Drug and Alcohol Dependence Reports 7 (2023) 100157

Contents lists available at ScienceDirect

Drug and Alcohol Dependence Reports

journal homepage: www.elsevier.com/locate/dadr

Associations between e-cigarette policies and adolescent use and access to e-cigarettes

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HIGHLIGHTS

- MLSA laws for e-cigarettes had conflicting short and longer-term associations with use.
- After 1-year, MLSA laws were no longer associated with e-cigarette use.
- E-cigarette taxes were associated with decreases in e-cigarette use.
- After 1-year, smoke-free legislation was associated with decreases in e-cigarette use.
- MLSA laws were associated with decreases in store purchases, but increases in acquiring e-cigarettes from others.

ARTICLE INFO

Keywords:
Adolescent
E-cigarettes
Smoke-free legislation
Taxes

ABSTRACT

Background: Tobacco control policies have been adapted to address rising levels of adolescent e-cigarette use. Despite new restrictions, adolescents are continuing to access e-cigarettes.
Methods: We linked 2015–2019 Youth Risk Behavior Survey data on 503,154 14–18-year-olds from 40 states with state-level e-cigarette minimum legal sales age (MLSA) laws, taxes, and smoke-free legislation. Using two-way fixed effects probit regression models, we first examined the associations between these statewide e-cigarette policies and adolescent use and, second, with access to e-cigarettes. We subsequently tested interactions between age and each policy and present average marginal effects as percentage point (pp) changes.
Results: While MLSA laws for e-cigarettes were associated with slight increases in e-cigarette use (2.72 pp; 1.29, 4.15), associations were no longer significant after at least 1-year post-implementation. MLSA laws were also associated with decreases in e-cigarette purchases in stores (-9.50 pp; -18.21, -0.79) and increases in acquiring them from someone else (13.26 pp; 4.10, 22.42), particularly among 18-year-olds. E-cigarette taxes were associated with decreases in use (-9.18 pp; -11.63, -6.73), but there were limited associations with e-cigarette access. While smoke-free legislation prohibiting e-cigarettes was associated with slight increases in use (1.87 pp; 0.23, 3.50), after at least 1-year post-implementation, they were associated with decreases in use. Smoke-free legislation was also associated with decreases in purchases in stores by 14-year-olds, but increases in online purchases by 18-year-olds.
Conclusion: Understanding the immediate and longer-term consequences of e-cigarette policies is essential to influence adolescent e-cigarette use. Adolescents will continue acquiring e-cigarettes across varying sources if measures are not taken to address access alongside policies aimed at reducing use.

1. Introduction

Prior to the COVID-19 pandemic, past 30-day e-cigarette use among adolescents reached a high of 27.5% in 2019 (Gentzke et al., 2020). Despite recent declines, e-cigarettes continue to be the most commonly used tobacco product (Gentzke et al., 2022, 2020). Policies to address combustible cigarette use and secondhand exposure–age restrictions, taxes, and smoke-free legislation–have been adapted to tackle

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https://doi.org/10.1016/j.dadr.2023.100157
Received 12 January 2023; Received in revised form 24 March 2023; Accepted 4 April 2023
Available online 6 April 2023

adolescent e-cigarette use (US Department of Health and Human Services, 2016). Tobacco control policies aim to reduce access to e-cigarettes by implementing barriers to purchasing through increases in the minimum legal sales age (MLSA) and higher costs or by limiting locations for use.

Prior to the federal Tobacco 21 (T21) law in December 2019 prohibiting the sales of all tobacco products to those under aged 21 years, the majority of states had already raised the MLSA for e-cigarettes to at least age 18 years or implemented their own T21 law. A federal MLSA of age 18 years for e-cigarettes also came into effect in August 2016 (US Food and Drug Administration, 2019). Evaluations of T21 laws in California, Hawaii, and Maine have reported mixed results on adolescent e-cigarette use (Choi et al., 2021; Grube et al., 2021; Schiff et al., 2021). E-cigarette taxes vary in terms of the components that are taxed, limiting comparability across states (Centers for Disease Control and Prevention (CDC), 2022). One study examined the effects of any e-cigarette tax on adolescent use (Choi et al., 2021), while others have investigated price sensitivity and found varying results (Cantrell et al., 2020; Pesko et al., 2018). Although there is evidence that the enactment of smoke-free legislation reduces adolescent use of combustible cigarettes (Garritsen et al., 2022; Hawkins et al., 2016), the effects of legislation to prohibit the use of e-cigarettes indoors has received little attention (Choi et al., 2021). Overall, gaps remain on the effectiveness of e-cigarette-related policies on adolescent e-cigarette use. Research has been limited by the number of states included, the lack of quasi-experimental methods with comparisons across states, and control for the broader tobacco policy context.

