data were drawn from the 2015–2018 National Youth Tobacco Survey – a nationally representative survey of US middle and high school students. Multivariable logistic regression was used to assess the association between ever e-cigarette use and past 30-day abstinence from cigarette smoking. The analytical sample comprised ever established cigarette smokers with or without a history of e-cigarette use after smoking initiation.

Results:

Neither experimental (adjusted odds ratio 0.67, 95% confidence interval 0.39–1.14) nor prior established (1.56, 0.96–2.56) nor current established (0.65, 0.41–1.03) e-cigarette use was statistically significantly associated with past 30-day abstinence from cigarette smoking among adolescent ever established smokers. These findings were largely consistent across sensitivity analyses using alternative key definitions, although experimental and current established e-cigarette use was significantly negatively associated with past six-month abstinence.

Conclusions:

We found no evidence that e-cigarette use among US adolescents already smoking cigarettes is associated with subsequent abstinence from cigarette smoking; there was some evidence of an inverse association among experimental and current established e-cigarette users. These

findings could inform future regulatory and public health efforts regarding youth e-cigarette use and the reduction of youth cigarette smoking in the US.

INTRODUCTION

Electronic cigarettes (e-cigarettes) are generally considered less harmful than conventional cigarettes, although they are by no means harmless.[1] While current research is still insufficient to quantify the long-term health risks associated with e-cigarette use, the use of e-cigarettes during adolescence is not considered safe by the United States (US) Surgeon General.[1,2]

In theory, e-cigarettes may represent an effective smoking cessation aid because, unlike current options, they mimic the sensory and behavioural aspects of smoking in addition to providing users with nicotine upon cessation.[3] They are therefore frequently marketed as a smoking cessation aid.[4,5] In reality, however, the current evidence base for this remains preliminary and conflicting. Among adults, there has been some evidence suggesting that e-cigarettes may be effective cessation aids under controlled trial conditions, but not under real-world conditions in population studies, as summarised elsewhere.[6] E-cigarettes as a smoking cessation aid are therefore neither endorsed by the World Health Organization (WHO) nor approved by the US Food and Drug Administration (FDA).[7,8] Among adolescents, who frequently perceive themselves as experimental rather than regular smokers and hence would not necessarily aim to quit, smoking cessation may not be an appropriate term to use. The fundamental question of whether e-cigarette use among adolescents already smoking cigarettes has any influence on subsequent abstinence from cigarette smoking, however, remains of interest, and evidence on this is limited.

Despite these uncertainties, the US have seen a rapid increase in e-cigarette use over recent years – particularly among adolescents. For example, current (past 30-day) use of e-cigarettes among US high school students rose from just 1.5% in 2011 to 20.8% in 2018.[9] This trend is

referred to as an epidemic of youth e-cigarette use by the US Surgeon General and the FDA.[10,11] It has been driven by a number of factors, including aggressive marketing of e-cigarettes as smoking cessation aids and healthy alternatives to conventional cigarettes,[4,5] the appearance of high tech e-cigarettes such as JUUL attracting youth with appealing flavours and heavy reliance on social media for aggressive marketing,[12,13] as well as a delayed regulatory response.[14–16] Accordingly, commonly cited reasons for e-cigarette use among youth have included curiosity, the availability of appealing flavours, the ability to use e-cigarettes in smoke-free public places, and the perception of them being a less harmful alternative to conventional cigarettes.[2] As expected, smoking cessation is not reported as a primary reason for e-cigarette use among youth.[2]

This has prompted concerns and debate around the public health impact of e-cigarettes. Although evidence remains unclear, it has been suggested that e-cigarettes may lead to a renormalisation of smoking, encourage long-term dual use, or act as a gateway to smoking initiation, especially among youth, rather than acting as a means for tobacco harm reduction in the population.[1,17,18] Dual use in particular may be a reason for concern, as it has been linked to increased health risks.[19] A thorough understanding of the relationship between e-cigarette use and subsequent continuation of or abstinence from cigarette smoking among adolescent smokers will therefore help inform future regulatory action and public health efforts.

The current evidence on this relationship specifically among adolescents (defined here as those aged around 10–18 years), however, is limited. Two earlier cross-sectional studies from the US and Korea found that current[20,21] or ever[21] e-cigarette use was negatively associated with past 30-day[20,21], 6-month[21] or 1-year[21] abstinence from cigarette smoking among

adolescents who had ever smoked ≥1 puff[20,21] or those who had smoked ≥100 cigarettes[21] in their lifetime. Another study from the US[22] examined ever abstinence from smoking. It found that current dual users were significantly less likely than only cigarette smokers to report ever 6-month or 1-year abstinence from smoking, but around equally as likely to report ever 30-day abstinence.

