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E-Cigarette Use and Adverse Respiratory Symptoms Among Adolescents and Young Adults in the United States

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Abstract

E-cigarette use among adolescents and young adults has been associated with adverse respiratory symptoms, including symptoms of asthma and bronchitis. This investigation examined whether such associations differ by primary type of e-cigarette device used. This cross-sectional study included data from four study populations in California and Connecticut, United States, ages 13–21 years (N=10,483), who self-reported their tobacco use behaviors and health status from 2018–2020. Adverse respiratory symptoms were grouped as bronchitis, asthma exacerbation, and shortness of breath. Associations with e-cigarette use were examined by frequency of e-cigarette use (regardless of device type) and most-frequently use device type in the past 30 days (pod, pen/tank, disposable, or mod). Multivariable modeling accounted for demographic variables and use of other tobacco and cannabis. Results were pooled at the study level via random-effects meta-analysis. Across the four studies, e-cigarette use >5 days/month versus never use was associated with bronchitic symptoms (summary odds ratio, sOR: 1.56; 95% confidence interval, CI: 1.37, 1.77) and shortness of breath (sOR: 1.68; 95% CI: 1.35, 2.08) but not statistically significantly with asthma exacerbations (sOR: 1.36; 95% CI; 0.95, 1.95). Among past 30-day e-cigarette users, associations with respiratory symptoms did not differ by device type. In these populations, e-cigarette use was positively associated with symptoms of bronchitis and shortness of breath, but adjusted odds of symptoms did not differ meaningfully by device type. These findings suggest that risk of these respiratory outcomes is elevated among more frequent e-cigarette users regardless of device type used.

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Keywords

adolescent health; e-cigarettes; respiratory health; tobacco; asthma; bronchitis

Introduction

Electronic cigarette (e-cigarette) use among adolescents and young adults has grown increasingly common in the past decade, raising potential health concerns. Among United States high school students, prevalence of past 30-day e-cigarette use reached 27.5% in 2019 before declining to 19.6% in early 2020.[1,2] Among United States young adults (age 18–24), e-cigarette use was 9.3% in 2019, with more than half of e-cigarette users having never smoked conventional cigarettes.[3]

Human and animal studies have demonstrated adverse biologic effects of e-cigarette aerosol exposure to respiratory cells and tissues.[4,5] Case reports have described serious acute respiratory symptoms associated with the use of e-cigarettes.[6,7] Population-based studies have also described positive associations between e-cigarette use and adverse respiratory health outcomes, including chronic and subclinical conditions. Among youth, positive associations between e-cigarette use and asthma diagnosis or symptoms have been reported;[8,9] and asthma associations persisted after covariable adjustment in some[10,11] but not all studies.[12,13] Asthma symptoms have also been associated with e-cigarette use among adults,[14,15] albeit weakly in some studies.[16] Among other respiratory conditions, e-cigarette use was associated with symptoms of chronic bronchitis among adolescents in California[17] and among adults, with chronic pulmonary disorder,[15] cough, wheeze, and sputum production,[18] and incident chronic obstructive pulmonary disease, bronchitis, and emphysema.[14] Potential mechanisms may relate to increased inflammation and altered airway function following e-cigarette use.[19]

E-cigarettes have evolved substantially in their design characteristics and are now available in a wide variety of device types, which include small disposable products, refillable tanks and pens, highly customizable and modifiable “mods”,[20] and devices fitted for replaceable prefilled pods.[21] Different product characteristics could influence health effects. Pod devices, for example, may deliver nicotine to young users at higher levels than other product designs.[22] It is not well understood whether e-cigarettes that differ in their characteristics, such as nicotine delivery efficiency, use patterns, and mix of possible toxins, also differ in their potential risk of harmful respiratory effects. Notably, most existing studies to date have been based on data collected prior to emergence of pod-style e-cigarette devices. To our knowledge, no published population-based studies report respiratory outcomes by e-cigarette device type. Such information could inform tobacco product regulations and policies, such as measures to restrict access to products with potentially more harmful characteristics.

This investigation aims to examine the prevalence of self-reported adverse respiratory health symptoms among adolescent and young adult e-cigarette users from four study populations in California and Connecticut, United States. We first examine whether self-reported adverse respiratory health symptoms are associated with more frequent use of e-cigarettes, regardless

of device type. Next assessed are associations by e-cigarette device type among past 30-day e-cigarette users, including pod, pen/tank, disposable, and mod devices.

Methods

The present study is a cross-sectional analysis of data collected during four ongoing studies of tobacco use behaviors, perceptions, and health outcomes among youth and young adults. These four studies were included because they are currently active youth and young adult cohorts under the Tobacco Centers of Regulatory Science program, a research initiative to generate evidence to inform potential Food and Drug Administration tobacco product regulation.[23] While data were collected independently at three separately-funded centers, coordination among investigators during analysis allowed for harmonization of variable and model specification. The inclusion of multiple study populations allows for greater sample diversity (e.g., by age group, geographic region, and urbanicity) and evaluation of the consistency of findings across studies while enhancing statistical power. Procedures for all four studies received ethical approval from internal review boards at the sponsoring universities. Table 1 includes characteristics of the four study populations.