Despite these new restrictions, adolescents are continuing to access e-cigarettes. Although the majority of adolescents report obtaining e-cigarettes from social sources (Baker et al., 2019; Gentzke et al., 2022; Meyers et al., 2017), there is evidence that older adolescents of legal purchasing age are more likely to obtain them commercially (Baker et al., 2019). However, even with local laws restricting access, research has shown that underage users are still able to purchase products in stores and online (Baker et al., 2019; Chois et al., 2021; Cwalina et al., 2021; Meyers et al., 2017; Williams et al., 2015).

Capitalizing on the natural experiment created with the implementation of state-wide MLSA laws, taxes, and smoke-free legislation for e-cigarettes, we linked policy data to adolescents from 40 states who participated in the Youth Risk Behavior Survey (YRBS) as information on e-cigarette use was first collected in 2015 and accessing e-cigarettes in 2017. Our aims were to first examine the associations between these three statewide e-cigarette policies and adolescent use and, second, with access to e-cigarettes. We examined these associations overall as well as tested differential policy effects by age.

2. Materials and methods

2.1. Data source

The YRBS is a biennial, cross-sectional, state-representative survey conducted by the Centers for Disease Control and Prevention (CDC) to monitor the health and health-related behaviors of adolescents (CDC, 2021a; Underwood et al., 2020). Each state uses a two-stage, cluster sample design to produce representative samples of 9–12th grade students from public and private schools who complete a self-administered questionnaire. The CDC requires a minimum overall response rate of 60% (Underwood et al., 2020).

We analyzed 2015, 2017, and 2019 data on 512,442 adolescents from 40 states with at least 2 years of data collection–39 states via the CDC and we received data directly from Massachusetts (CDC, 2021a; Underwood et al., 2020). We excluded adolescents if they were missing information on sex (4218), age (1258), or if they were younger than 14 years old (3812). The final analytic sample to examine the associations between e-cigarette policies and use included 503,154 adolescents. Starting in 2017, a subset of states asked adolescents about how they accessed e-cigarettes. The final analytic sample to examine the associations between e-cigarette policies and access to e-cigarettes included 47,738 adolescent e-cigarette users from 26 states. The Institutional Review Board at Boston College considered this study exempt.

2.2. Current and frequent E-cigarette use

Current and frequent e-cigarette use was determined through two questions. First, adolescents were asked, “Have you ever used an electronic vapor product?” (yes/no). If yes, adolescents were asked, “During the last 30 days, on how many days did you use an electronic vapor product?” (0, 1–2, 3–5, 6–9, 10–19, 20–29, or all 30 days). We defined current e-cigarette use as yes (1–30 days) versus no (0 days). Among e-cigarette users, frequent use was defined as use on 20+ days in the past month (yes) versus 1–19 days (no).

2.3. E-cigarette access

In 2017 and 2019, adolescents were asked “During the past 30 days, how did you usually get your own electronic vapor products?”: (1) I did not use any electronic vapor products during the past 30 days; (2) I bought them in a store such as a convenience store, supermarket, discount store, gas station, or vape store; (3) I got them on the Internet; (4) I gave someone else money to buy them for me; (5) I borrowed them from someone else; (6) A person who can legally buy these products gave them to me; (7) I took them from a store or another person; (8) I got them some other way. Adolescents selected one response only. Among e-cigarette users, we created three dichotomous measures to indicate the most common categories of how adolescents access e-cigarettes (Baker et al., 2019; Gentzke et al., 2022; Meyers et al., 2017): First, from a store (response 2); second, from the internet (response 3); and third, from someone else (responses 4, 5, or 6).

2.4. Demographics

Adolescents reported their age (14, 15, 16, 17, 18 years), race and ethnicity (White, Black, Hispanic, Other), and sex (male, female). As there is a high degree of dual use of e-cigarettes and conventional cigarettes (Glasser et al., 2021), we included an indicator of current cigarette use defined as use on 0 (no) versus 1–30 (yes) days. Missing values for race and ethnicity and cigarette use were coded to be retained in the analyses.