These studies have two important limitations: analyses were not limited to individuals who initiated their e-cigarette use after cigarette smoking, making it impossible to determine the direction of the association, and used data from 2011–2013, meaning their conclusions may not necessarily be applicable to the present. To fill this gap in the literature and help guide future regulatory and public health efforts, this study aims to determine the relationship between e-cigarette use and abstinence from cigarette smoking among US adolescent established smokers who initiated cigarette smoking first under real-world conditions. A secondary aim is to investigate this relationship specifically among those reporting to have used e-cigarettes as a tobacco cessation aid.

METHODS

Data source

Data were drawn from the National Youth Tobacco Survey (NYTS) – an annual, nationally representative, self-administered survey of US middle and high school students, enrolled in grades 6–12.[23] The NYTS uses stratified, three-stage cluster sampling: random sampling without replacement is conducted to select Primary Sampling Units (PSUs) within each stratum, schools within each PSU, and students within each school, producing a nationally representative sample.[24–27] Selected students then complete a paper-and-pencil questionnaire. Since selection of primary and secondary sampling units is proportional to size, non-Hispanic (NH) Black students are oversampled, and participation is voluntary for both schools and students, a weighing factor is subsequently applied to adjust for differential nonresponse and the probability of selection.[24–27] Further details of survey design and methodology are outlined elsewhere.[23–27] This study pooled data from the 2015–2018 NYTS iterations to augment sample size in sub-group analyses. Participation rates and number of completed questionnaires were 63.4% (17,711) in 2015, 71.6% (20,675) in 2016, 68.1% (17,872) in 2017, and 68.2% (20,189) in 2018.[24–27]

Measures

Full questionnaire wording is available elsewhere.[23] The process of selection of the main analytical sample is visualised in Figure 1.

Cigarette smoking

Ever smoking was assessed using the question “Have you ever tried cigarette smoking, even one or two puffs?”. Students who responded “Yes” were considered ever smokers, those who

responded “No” never smokers. Characteristics of ever smoking were assessed using the questions “About how many cigarettes have you smoked in your entire life?”, and “How old were you when you first tried cigarette smoking, even one or two puffs?”.

All analyses were initially restricted to ever cigarette smokers (Figure 1). Since not all ever smokers have necessarily developed dependence on nicotine, we further restricted our analyses to ever established smokers for greater specificity and to yield a better-defined study population (Figure 1). The standard cut-off used to define smoking status among adults is 100 lifetime cigarettes smoked.[28] Among youth, however, there is no universally accepted definition of established smoking. Previous research has suggested that symptoms of nicotine dependence among youth can be experienced even after extremely low cigarette exposure.[29–32] In this study, we therefore used the following criteria for our main definition of ever established smoking: >25 lifetime cigarettes smoked (i.e. more than one pack) and first started smoking >12 months ago (assessed by comparing current age and age at first cigarette use). We also performed sensitivity analyses using a more stringent definition (≥100 lifetime cigarettes smoked).

E-cigarette use

Ever e-cigarette use was assessed using the question “Have you ever used an e-cigarette, even once or twice?”. Students who responded “Yes” were considered ever e-cigarette users, those who responded “No” never e-cigarette users. Characteristics of ever use were assessed using the questions “In total, on how many days have you used e-cigarettes in your entire life?”, and “How old were you when you first tried using an e-cigarette, even once or twice?”.

E-cigarette use was the main exposure examined. Amongst ever e-cigarette users, we differentiated between two levels of intensity of lifetime use – experimental and established (Figure 1). With no standard definitions available in the literature, we defined experimental users as having used e-cigarettes on ≤10 days, and ever established users as having used e-cigarettes on >10 days in their lifetime. We then subdivided ever established e-cigarette users into current (past 30-day) and prior (not in past 30 days) established users, based on the question "During the past 30 days, on how many days did you use e-cigarettes?".

History of initiation

To be able to determine how e-cigarette use may influence subsequent cigarette smoking, ever established smokers were only included in the analytical sample if they had either never used e-cigarettes, or initiated their e-cigarette use after cigarette smoking (Figure 1). To reconstruct the history of initiation of the two products, respondents' ages (in years) at first use of either product were compared. Only students with a higher age of first e-cigarette use were included, indicating that they initiated their e-cigarette use after cigarette smoking. This allows exploration of whether e-cigarette use is associated with subsequent abstinence from cigarette smoking, implying that cigarette smoking must precede e-cigarette use. Initiation patterns in the reverse direction (e-cigarette use preceding cigarette smoking) may be more consistent with gateway effects. Respondents who initiated both products at the same age had to be excluded based on the available data.