Connecticut Adolescents:

The Yale Adolescent Survey Study is an anonymous school-wide survey conducted yearly since 2013 in high schools in urban and suburban areas of southeastern Connecticut. The present analysis includes cross-sectional surveys conducted from April 2019 to May 2019 (Six high schools; N=4875 participants). Surveys were administered using tablet computers during homeroom/advisory, health, or English classes. Further methodologic details are described elsewhere.[24]

Northern California Adolescents:

The UCSF Adolescent Tobacco Study is a prospective cohort of 9th and 10th grade students attending 8 rural Northern California public high schools (N=1423). The present analysis uses cross-sectional baseline data collected from March 2019 to February 2020. Surveys were administered using tablet computers during required classes. Further methodological details are described elsewhere.[25]

Southern California Young Adults (CHS):

The USC California Children's Health Study (CHS) is a prospective cohort study of youth in 13 communities in Southern California. In 2014, 11th and 12th grade students completed surveys assessing tobacco product use with staff supervision at study schools (N=2097). This analysis includes cross-sectional data from the fourth data collection wave (April 2018 to November 2019; N=1637). Further methodological details are described elsewhere.[26–29]

Southern California Young Adults (HH):

The USC Happiness and Health Study (HH) is a prospective cohort study of youth from 10 high schools in Southern California, initially recruited in 9th grade in 2013. The current study uses cross-sectional data collected via online survey during the first follow-up wave

after high school (October 2018 to August 2019; N=2548). Further methodological details are described elsewhere.[30]

Measuring E-Cigarette Use:

All surveys asked about ever (yes/no) and past 30-day (number of days) e-cigarette use. Survey measures varied slightly across studies but shared common features. E-cigarette measures were introduced with brief text descriptions, example brands, and, for the adolescent studies, product images. All surveys featured questions about different e-cigarette device types, which were grouped into four mutually exclusive categories for this analysis: pods (including JUUL, pod-mods, and other rechargeable pod devices), vape pens and tanks (including refillable, reusable devices with no or limited modifications), disposables (including cigalikes and, for Northern California youth, disposable pods, like Puff Bar), and mods (including box-mods, rebuildable, and drip devices).

Many participants reported using more than one device type in the past 30 days. To define the most-frequently used device, the young adult (Southern California) studies asked participants which device type they used the most and then how many days used in the past 30 days. The adolescent surveys (Connecticut and Northern California) inquired about days used in the past 30 days for each device type separately; most-frequently used device was later determined based on highest number of days used (or designated “multiple devices” in the case of ties). Table A.1 describes device type use according to these analytic categories.

Measuring Respiratory Symptoms:

Three types of conditions were included in analysis: bronchitic symptoms, asthma exacerbations, and shortness of breath. Some, but not all, survey items were common across all four studies. For bronchitic symptoms, all four surveys asked, “Other than with colds, do you usually seem congested in the chest or bring up phlegm?” Asthma measures included diagnosis, use of medications, and symptoms, such as wheezing or whistling, ever and in the past 12 months. While the Connecticut youth and young adult studies used identical shortness of breath measures, including, “Are you troubled by shortness of breath when hurrying on level ground or walking up a slight hill?”, the Northern California youth study asked, “When you are physically active, do you get tired more easily compared to other people your age?” Table 2 lists all individual measures included in analysis.

To reflect respiratory impacts broadly while reducing the total number of outcome variables, individual symptoms were collapsed into composite measures for each condition (i.e., bronchitis, asthma, shortness of breath), defined as endorsing ≥1 of the symptoms or exacerbations for that condition. Ever-history of asthma or wheeze were excluded from the asthma composite to capture only recent experiences.

Other Covariables:

Additional participant characteristics and behaviors included in analysis were gender, race/ethnicity, school lunch program participation (adolescent studies only), personal income (young adult studies only), age, past 30-day combustible tobacco use, past 30-day cannabis use. These covariables were selected both for being plausible confounders of e-cigarette use

and respiratory symptoms associations and for being collected using similar measures across the studies.

Statistical analysis:

Within each study, the prevalence of adverse respiratory symptoms (all symptoms and composite measures) was compared between past 30-day e-cigarettes users and non-users, regardless of device type (chi-square test). Additionally, logistic regression models were fitted for each respiratory composite measure (dependent variable) according to e-cigarette use frequency (independent variable; categories: never used, even used but not in the past 30 days, and used 1–5 or 6–30 days in the past 30 days), regardless of device type. Among all past 30-day e-cigarette users, another set of logistic regression models was fitted for each respiratory composite measure according to most-frequently used e-cigarette device type (categories: pod, pen/tank, disposable, mod, multiple devices). Device-type models were additionally adjusted for past 30-day e-cigarette use frequency (1–5 or 6–30 days). The reference category was pod devices, because this was the most commonly used device type in three of the four studies. To obtain summary measures of association across the four studies, DerSimonian-Laird random-effects meta-analyses were conducted using the metan command in Stata 16. Results were considered statistically significant if 95% confidence intervals excluded the null value.

Results

Participant Characteristics:

The four studies considered in the present analysis included 10,483 participants and 2448 past 30-day e-cigarette users. All studies included more female than male participants (Table 1). In the three studies based in California, approximately half the study populations identified as Hispanic/Latinx (Table 1). Past 30-day combustible tobacco use and cannabis use were more common in the young adult studies than in the adolescent studies (Table 1). Among past 30-day e-cigarette users, pod devices were the most commonly used device type in three of the studies, the exception being the Northern California adolescent study (Table 1).