2.5. E-cigarette policies

We linked the effective dates of three statewide e-cigarette policies to each adolescent based on the state and year of survey completion (CDC, 2021b): MLSA laws, taxes, and smoke-free restaurant legislation. A MLSA law for e-cigarettes determines the minimum legal age an individual can be sold e-cigarettes. Eighteen-year-olds who resided in states with a MLSA of 18 years were coded as not exposed to the policy throughout the study period as the policy allows 18-year-olds to purchase e-cigarettes. Since laws restricting access could indirectly influence other age groups, we also created a dichotomous, state-level indicator of any MLSA law for e-cigarettes below age 21 years. Due to the variability in e-cigarette taxation in each state (CDC, 2022), taxes were assessed solely on the basis of whether a statewide tax was in effect (yes/no). We used smoke-free restaurant legislation for e-cigarettes as a proxy for state smoke-free e-cigarette policies due to the overlap with smoke-free workplace legislation (CDC, 2021b).

We also linked two statewide policies for conventional cigarettes to control for the broader tobacco control policy environment: taxes (translated into real 2019 dollars) and smoke-free restaurant legislation (CDC, 2021b). States were coded as having implemented each policy (yes/no) if it was in effect by April 1st of the survey year, as month was not available but surveys were generally completed in the spring

(Underwood et al., 2020).

2.6. Statistical analysis

We assessed the associations between e-cigarette use with adolescent demographic characteristics (age, race and ethnicity, sex), and cigarette use. Among e-cigarette users, we then assessed characteristics of frequent e-cigarette use. Logistic regression models included year and state fixed effects to account for time trends and time-invariant state characteristics, respectively.

To address our first study aim, we conducted two-way fixed effects probit regression models (De Chaisemartin and D'Haultfoeuille, 2020), to evaluate the associations between three statewide e-cigarette policies (MLSA laws, taxes, smoke-free legislation) and e-cigarette use, controlling for demographic characteristics, cigarette use, cigarette taxes, smoke-free legislation for cigarettes, and state and year fixed effects. Policies were included as simultaneous regressors in the model. As MLSA laws vary by age, we subsequently tested an interaction between age and each e-cigarette policy, separately, which was evaluated using a Wald test. Only interactions that were jointly significant at $p \leq 0.05$ level were retained. We repeated this series of models to assess frequent use among current e-cigarette users.

We conducted three sensitivity analyses with the main models for current and frequent e-cigarette use. First, we removed states with T21 laws (California, Hawaii, Maine, Massachusetts), in order to isolate the effect of MLSA laws for e-cigarettes of 18 or 19 years only. Second, we replaced the individual-level indicator of the MLSA law with a state-level indicator of any MLSA law below age 21 years to test the broader effects of the policy on social norms. Third, we generated a 1-year lag for all three e-cigarette policies to test their effectiveness after fully being in place at least 1 year prior to the typical cut-off of April 1st of the current survey year.

For our second study aim, we conducted a series of models among current e-cigarette users to assess the associations between e-cigarette policies and accessing e-cigarettes using 2017 and 2019 data. We first assessed the associations between each type of access (Store, Internet, Someone else) with demographic characteristics (age, race and ethnicity, sex) and cigarette use. State and year fixed effects were

Table 1
Characteristics of states and e-cigarette policies, 2015–2019 (N = 503 154).