Abstinence from cigarette smoking

Abstinence from cigarette smoking was the primary outcome examined. Consistent with previous studies in adolescents (e.g.[20]), this was primarily defined as past 30-day abstinence. Using the question "When was the last time you smoked a cigarette, even one or two puffs?",

respondents who had last smoked >30 days ago were defined as having been abstinent. We also performed sensitivity analyses using a stricter definition of past 6-month abstinence.

Reason for e-cigarette use

The reason for ever e-cigarette use was determined using the question "What are the reasons you have used e-cigarettes?". Respondents who selected "To try to quit using other tobacco products, such as cigarettes" were considered to have used e-cigarettes as a tobacco cessation aid; those who only selected one or more of the other responses were considered to have used them for other reasons.

Covariates

Assessed sociodemographic characteristics included: current age (9–13, 14–15, 16–17, or ≥18 years), sex (male/female), race/ethnicity (NH-White, NH-Black, Hispanic, or other/multiple [NH-Asian, NH-American Indian/Alaska Native, NH-Native Hawaiian, Pacific Islander, or multiple races], per Centers for Disease Control and Prevention (CDC) classification), and whether a language other than English is spoken at home (yes/no) – a possible indicator of migration status. It was additionally assessed whether a participant's household member smokes cigarettes (yes/no), and whether the participant had ever used any other tobacco products (yes/no). This binary variable was based on several questions regarding ever use of cigars, cigarillos, little cigars, chewing tobacco, snuff, dip, hookah/waterpipe, snus, dissolvable tobacco, and bidis.

Statistical analysis

Descriptive analyses were performed to describe characteristics of the total and main analytical sample. Results are reported as unweighted counts and weighted percentages with their 95%

confidence intervals (CIs). Subsequently, multivariable logistic regression analyses were conducted to examine the association between (1) ever e-cigarette use and abstinence from cigarette smoking (main analysis), and (2) ever use of e-cigarettes as a tobacco cessation aid and abstinence from cigarette smoking in the analytical sample of ever established smokers.

After adjusting for a key set of potential confounders (age, sex, race/ethnicity, survey year), models adjusting for additional potential confounders were explored using Akaike information criterion and Bayesian information criterion. Consequently, the final models also adjusted for whether a household member smokes cigarettes, the lifetime number of cigarettes smoked, ever use of any other tobacco products, and whether a second language is spoken at home. The exploration of models including these variables was informed by previous research, which has shown that factors such as the level of nicotine dependence, pro-tobacco social influences, and other sociodemographic factors can impact the success of smoking cessation.[33–35] Among the variables we explored, only 'school grade' and 'school level' were not included in the models due to collinearity with age. For the main analysis, models including interaction terms between the main exposure variable and each of the other variables were explored, but no interaction term was statistically significant, so they were not included in the final model. Subsequently, three sensitivity analyses of the main model using different combinations of the primary and alternative definitions described above were performed. For each model, adjusted odds ratios (aORs) with their 95% CIs and p-values (statistical significance level: 0.05) are reported. All analyses were conducted among complete cases only, weighted (using weights provided in the official dataset), and performed using Stata 15.1.[36]

RESULTS

Sample characteristics

Table 1 provides a description of characteristics of the main analytical sample (*n* = 1,697). It shows that 14.6% of adolescents in the analysis were never e-cigarette users, 25.0% were experimental users, 15.8% were prior established users, and 44.6% were current established users. Additionally, 26.6% had not smoked in the past 30 days.

The total sample (*n* = 76,447) is described in Supplementary Tables 1–4.

Table 1: Characteristics of the main analytical sample, consisting of ever established cigarette smokers among a representative sample of middle and high school students from the United States, National Youth Tobacco Survey 2015–2018.