Respiratory Symptoms Prevalence, E-Cigarettes Users and Non-Users:

In all studies, symptoms of bronchitis were statistically significantly more prevalent among past 30-day e-cigarette users than among past 30-day non-users (Table 2). Past 12-month wheezing or whistling in the chest was also statistically significantly more common among e-cigarette users in the three studies that measured this outcome (Table 2). However, ever-history of asthma and taking asthma medications (all four studies), as well as recent asthma events (measured in one study), did not differ by e-cigarette use status (Table 2). Among adolescents, shortness of breath (Connecticut) and tiring easily (California) were statistically significantly more common among e-cigarette users than non-users, but this association was not observed among young adults (Table 2).

Models of Respiratory Symptoms, by E-Cigarette Use Frequency:

In models adjusted for participant characteristics and behaviors, the odds of bronchitic symptoms were highest among the most frequent e-cigarette users (≥6 days in the past 30 days) in all studies, with statistically significant adjusted odds ratios observed (reference: never users) in three of the four studies (Table 3, Figure 1). Combining the four study results, the adjusted odds of bronchitic symptoms were more than 1.5-times higher among frequent e-cigarette users (summary odds ratio, sOR: 1.56; 95% confidence interval, CI: 1.37, 1.77). The adjusted odds of asthma exacerbations, in contrast, did not differ between e-cigarette never users and frequent users in two of the studies and were higher but not statistically significantly in another (Table 3). Meta-analysis did not yield a statistically significant sOR (1.36; 95% CI: 0.95, 1.95) for asthma exacerbations among frequent e-cigarette users vs. never users (Table 3, Figure 1). Shortness of breath symptoms were statistically significantly associated with frequent e-cigarette use in both adolescent studies (Table 3, Figure 1). Overall, the sOR comparing shortness of breath symptoms between frequent e-cigarette users and never users was 1.68 (95% CI: 1.35, 2.08).

Models of Respiratory Symptoms, by E-Cigarette Device Type:

In adjusted models restricted only to past 30-day e-cigarette users (Table 4, Figure 2), in no individual study was there a statistically significant difference in the odds of reporting bronchitic symptoms, asthma exacerbations, or shortness of breath symptoms for any of the e-cigarette device types compared to a reference of pod devices. However, among adolescents, those using multiple devices were at greater odds of reporting asthma exacerbations (sOR: 1.64; 95% CI: 1.21, 2.21) and use of multiple devices was associated with greater odds of shortness of breath in one adolescent study but not statistically significantly in both adolescent studies combined (sOR: 1.28; 95% CI: 0.76, 2.16).

Discussion

In this analysis, using any type of e-cigarette more than 5 days/month was associated with greater odds of self-reported symptoms of bronchitis and shortness of breath compared to e-cigarette never use but not statistically significantly with self-reported asthma exacerbations in covariable-adjusted meta-analysis. There was no strong or consistent evidence to suggest that the odds of any of the examined respiratory conditions differed according to the most-frequently used e-cigarette device type.

Previous population-based studies have more often focused on associations of e-cigarette use with asthma than with other respiratory conditions. Cross-sectional studies of adolescents have consistently reported positive associations between e-cigarette use and ever or current history of asthma.[8–11,31] In contrast, our present findings did not find a statistically significant association with recent experience of asthma exacerbations in analyses that included individuals both with and without a past asthma diagnosis. Ever-history of asthma may reflect a prior diagnosis that preceded e-cigarette use and was not included as part of the composite outcome variable in our analysis. This could explain why our results differ from prior findings. The distinction between and temporal sequence of asthma ever-diagnosis and symptoms, such as asthma attacks and wheeze, should be carefully examined

in further longitudinal studies. For example, non-causal associations could arise if youth with existing asthma were motivated to use e-cigarettes over combustible tobacco. Asthma exacerbations, on the other hand, have been associated with secondhand aerosol exposure in at least two investigations.[32,33] We found that the odds of asthma exacerbations were numerically elevated, but not statistically significantly, among e-cigarette users; thus, it is plausible that any effects of e-cigarettes on this outcome are absent or weak.

The present findings identified positive associations of frequent e-cigarette use, regardless of device type, with symptoms of bronchitis and shortness of breath. This is a possible indicator that respiratory risks may increase with the frequency of e-cigarette use. Here, frequent use was defined as e-cigarette use 6 or more days in the past 30 days. Had e-cigarette use been categorized only as past 30-day use (1 or more days) that category would have presumably included some individuals with only minimal recent exposure to e-cigarette use, particularly in youth populations, potentially obscuring meaningful health effects potentially connected to higher levels of exposure.

Our findings add to the consistency with which associations between e-cigarette use and non-asthma respiratory symptoms have been observed across ages and geographies. Among youth in Hong Kong, e-cigarette use was also associated with chronic bronchitis, including after stratifying by current and former cigarette use.[34] The Hong Kong data were collected in 2012–2013, preceding substantial changes in e-cigarette design; however, our results suggest device type may not be a major driver of respiratory outcomes. Among adults who smoke cigarettes in Sweden, multiple respiratory symptoms, including cough, sputum production, and wheeze, were associated with e-cigarette use.[18] In a longitudinal study of United States adults, e-cigarette use was associated with incident self-reported asthma, emphysema, and chronic obstructive pulmonary disease.[14]