State[a]	Years	N	%[b]	Mean%[b] E-cigarette use	Mean%[b,c] Frequent e-cigarette use	MLSA[d] for e-cigarettes (age 18 years unless specified)	Any e-cigarette tax	Smoke-free legislation for e-cigarettes
Alabama	15,19	3172	2.0	21.9	22.4	Aug 1, 2013 (19)		
Alaska	15–19	4287	0.3	19.5	18.8	Aug 22, 2012 (19)		
Arizona	15–19	5795	2.8	20.8	25.2	Sep 13, 2013		
Arkansas	15–19	5705	1.3	21.3	27.0	May 1, 2015[e]		
California	15–19	4725	15.6	19.0	14.3	Sep 27, 2010 (18), Jun 9, 2016 (21)	Apr 1, 2017	Jun 9, 2016
Colorado	17–19	2751	2.4	27.4	27.7	Mar 25, 2011		Jul 1, 2019
Delaware	15–17	5294	0.4	18.6	13.6	Jun 12, 2014[e]	Jan 1, 2018	Oct 5, 2015
Hawaii	15–19	16,918	0.4	26.8	23.8	Jun 27, 2013 (18), Jan 1, 2016 (21)		Jan 1, 2016
Idaho	15–19	4388	0.8	20.5	24.3	Jul 1, 2012		
Illinois	15–19	9575	5.2	20.0	25.0	Jan 1, 2014[e]	Jul 1, 2019	
Iowa	17–19	2774	1.3	14.3	32.4	Jul 1, 2014		
Kansas	17–19	3390	1.3	16.0	32.1	Jul 1, 2012	Jul 1, 2017	
Kentucky	15–19	5842	1.8	21.0	25.8	Apr 10, 2014		
Louisiana	17–19	1989	1.6	17.2	29.7	May 28, 2014	Jul 1, 2015	
Maine	15–19	25,359	0.6	20.6	20.9	Jul 1, 2018 (21)		Oct 14, 2015
Maryland	15–19	134,239	2.4	18.5	16.9	Oct 1, 2012[e]		
Massachusetts	15–19	8374	2.9	25.2	21.9	Dec 31, 2018 (21)		Dec 31, 2018
Michigan	15–19	9763	3.9	19.7	26.0	Sep 2, 2019		
Mississippi	15,19	3508	1.2	21.9	22.1	Jul 1, 2013		
Missouri	15–19	3957	2.4	18.1	26.0	Oct 10, 2014		
Montana	15–19	11,959	0.4	27.2	24.3	Jan 1, 2016		
Nebraska	15–19	3929	0.8	16.2	20.9	Apr 9, 2014		
Nevada	15–19	4285	1.3	21.5	19.2	Oct 1, 2015		
New Hampshire	15–19	38,526	0.6	27.3	27.4	Jul 31, 2010 (18), Jul 1, 2019 (19)		
New Mexico	15–19	21,065	1.0	27.5	17.9	Jun 19, 2015	Jul 1, 2019	Jun 14, 2019
New York	15–19	29,988	7.2	19.3	21.2	Jan 1, 2013[e]	Dec 1, 2019	Nov 22, 2017
North Carolina	15–19	11,833	4.6	29.0	23.1	Aug 1, 2013	Jun 1, 2015	
North Dakota	15–19	6056	0.3	25.5	24.4	Aug 1, 2015		Dec 6, 2012
Oklahoma	15–19	4640	1.7	22.4	25.4	Nov 1, 2014		
Pennsylvania	15–19	7960	4.8	20.1	25.8		Jul 13, 2016	
Rhode Island	15–19	6849	0.4	22.9	22.7	Jan 1, 2015		Jul 1, 2018
South Carolina	15–19	3559	1.8	17.3	24.4	Jun 7, 2013		
South Dakota	15,19	2527	0.4	20.1	28.1	Jul 1, 2014		Jul 1, 2019
Tennessee	15–19	7621	2.7	18.2	22.9	Jul 1, 2015		
Texas	17–19	3484	13.0	14.4	29.5	Oct 1, 2015[e]		
Utah	17–19	2865	1.5	8.6	34.9	May 11, 2010 (19)		May 8, 2012
Vermont	15–19	54,625	0.3	17.4	27.9	Jul 1, 2013[d]	Jul 1, 2019	Jul 1, 2016
Virginia	15–19	11,912	3.6	16.2	25.1	Jul 1, 2014[e]		
West Virginia	15–19	4051	0.7	26.8	28.8	Jun 6, 2014	Jul 1, 2016	
Wisconsin	17–19	3433	2.4	16.0	35.5	Apr 20, 2012	Jul 5, 2019	

[a] Among the 47 states that participated in the YRBS, 7 states were excluded. Five states had only one year of data from 2015 to 2019 (Georgia, Indiana, New Jersey, Ohio, Wyoming) and 2 states did not ask about e-cigarette use across at least two survey years (Connecticut, Florida).
[b] Weighted.
[c] Frequent use defined as use on 20+ days per month among e-cigarette users (N = 106,125).
[d] Minimum legal sales age.
[e] State T21 law in effect from July 2019 onwards, which occurred after YRBS data collection in Spring 2019.

included in all models. We then conducted separate two-way fixed effects probit regression models to evaluate the associations between e-cigarette policies and each type of access overall, and according to age.

We calculated average marginal effects to present the change in the probability of each outcome (e-cigarette use, frequent use, and each type of access) with the implementation of each e-cigarette policy. We present average marginal effects as percentage point changes both overall and, based on significant interactions from Wald tests ($p \leq 0.05$), stratified by age.