	Main analytical sample [a] (n = 1,697)	
Characteristics	*n*	Wgt % (95% CI)
E-cigarette use		
Never	265	14.6 (12.2–17.4)
Experimental [b]	416	25.0 (22.4–27.9)
Prior established [c]	260	15.8 (13.4–18.5)
Current established [d]	756	44.6 (40.7–48.5)
Missing	0	–
Reason for e-cigarette use		
Never	265	14.7 (12.3–17.4)
Ever, for tobacco cessation	471	30.3 (27.1–33.7)
Ever, for other reason(s)	953	55.0 (52.3–57.8)
Missing	8	–
Past 30-day smoking abstinence		
No	1,247	73.4 (70.5–76.1)
Yes	432	26.6 (23.9–29.5)
Missing	18	–
Survey year		
2015	513	32.8 (24.8–41.9)
2016	450	28.5 (20.8–37.7)
2017	321	18.5 (13.2–25.3)
2018	413	20.2 (14.7–27.2)
Missing	0	–
Age (years)		
9–13	67	4.2 (2.9–6.0)
14–15	269	17.0 (14.6–19.8)
16–17	894	52.7 (49.4–55.9)
≥18	467	26.1 (23.4–29.0)
Missing	0	–
Sex		
Male	1,018	57.7 (54.0–61.4)
Female	666	42.3 (38.6–46.0)
Missing	13	–
Race/ethnicity		
Non-Hispanic White	1,024	68.2 (64.3–71.8)
Non-Hispanic Black	87	4.6 (2.9–7.3)
Hispanic	352	17.6 (14.9–20.6)
Other/multiple	188	9.7 (7.7–12.1)
Missing	46	–
Languages spoken at home		
English only	1,246	80.7 (77.4–83.5)
English + other(s)	342	19.3 (16.5–22.6)
Missing	109	–
Lives with smoker		
No	690	43.0 (39.2–46.9)
Yes	861	57.0 (53.1–60.8)
Missing	146	–
No. of cigarettes smoked in lifetime		
26–99	584	34.7 (31.7–37.8)
≥100	1,113	65.3 (62.2–68.3)
Missing	0	–
Ever use of any other tobacco products [e]		
No	109	6.2 (4.8–7.9)
Yes	1,586	93.8 (92.1–95.2)
Missing	2	–

Based on unweighted counts and weighted percentages over complete cases. CI = confidence interval. Wgt = weighted. *n* = number of observations. E-cigarette = electronic cigarette.

[a] Comprises ever established smokers (>25 lifetime cigarettes smoked and first started smoking >12 months ago) with or without a history of e-cigarette use after initiating cigarette smoking.

[b] Defined as having used electronic cigarettes on ≤10 days in lifetime.

[c] Defined as having used electronic cigarettes on >10 days in lifetime, but not in past 30 days.

[d] Defined as having used electronic cigarettes on >10 days in lifetime, and on ≥1 day in past 30 days.

[e] Including cigars, cigarillos, little cigars, chewing tobacco, snuff, dip, hookah/waterpipe, pipe, snus, dissolvable tobacco, and bidis.

Association between ever e-cigarette use and smoking abstinence

As seen in Table 2, there was no statistically significant association between experimental (aOR 0.67, 95% CI 0.39–1.14) or prior established (aOR 1.56, 95% CI 0.96–2.56) or current established (aOR 0.65, 95% CI 0.41–1.03) e-cigarette use and past 30-day abstinence from cigarette smoking. The fact that all tested two-way interaction terms were not significant indicates that this association did not differ across sociodemographic subgroups.

The results also show that students who lived with a smoker had significantly lower odds of having been abstinent from cigarette smoking compared to those who did not (aOR 0.57, 95% CI 0.41–0.80). Established smokers who had smoked ≥100 cigarettes in their lifetime had 77% lower odds of having been abstinent compared to those who had smoked 26–99 lifetime cigarettes (aOR 0.23, 95% CI 0.17–0.32), and those who had ever used any other tobacco products had 58% lower odds of having been abstinent compared to those who had not (aOR 0.42, 95% CI 0.24–0.75). The other variables included in the model were not associated with smoking abstinence (Table 2).

Figure 2 shows a forest plot visualising the results of the sensitivity analyses of the main regression model (full results see Supplementary Table 5). All three sensitivity analyses gave largely consistent results in terms of direction and magnitude of effect compared to the original analysis, suggesting that the results are relatively insensitive to changes in the key definitions. Contrary to the original analysis, however, the estimates for experimental and current established e-cigarette use reached statistical significance in sensitivity analysis 2, where the definition of smoking abstinence was changed to a more stringent past 6-month abstinence.

Association between ever use of e-cigarettes as a cessation aid and smoking abstinence

Table 2 also shows that there was no statistically significant association between ever e-cigarette use for tobacco cessation and smoking abstinence (aOR 0.66, 95% CI 0.40–1.07). ‘Ever use’ in this analysis comprises both experimental and ever established e-cigarette use.

Table 2: Multivariable logistic regression analyses examining the association between (1) ever electronic cigarette use and smoking abstinence, and (2) ever use of electronic cigarettes as a cessation aid and smoking abstinence among ever established cigarette smokers in a representative sample of middle and high school students from the United States, National Youth Tobacco Survey 2015–2018.