The respiratory conditions considered in this investigation cover a range of potential underlying pathophysiological processes. Specifically, asthma is an inflammatory condition with genetic and environmental causes; whereas bronchitis is upper airway inflammation usually subsequent to infection. Shortness of breath upon exertion may be symptomatic of several heart or lung problems, including impaired gas exchange in the lower airway, as reported in cases of severe lung injury, termed e-cigarette, or vaping, product use associated lung injury, primarily linked to vaping cannabis products.[35] Bronchiolitis obliterans, a rare but serious outcome potentially linked to inhaling the flavoring compound diacetyl from e-cigarettes,[36] may also present with shortness of breath symptoms. That e-cigarette use could be implicated in multiple adverse respiratory conditions is plausible given laboratory, animal model, and clinical evidence demonstrating potential for e-cigarette exposure to cause a wide range of physiologic effects on the pulmonary system, including altered gene expression, inhibited nasal and bronchial cilia, impaired macrophage function, increased endothelial stiffness, and increased inflammation, as reviewed elsewhere.[4,5,19]

Concurrent use of combustible tobacco and/or cannabis by e-cigarette users is an important consideration in interpreting study results. We included past 30-day use of tobacco and cannabis as adjustment covariables in all statistical models. However, residual confounding by past use behaviors cannot be ruled out. Vaping cannabis has also been positively

associated with bronchitis and wheezing symptoms.[37] In a cross-sectional study of United States youth, lifetime use of cannabis in an electronic nicotine delivery system was positively associated with wheezing symptoms, but past 30-day e-cigarette use was not after adjustment for cannabis vaping.[38]

To our knowledge, this investigation is the first to examine associations with adverse respiratory symptoms according to the type of e-cigarette device used most often. We analyzed data collection from late 2018 to early 2020, a time-frame that followed a surge in use of pod-style e-cigarette devices, such as JUUL.[39] While pod devices differ from their predecessors in using high-concentration nicotine-salt formulations, we did not detect evidence of differences in self-reported respiratory symptoms compared to other device types. Three of the four study populations concluded data collection before disposable pod devices, such as Puff Bar, gained substantial market share.[40] Therefore, findings related to disposable devices should be interpreted cautiously. The category of disposable devices in the Northern California adolescent study reflects primarily disposable pod use, but no statistically significant differences in respiratory symptoms were observed compared to reusable pods, although associations were positive in direction. Notably, in the adolescent populations, we did identify statistically significantly higher odds of asthma exacerbations among multiple-device users compared to primarily pod users, but this association is plausibly confounded by a greater mean number of days of use per month among multiple-device users.

The large sample size achieved by combining findings across four study populations was a strength of this study. This also allowed an examination of the consistency of associations under different contexts and age groups. However, the selection of these four studies was by convenience and results may not generalize to other geographies. Even when data were combined, sample sizes were limited for some device types, such as disposable devices. Among other limitations, all health outcomes were by self-report, which may not correspond to a clinical diagnosis. The grouping of participants by most-frequently used device does not necessarily reflect exclusive use of that device type. Dual- and poly-use of more than one device type are common, which may have limited the ability of this investigation to detect differences in health effects by device type. All reported associations are cross-sectional; in particular, the time-frame for e-cigarette use (past 30 days) was not fully overlapping with at least some respiratory outcomes (e.g., use of asthma medication in the past 12 months). Future studies should examine device-type use patterns and health effects over time to allow for clearer temporal sequencing in drawing causal inference.

Among the implications of the present findings, e-cigarette regulations and guidelines should regard adverse respiratory outcomes as potential negative health effects of e-cigarette use in this age range. Mass communication to discourage youth e-cigarette use may consider respiratory health messages, as might specific youth prevention programs. Mandated product warnings and restrictions may be warranted with further confirmatory evidence.

Conclusions

In these populations of adolescents and young adults, e-cigarette use was positively associated with symptoms of bronchitis and shortness of breath, but not statistically significantly with asthma exacerbations. However, we found no evidence under this study design that respiratory symptoms varied by the e-cigarette device types investigated.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Funding and Conflicts of Interest:

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Non-standard abbreviations:

AOR	adjusted odds ratio
CHS	California Children's Health Study
HH	Happiness and Health Study
sOR	summary odds ratio