	Outcome: Smoking abstinence [a]			
	Model 1 (*n* = 1,484)		**Model 2** (*n* = 1,525)	
Variables	**aOR (95% CI)**	**p-value**	**aOR (95% CI)**	**p-value**
E-cigarette use (Model 1)				
Never (referent)	1.00	–	–	–
Experimental [b]	0.67 (0.39–1.14)	0.134	–	–
Prior established [c]	1.56 (0.96–2.56)	0.075	–	–
Current established [d]	0.65 (0.41–1.03)	0.067	–	–
E-cigarette use (Model 2)				
Never (referent)	–	–	1.00	–
Ever, for tobacco cessation	–	–	0.66 (0.40–1.07)	0.089
Ever, for other reason(s)	–	–	0.85 (0.55–1.32)	0.474
Survey year				
2015 (referent)	1.00	–	1.00	–
2016	1.13 (0.75–1.71)	0.546	1.25 (0.84–1.86)	0.273
2017	1.05 (0.64–1.73)	0.850	1.10 (0.70–1.73)	0.682
2018	1.32 (0.87–2.02)	0.192	1.27 (0.85–1.91)	0.248
Age				
9–13 (referent)	1.00	–	1.00	–
14–15	1.01 (0.37–2.79)	0.979	0.93 (0.34–2.51)	0.878
16–17	1.68 (0.64–4.39)	0.292	1.60 (0.62–4.15)	0.332
≥18	1.77 (0.68–4.61)	0.243	1.61 (0.62–4.20)	0.329
Sex				
Male (referent)	1.00	–	1.00	–
Female	0.82 (0.56–1.19)	0.288	0.79 (0.55–1.15)	0.222
Race/ethnicity				
Non-Hispanic White (referent)	1.00	–	1.00	–
Non-Hispanic Black	0.60 (0.21–1.73)	0.345	0.64 (0.24–1.69)	0.360
Hispanic	1.05 (0.70–1.56)	0.820	0.98 (0.68–1.43)	0.922
Other/multiple	0.88 (0.49–1.59)	0.673	0.85 (0.47–1.52)	0.582
Languages spoken at home				
English only (referent)	1.00	–	1.00	–
English + other(s)	0.96 (0.61–1.50)	0.856	0.98 (0.64–1.51)	0.931
Lives with smoker				
No (referent)	1.00	–	1.00	–
Yes	0.57 (0.41–0.80)	0.001	0.57 (0.41–0.79)	0.001
No. of cigarettes smoked in lifetime				
26–99 (referent)	1.00	–	1.00	–
≥100	0.23 (0.17–0.32)	<0.001	0.25 (0.18–0.34)	<0.001
Ever use of any other tobacco products [e]				
No (referent)	1.00	–	1.00	–
Yes	0.42 (0.24–0.75)	0.003	0.42 (0.24–0.73)	0.002

Analyses restricted to ever established smokers (>25 lifetime cigarettes smoked and first started smoking >12 months ago) with or without a history of electronic cigarette use after initiating cigarette smoking. aOR = adjusted odds ratio (adjusted for all variables listed in table). CI = confidence interval. *n* = number of observations. E-cigarette = electronic cigarette.

[a] Defined as past 30-day abstinence from cigarette smoking.

[b] Defined as having used electronic cigarettes on ≤10 days in lifetime.

[c] Defined as having used electronic cigarettes on >10 days in lifetime, but not in past 30 days.

[d] Defined as having used electronic cigarettes on >10 days in lifetime, and on ≥1 day in past 30 days.

[e] Including cigars, cigarillos, little cigars, chewing tobacco, snuff, dip, hookah/waterpipe, pipe, snus, dissolvable tobacco, and bidis.

DISCUSSION

This secondary analysis of NYTS data found that neither experimental nor prior established nor current established e-cigarette use was statistically significantly associated with having been abstinent from cigarette smoking among adolescent ever established smokers in the US who initiated cigarette smoking first. Sensitivity analyses suggest that there may be an inverse association between experimental as well as current established e-cigarette use and past 6-month smoking abstinence in this sample.

Previous research among adolescents examining the same outcome (past 30-day abstinence) has shown evidence of a negative association with e-cigarette use.[20,21] In this study, we found some suggestion of such an association among experimental and current established e-cigarette users, but not among prior established e-cigarette users. Unlike in these previous studies, however, this negative association between e-cigarette use and smoking abstinence reached statistical significance only in the sensitivity analysis which used a more stringent definition of smoking abstinence, and not in our main analysis.