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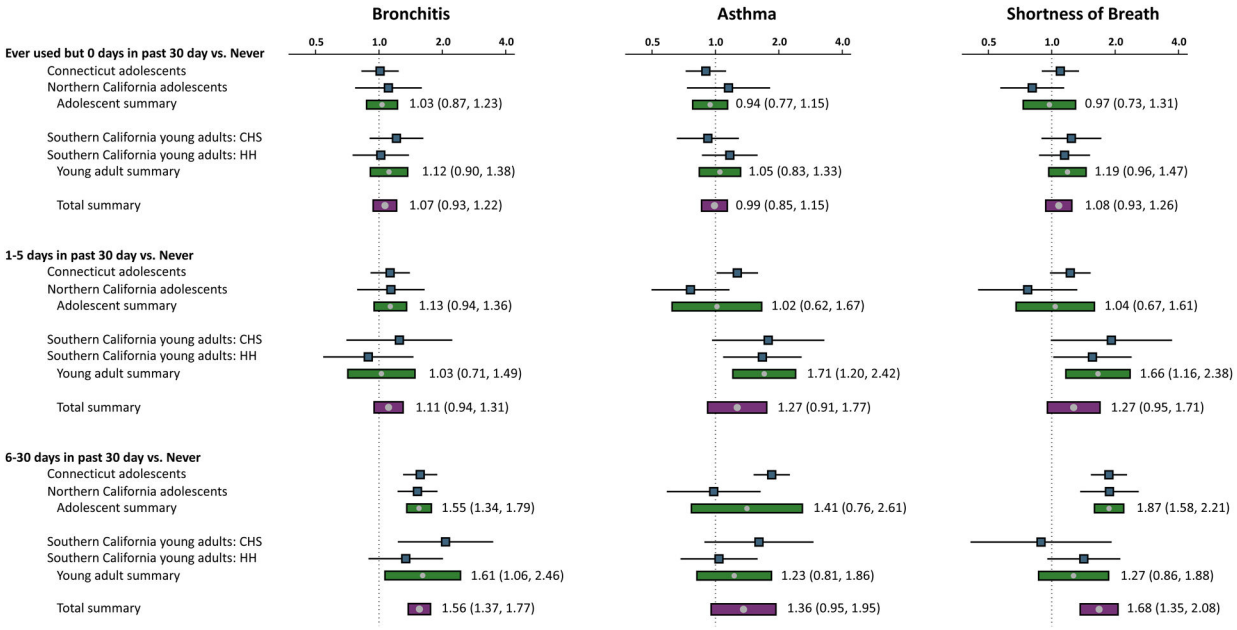

Figure 1. Self-Reported Adverse Respiratory Symptoms by Frequency of E-Cigarette Use: Meta-Analysis Forest Plots

Meta-analysis forest plots are shown for three different respiratory conditions (bronchitis, asthma, and shortness of breath) at three different levels of e-cigarette use frequency (used 0, 1–5, or 6–30 days in the past 30 days vs. reference of never use). Shown are individual study odds ratio point estimates (square boxes; equally-sized boxes do not reflect meta-analysis weighting) with 95% confidence intervals (black lines) and summary odds ratios point estimates (circles) with 95% confidence intervals (rectangles, adolescent or young adult studies pooled; all studies pooled). Graphed on the log scale.

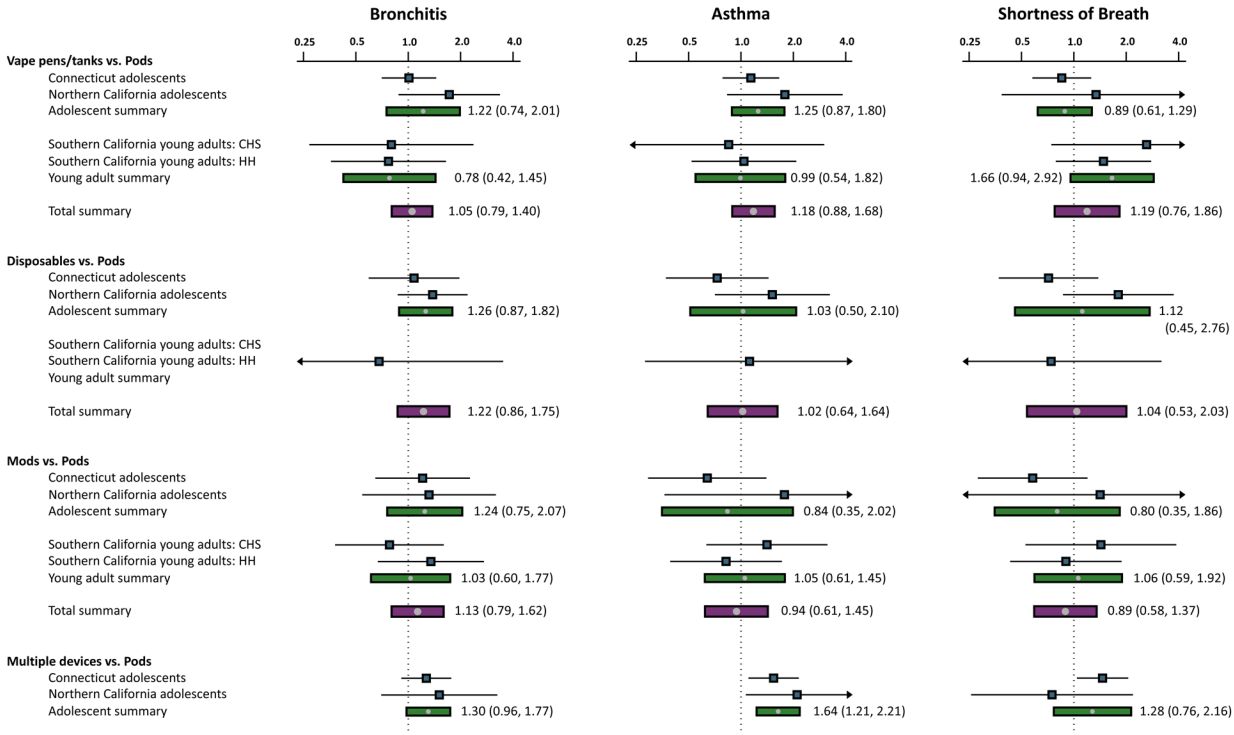

Figure 2. Self-Reported Adverse Respiratory Symptoms by E-Cigarette Device Type: Meta-Analysis Forest Plots

Meta-analysis forest plots are shown for three different respiratory conditions (bronchitis, asthma, and shortness of breath) for four categories of most-frequently used e-cigarette device type in the past 30 days (pen/tank, disposable, mod, or multiple devices vs. reference of pod). Shown are individual study odds ratio point estimates (square boxes; equally-sized boxes do not reflect meta-analysis weighting) with 95% confidence intervals (black lines) and summary odds ratios point estimates (circles) with 95% confidence intervals (rectangles, adolescent or young adult studies pooled; all studies pooled). Graphed on the log scale.

Table 1.

Participant Characteristics: Four Studies of Adolescents or Young Adults (N=10,483)

	Connecticut Adolescents N=4875[3]	Northern California Adolescents N=1423[3]	Southern California Young Adults: CHS[1] N=1637[3]	Southern California Young Adults: HH[2] N=2548[3]
Demographic Characteristics [4]				
Gender				
Male	48.4	42.4	48.6	41.5
Female	51.6	56.0	51.4	58.5
Other	<0.5	1.5	--[5]	--[5]
Race/ethnicity				
Non-Hispanic White	44.0	34.1	37.5	13.4
Hispanic/Latinx	30.8	53.2	49.5	52.7
Other	25.0	12.7	13.0	33.9
School lunch program participant[6]				
Yes	46.4	58.7	--[5]	--[5]
No	33.6	26.3	--[5]	--[5]
Don't know	19.9	15.0	--[5]	--[5]
Personal income				
Live comfortably	--[5]	--[5]	35.2	45.2
Meet needs with a little left	--[5]	--[5]	35.9	28.3
Just meet basic expenses	--[5]	--[5]	24.7	21.2
Don't meet basic expenses	--[5]	--[5]	4.2	5.3
Age in years: mean (SD)	16.0 (1.3)	15.2 (0.7)	21.9 (0.8)	19.7 (0.5)
Past 30-Day Tobacco and Substance Use [4]				
Combustible tobacco use	6.2	4.8	13.9	26.3
Cannabis use	20.8	21.0	25.7	33.8
E-cigarette use	29.7	21.2	14.8	24.7
Among past 30-day e-cigarette users: Most frequent e-cigarette device				

	Connecticut Adolescents N=4875[3]	Northern California Adolescents N=1423[3]	Southern California Young Adults: CHS[1] N=1637[3]	Southern California Young Adults: HH[2] N=2548[3]
Pods, including JUUL	60.5	24.2	45.7	61.1
Vape pens/tank	14.7	26.5	12.9	18.9
Disposables	4.9	25.2	0.5	3.3
Mods, including box mods	3.8	6.0	37.7	15.1
Multiple devices	16.1	18.2	--[5]	--[5]
Other	--[5]	--[5]	3.2	1.7
Among past 30-day e-cigarette users: E-cigarette use frequency[7]				
1–5 days in past 30 days	43.5	57.3	45.3	39.6
6–30 days in past 30 days	56.5	42.7	51.2	59.0

1. Children's Health Study

2. Happiness and Health Study

3. Sample size may be less than the total for some variables due to missing data

4. All values report as percent unless indicated otherwise

5. Response option or survey item not included in the study questionnaire

6. Participation in the means-tested federal school lunch program included as a marker of family socioeconomic position

7. Percentages for Southern California young adult studies add to <100% due to some participants indicating "yes" for past 30-day use but "0" for the number of days

Table 2.

Prevalence of Self-Reported Adverse Respiratory Symptoms: Past 30-Day E-Cigarette Users (N=2448) and Non-Users (N=7783)

	Connecticut Adolescents		Northern California Adolescents		Southern California Young Adults: CHS[1]		Southern California Young Adults: HH[2]	
	E-Cigarette Use[3,4]		E-Cigarette Use[3,4]		E-Cigarette Use[3,4]		E-Cigarette Use[3,4]	
	Yes N=1447	No N=3420	Yes N=302	No N=1120	Yes N=195	No N=1213	Yes N=504	No N=2030
Bronchitis Symptoms[5,6]								
Usually seem congested in the chest	**16.3**	**10.9**	14.3	10.6	**27.7**	**16.2**	**15.2**	**10.7**
Persistent cough upon waking (past 12 months)	**9.0**	**6.3**	--[7]	--[7]	**9.7**	**5.0**	4.3	2.9
Persistent cough other times (past 12 months)	**13.5**	**9.2**	--[7]	--[7]	**13.3**	**6.4**	4.5	3.8
Heavy coughing (past 30 days)	--[7]	--[7]	**32.6**	**20.4**	--[7]	--[7]	--[7]	--[7]
Had bronchitis (past 12 months)	**4.7**	**3.4**	--[7]	--[7]	**9.2**	**4.6**	4.9	3.7
Bronchitis composite: ≥1 of the above	**27.2**	**21.5**	**37.2**	**26.7**	**37.4**	**22.8**	**19.3**	**15.5**
Asthma Symptoms[5,6]								
Ever doctor diagnosed asthma	21.7	23.3	20.5	19.4	28.4	23.4	22.9	22.2
Asthma episode or attack (past 12 months)	--[7]	--[7]	6.7	6.1	--[7]	--[7]	--[7]	--[7]
Emergency/urgent care for asthma (past 12 months)	--[7]	--[7]	1.0	2.6	--[7]	--[7]	--[7]	--[7]
Hospital overnight for asthma (past 12 months)	--[7]	--[7]	1.0	1.0	--[7]	--[7]	--[7]	--[7]
Medication for asthma or wheeze (past 12 months)	11.2	10.7	15.8	15.7	9.8	8.2	8.0	8.0
Asthma attack (past 30 days)	--[7]	--[7]	3.5	2.8	--[7]	--[7]	--[7]	--[7]
Wheezing or whistling (ever)	**26.2**	**21.4**	--[7]	--[7]	**48.7**	**29.0**	27.2	26.3
Wheezing or whistling (past 12 months)	**20.1**	**12.0**	--[7]	--[7]	**28.7**	**12.4**	**15.7**	**12.4**
Asthma composite: ≥1 of the above[8]	**23.8**	**16.0**	19.3	18.1	**29.4**	**15.2**	**20.1**	**15.5**
Shortness of Breath[5,6]								
Tire easily when physically active	--[7]	--[7]	**25.7**	**18.9**	--[7]	--[7]	--[7]	--[7]
Shortness of breath when hurrying or walking uphill	**25.8**	**18.4**			15.9	17.1	23.6	19.8