This may be because our analysis differs from these previous studies in several important aspects beyond the use of more recent data. For example, we restricted analyses to ever established smokers, as primarily defined here, in an effort to exclude experimenters but include all those who returned to smoking after initial experimentation. Unlike previous studies, we also reconstructed the respondents' lifetime history of cigarette and e-cigarette use and limited our analyses to individuals who initiated their e-cigarette use after cigarette smoking, to some extent making it possible to determine the direction of influence. Additionally, the multivariable regression models presented here adjusted for the effect of several important potential confounders which were not taken into account in previous studies

(e.g. social context). Taken together, these unique analytical choices add value to the current study and give confidence in the observed results.

These real-world findings may simply reflect the fact that smoking cessation is not among the most commonly cited motivations for e-cigarette use among youth.[2] Our second analysis, however, found that even adolescents who explicitly report having used e-cigarettes as a tobacco cessation aid had no higher odds of smoking abstinence compared to never e-cigarette users. Although we cannot exclude residual confounding, it is unlikely that this would fully explain these findings.

Notably, the point estimates for prior established e-cigarette users differed somewhat from those for experimental and current established users, although confidence intervals largely overlapped. This finding could reflect the fact that some participants may have been actively attempting to quit smoking using e-cigarettes at the time of the survey, but not have achieved abstinence yet. The relatively small size of this group could also suggest that trying e-cigarettes may often lead to long-term dual use of both products, which is frequent among adolescents.[37] One should also consider that e-cigarettes evolve rapidly. Compared to prior established users, those identified as current users may be using products with substantially higher nicotine concentrations, which have become more popular recently.[38]

This study provides a novel insight into one aspect of the current debate surrounding the public health impact of e-cigarettes – how e-cigarette use among adolescents already smoking cigarettes may influence subsequent cigarette smoking. Importantly this analysis does not assess if e-cigarettes are useful as a long-term harm reduction strategy (e.g., if adolescents who would have otherwise initiated cigarette smoking instead choose to initiate e-cigarette use).

Nevertheless, the findings presented here should be taken into account in future policy making. They are in support of a precautionary approach and the implementation of increased regulatory and public health efforts to reduce youth e-cigarette use without any further delay, and hence in support of the FDA's recently imposed federal restrictions on certain flavoured e-cigarettes.[16] Furthermore, public health efforts to prevent and reduce youth cigarette smoking should focus on evidence-based prevention of experimentation and transition to regular smoking, as well as established ways to encourage cessation,[39] rather than the promotion of e-cigarettes.

Despite providing a valuable, up-to-date insight into the relationship between e-cigarette use and subsequent smoking abstinence among young smokers, this study has several limitations. For example, the findings are generalizable only to US adolescents who attend school and not to home-schooled adolescents or school dropouts. Data from the US Census Bureau, however, show that approximately 98% of US youth aged 10–15 years and approximately 92% of US youth aged 16–17 years were enrolled in school in 2018.[40] Additionally, data were self-reported and hence potentially subject to misreporting, although previous research has shown that self-reported smoking status among adolescents tends to be accurate.[41,42] The definitions of ever established smoking and smoking abstinence can be debatable, but our findings were fairly robust to other reasonable and widely-used definitions. Furthermore, our analysis assumes that established smokers smoked >25 cigarettes in approximately the first year after their first puff and before trying an e-cigarette, which might not be true – some may have tried smoking, then experimented with e-cigarettes, and later started smoking more steadily.

The use of cross-sectional, secondary data means that there may be unknown or unmeasured confounders, representing another limitation. Examples include the state of residence and hence regulatory environment, the socioeconomic status and hence financial resources available to adolescents, or the type of e-cigarette used, as suggested by previous research in adults.[43,44] These may have a direct impact on smoking abstinence, but could not be assessed here as the NYTS does not collect such data. Although randomised controlled trials could address these sources of confounding, population studies have the advantage of examining the role of e-cigarettes as they are actually used by consumers in the real world. Lastly, an intrinsic limitation of cross-sectional studies is that they cannot be used to infer causality. Findings should hence be verified using studies with longitudinal follow-up. The rapidly evolving nature of the e-cigarette market and regulatory environment, both of which may affect the relationship between e-cigarette use and smoking abstinence,[45] also means that such evidence must be constantly updated.

In summary, we found no evidence that e-cigarette use among US adolescents already smoking cigarettes is associated with subsequent abstinence from cigarette smoking, but our findings suggest that an inverse association between experimental as well as current established e-cigarette use and smoking abstinence may exist. While the overall public health impact of e-cigarettes at the population level remains uncertain, these findings could inform future regulatory and public health efforts regarding youth e-cigarette use and the prevention and reduction of youth cigarette smoking. This study provides a novel and up-to-date insight into the role of e-cigarettes in the continuation of or abstinence from cigarette smoking among young smokers, but more longitudinal research is needed to assess and consistently monitor this role.