	Connecticut Adolescents		Northern California Adolescents		Southern California Young Adults: CHS[1]		Southern California Young Adults: HH[2]	
	E-Cigarette Use[3,4]		E-Cigarette Use[3,4]		E-Cigarette Use[3,4]		E-Cigarette Use[3,4]	
	Yes N=1447	No N=3420	Yes N=302	No N=1120	Yes N=195	No N=1213	Yes N=504	No N=2030
Ever stop for breath when walking on level ground[9]	**6.6**	**3.4**	--[7]	--[7]	2.6	1.8	3.6	3.8
Ever stop for breath when walking 100 yards[9]	**6.1**	**3.4**	--[7]	--[7]	2.6	1.6	2.4	3.2
Too short of breath to leave house or when dressing[9]	**3.3**	**1.4**	--[7]	--[7]	1.0	1.0	1.5	1.7
`Walk slower on level ground due to shortness of breath[9]	**5.2**	**3.7**	--[7]	--[7]	6.2	4.1	5.6	5.9
Shortness of breath composite: ≥1 of the above	**25.8**	**18.4**	**25.7**	**18.9**	15.9	17.1	23.6	19.8

1. Children's Health Study

2. Happiness and Health Study

3. Yes indicates use of e-cigarettes ≥1 day in the past 30 days; No indicates no use in the past 30 days

4. Sample size may be less than the total for some respiratory outcomes due to missing data

5. All values report as percent

6. Bold text in table cells indicates statistically significant (P<0.05) difference in prevalence of the respiratory outcome between past 30-day e-cigarette users and non-users, calculated separately for each study (chi-square test)

7. Survey item not included in the study questionnaire

8. Excludes ever doctor diagnosed asthma and ever wheezing or whistling

9. Items only asked of those who reported shortness of breath when hurrying or walking uphill

Table 3.

Self-Reported Adverse Respiratory Symptoms by Frequency of E-Cigarette Use

	Connecticut Adolescents		Northern California Adolescents		Southern California Young Adults: CHS[1]		Southern California Young Adults: HH[2]	
	%[3]	AOR[4] (95% CI)	%[3]	AOR[4] (95% CI)	%[3]	AOR[4] (95% CI)	%[3]	AOR[4] (95% CI)
Outcome: Bronchitis[5,6]								
E-cigarette use categories:[7]								
Never used e-cigarettes	21.4	reference	26.0	reference	20.1	reference	14.2	reference
Ever used but 0 days in past 30 days	21.7	1.01 (0.83, 1.22)	28.9	1.11 (0.77, 1.60)	26.6	1.21 (0.90, 1.62)	17.0	1.02 (0.75, 1.39)
1–5 days in past 30 days	23.7	1.13 (0.91, 1.40)	32.9	1.14 (0.79, 1.65)	33.8	1.25 (0.70, 2.23)	15.9	0.89 (0.54, 1.45)
6–30 days in past 30 days	30.0	**1.57 (1.30, 1.89)**	43.0	**1.52 (1.22, 1.90)**	42.5	**2.07 (1.23, 3.49)**	23.2	1.34 (0.89, 2.01)
Outcome: Asthma[5,6]								
E-cigarette use categories:[7]								
Never used e-cigarettes	16.3	reference	17.3	reference	14.7	reference	14.6	reference
Ever used but 0 days in past 30 days	15.0	0.90 (0.72, 1.12)	20.5	1.15 (0.73, 1.82)	16.0	0.92 (0.66, 1.30)	18.1	1.17 (0.86, 1.58)
1–5 days in past 30 days	20.1	**1.27 (1.01, 1.59)**	17.0	0.76 (0.48, 1.17)	32.5	1.78 (0.96, 3.28)	25.2	**1.67 (1.09, 2.57)**
6–30 days in past 30 days	26.7	**1.85 (1.52, 2.26)**	22.5	0.98 (0.59, 1.64)	27.9	1.61 (0.89, 2.93)	18.5	1.04 (0.68, 1.58)
Outcome: Shortness of breath[5,6]								
E-cigarette use categories:[7]								
Never used e-cigarettes	17.9	reference	19.4	reference	15.2	reference	18.2	reference
Ever used but 0 days in past 30 days	19.9	1.10 (0.90, 1.35)	17.3	0.81 (0.57, 1.14)	18.9	1.24 (0.90, 1.73)	22.7	1.15 (0.87, 1.52)
1–5 days in past 30 days	22.4	1.23 (0.98, 1.53)	18.0	0.77 (0.45, 1.32)	23.4	1.92 (0.99, 3.73)	26.3	**1.56 (1.02, 2.40)**
6–30 days in past 30 days	28.5	**1.87 (1.53, 2.28)**	35.9	**1.88 (1.37, 2.59)**	11.5	0.89 (0.41, 1.92)	22.7	1.42 (0.95, 2.11)