WHAT THIS PAPER ADDS

What is already known on this subject:

- Recent years have seen a rapid increase in e-cigarette use among adolescents in the US.
- Among adults, research suggests that e-cigarettes may be effective in aiding smoking cessation under controlled trial conditions, but not under real-world conditions in population studies.

What important gaps in knowledge exist on this topic:

- Despite growing concerns around the public health impact of youth e-cigarette use and hence regulatory importance, epidemiological evidence on the relationship between e-cigarette use and the subsequent continuation of or abstinence from cigarette smoking specifically among adolescent smokers remains limited.
- The few existing cross-sectional studies conducted specifically among adolescents have two important limitations: they were not limited to individuals who initiated their e-cigarette use after cigarette smoking and used data from 2011–2013.

What this study adds:

- E-cigarette use appears not to be associated with subsequent abstinence from cigarette smoking among US adolescent ever established smokers under real-world conditions.
- An inverse association between experimental as well as current established e-cigarette use and past 6-month smoking abstinence may exist.

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Figure 1: Flowchart outlining the process of selection of the main analytical sample (dark grey). Total sample is a representative sample of middle and high school students from the United States, National Youth Tobacco Survey 2015–2018. Observations with missing values are removed at each step. *n* = number of observations. E-cigarette = electronic cigarette.

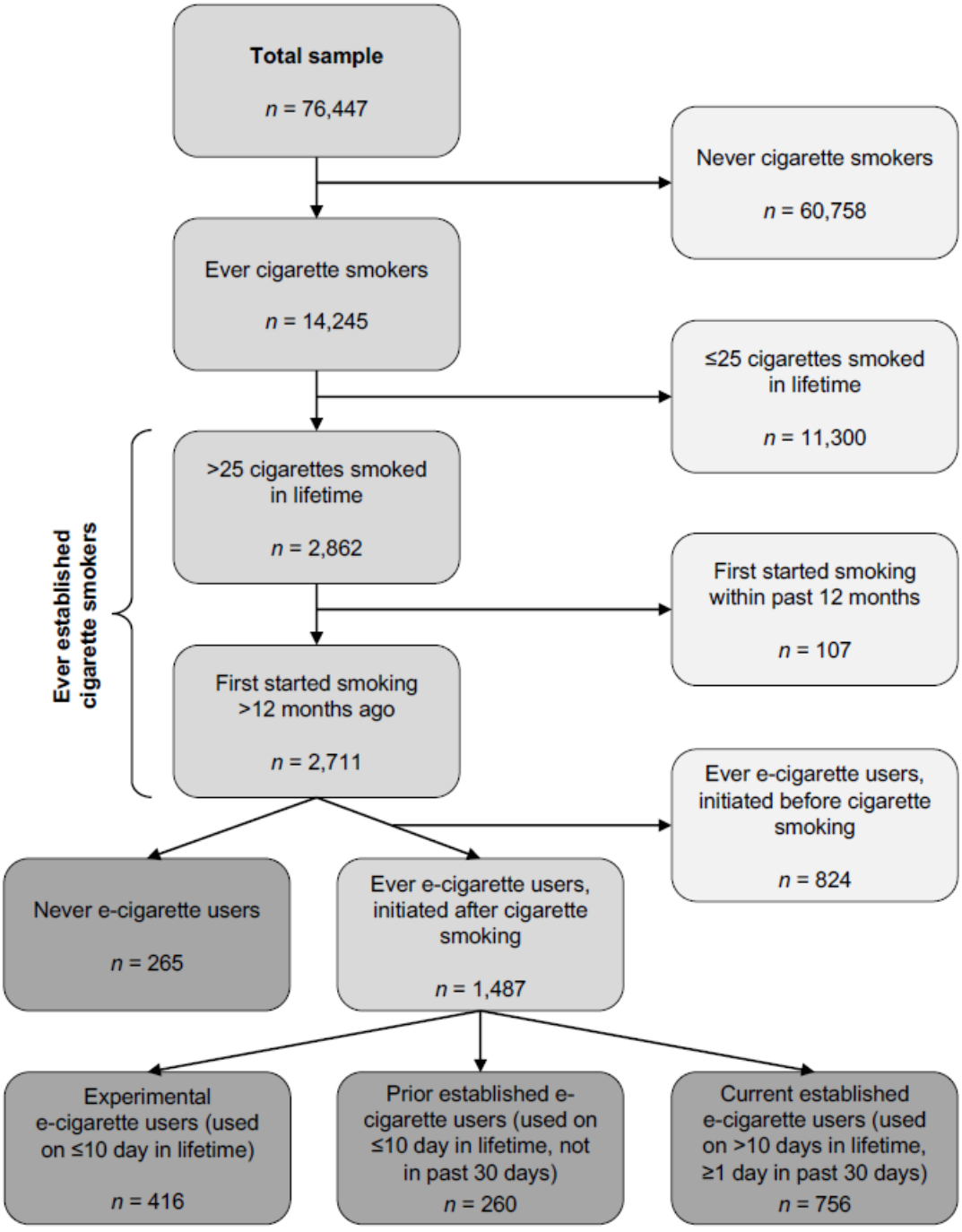
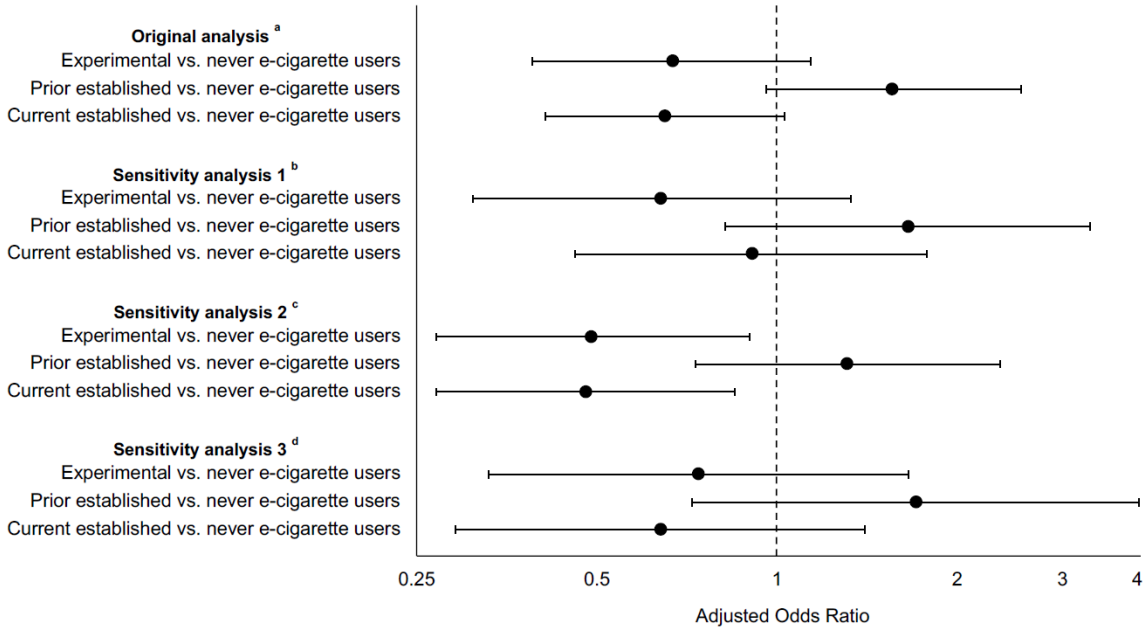


Figure 2: Forest plot summarising results of the three sensitivity analyses of the main regression model – a multivariable logistic regression model examining the association between ever electronic cigarette use and smoking abstinence among ever established cigarette smokers in a representative sample of middle and high school students from the United States,

National Youth Tobacco Survey 2015–2018. For full results see Supplementary Table 5. Logarithmic scale. Dotted line represents line of no effect. E-cigarette = electronic cigarette.



[a] **Original analysis (*n* = 1,484):** ever established smoking defined as >25 lifetime cigarettes smoked and first started smoking >12 months ago; smoking abstinence defined as past 30-day abstinence from cigarette smoking.
[b] Defined as having used electronic cigarettes on ≤10 days in lifetime.
[c] Defined as having used electronic cigarettes on >10 days in lifetime, but not in past 30 days.
[d] Defined as having used electronic cigarettes on >10 days in lifetime, and on ≥1 day in past 30 days.
[e] **Sensitivity analysis 1 (*n* = 967):** ever established smoking defined as ≥100 lifetime cigarettes smoked and first started smoking >12 months ago; smoking abstinence defined as past 30-day abstinence from cigarette smoking.
[f] **Sensitivity analysis 2 (*n* = 1,484):** ever established smoking defined as >25 lifetime cigarettes smoked and first started smoking >12 months ago; smoking abstinence defined as past 6-month abstinence from cigarette smoking.
[g] **Sensitivity analysis 3 (*n* = 967):** ever established smoking defined as ≥100 lifetime cigarettes smoked and first started smoking >12 months ago; smoking abstinence defined as past 6-month abstinence from cigarette smoking.