1. Children's Health Study

2. Happiness and Health Study

3. Prevalence of the respiratory outcome in each e-cigarette use category

4. Odds ratios from logistic regression models adjusted for gender, race/ethnicity, school lunch program participation (adolescents), personal income (young adults), age, past 30-day combustible tobacco, past 30-day use of cannabis. Missing covariable values multiply imputed for California samples.

[5]Composite outcome, including ≥1 symptom (see: Table 2)

[6]Bold text in table cells indicates statistically significant ($P<0.05$) difference in odds of the respiratory outcome compared to reference, calculated separately for each study

[7]Based on number of days used the most-frequently used e-cigarette device type

Abbreviations: AOR = adjusted odds ratio; CI = confidence interval

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Table 4.

Self-Reported Adverse Respiratory Symptoms by E-Cigarette Device Type

	Connecticut Adolescents		Northern California Adolescents		Southern California Young Adults: CHS[1]		Southern California Young Adults: HH[2]	
	%[3]	AOR[4] (95% CI)	%[3]	AOR[4] (95% CI)	%[3]	AOR[4] (95% CI)	%[3]	AOR[4] (95% CI)
Outcome: Bronchitis[5,6]								
E-cigarette use categories:[7]								
Pods, including JUUL	26.5	reference	29.2	reference	38.8	reference	20.7	reference
Vape pens/tanks	25.1	1.01 (0.71, 1.46)	41.3	1.72 (0.88, 3.37)	37.5	0.80 (0.27, 2.37)	16.2	0.77 (0.36, 1.65)
Disposables	27.1	1.08 (0.59, 1.96)	39.5	1.38 (0.87, 2.19)	--[7]	--[7]	15.4	0.68 (0.13, 3.47)
Mods, including box mods	29.4	1.21 (0.65, 2.27)	27.8	1.32 (0.54, 3.19)	37.1	0.78 (0.38, 1.60)	25.9	1.35 (0.67, 2.73)
Multiple devices	31.9	1.27 (0.91, 1.76)	41.8	1.51 (0.70, 3.25)	--[8]	--[8]	--[8]	--[8]
Outcome: Asthma[5,6]								
E-cigarette use categories:[7]								
Pods, including JUUL	23.2	reference	15.1	reference	27.1	reference	22.0	reference
Vape pens/tanks	22.4	1.14 (0.78, 1.65)	21.3	1.79 (0.83, 3.85)	25.0	0.85 (0.24, 3.01)	21.2	1.04 (0.52, 2.08)
Disposables	17.2	0.73 (0.37, 1.44)	17.3	1.51 (0.71, 3.24)	--[7]	--[7]	23.1	1.12 (0.28, 4.45)
Mods, including box mods	14.8	0.64 (0.29, 1.39)	16.7	1.78 (0.36, 8.70)	37.7	1.41 (0.63, 3.13)	19.0	0.82 (0.39, 1.71)
Multiple devices	**31.5**	**1.54 (1.10, 2.14)**	**25.9**	**2.10 (1.07, 4.15)**	--[8]	--[8]	--[8]	--[8]
Outcome: Shortness of breath[5,6]								
E-cigarette use categories:[7]								
Pods, including JUUL	25.9	reference	22.2	reference	11.8	reference	22.0	reference
Vape pens/tanks	21.4	0.85 (0.58, 1.26)	26.6	1.34 (0.39, 4.69)	29.2	2.62 (0.74, 9.21)	33.8	1.48 (0.79, 2.79)
Disposables	20.3	0.72 (0.37, 1.38)	34.2	1.80 (0.87, 3.75)	--[7]	--[7]	15.4	0.74 (0.15, 2.79)
Mods, including box mods	18.2	0.58 (0.28, 1.20)	22.2	1.42 (0.21, 9.46)	18.6	1.43 (0.53, 3.90)	20.3	0.90 (0.43, 1.88)
Multiple devices	**32.9**	**1.46 (1.04, 2.06)**	18.2	0.75 (0.26, 2.19)	--[8]	--[8]	--[8]	--[8]

1. Children's Health Study

2. Happiness and Health Study

3. Prevalence of the respiratory outcome in each e-cigarette use category

4. Odds ratios from logistic regression models restricted to past 30-day e-cigarette users and adjusted for gender, race/ethnicity, school lunch program participation (adolescents), personal income (young adults), age, past 30-day combustible tobacco, past 30-day use of cannabis, and past 30-day frequency of e-cigarette use (1–5 days vs. 6–30 days). Missing covariable values multiply imputed for California samples.

5. Composite outcome, including ≥1 symptom (see: Table 2)

6. Bold text in table cells indicates statistically significant (P<0.05) difference in odds of the respiratory outcome compared to reference, calculated separately for each study

7. Based on most-frequently used e-cigarette device type in the past 30 days

8. Response option not included in the study questionnaire

Abbreviations: AOR = adjusted odds ratio; CI = confidence interval