We conducted analyses using Stata statistical software, version 17.0 (StataCorp, College Station, TX), with 'svy' commands to account for the complex survey design and 'subpop' commands for analyses among e-cigarette users. We included sampling and nonresponse weights to generate state-representative estimates (Underwood et al., 2020).

3. Results

3.1. Policy summary

The period from 2015 to 2019 represented an active time of policy change for e-cigarettes: 12 states implemented MLSA laws, 8 states implemented smoke-free legislation, and 7 states implemented taxes (Table 1). However, there was minimal overlap between policies as the correlation coefficients ranged from r=−0.08 to 0.02.

3.2. Current and frequent e-cigarette use

Overall, 19.5% of adolescents currently used e-cigarettes, ranging from 8.6% in Utah to 29.0% in North Carolina (Table 1). E-cigarette use increased with age, was higher among males than females, and cigarette users were nearly 17 times more likely to use e-cigarettes than non-users (Table 2). In contrast, current e-cigarette use was lower among Black, Hispanic, and adolescents who identify as Other than White adolescents. Among e-cigarette users, 23.4% reported being frequent users, ranging across states (Table 1). Demographic patterns were overall consistent for frequent e-cigarette use (Table 2). Trends in use varied, such that there was only a small increase in e-cigarette use in 2019 compared to 2015; while, adolescents in 2019 were nearly four times as likely to be frequent users than in 2015.

3.3. Associations between statewide e-cigarette policies and use

We found conflicting results for the associations between MLSA laws and taxes for e-cigarettes with adolescent use immediately after they were implemented, but no differential effects by age (Table 3). State MLSA laws were associated with increases in e-cigarette use by 2.72 percentage points. In contrast, taxes were associated with decreases in e-cigarette use by 9.18 percentage points. We found some evidence that smoke-free legislation for e-cigarettes increased e-cigarette use by 1.87 percentage points.

Among e-cigarette users, we also found that the introduction of e-cigarette taxes was associated with a 6.45 percentage point reduction in frequent use overall, with no differential effects by age (Table 3). Although there were no overall associations between MLSA laws for e-cigarettes and frequent use, a significant interaction ($p = 0.04$) revealed that 15-year-olds were less likely to frequently use e-cigarettes after their implementation. The implementation of smoke-free legislation for e-cigarettes was not associated with frequent use overall or by age.

Supplemental Table 1 presents the results of the three sensitivity analyses with the main models. First, in excluding the four states with T21 laws, we found that the association between MLSA laws and e-cigarette use was attenuated, but remained significant. Second, we found consistent results when substituting a state-level indicator of MLSA laws for an individual-level indicator. Third, a 1-year lag for the e-cigarette-related policy variables indicated that MLSA laws were no longer associated with current or frequent use, while smoke-free legislation was associated with decreases in use. E-cigarette taxes continued to be associated with decreases in use after the 1-year lag.

3.4. Associations between e-cigarette policies and e-cigarette access

The 26 states with information available on e-cigarette access were representative in terms of e-cigarette policies, although only a few states implemented them from 2017 to 2019 (Supplemental Table 2). Overall, 62.2% of adolescent e-cigarette users reported accessing e-cigarettes from someone else, 19.2% from a store, and 4.4% from the internet.

Table 2
Characteristics of adolescent e-cigarette use and frequent e-cigarette use (among users), 2015–2019.

	Current e-cigarette use (N = 503,154)				Frequent e-cigarette use (among users) (N = 106,125)			
	N	%[a]	Mean%[a] e-cigarette use	Adjusted OR[c] (95% CI)	N	%[a]	Mean%[a,b] Frequent e-cigarette use	Adjusted OR[c] (95% CI)
Age								
14	79,111	12.5	13.8	1	11,914	8.9	13.4	1
15	136,153	25.5	16.2	1.21 (1.12, 1.31)	25.144	21.2	18.1	1.35 (1.08, 1.68)
16	131,962	25.4	19.7	1.47 (1.34, 1.62)	28,981	25.7	22.0	1.63 (1.33, 2.01)
17	111,833	23.6	22.2	1.63 (1.48, 1.79)	27,821	27.0	26.9	2.04 (1.66, 2.50)
18	44,095	12.9	25.9	1.83 (1.66, 2.02)	12,265	17.1	31.8	2.48 (2.05, 3.01)
Race and ethnicity								
White	275,364	49.3	22.4	1	61,558	56.8	27.6	1
Black	62,607	13.4	13.5	0.61 (0.57, 0.65)	8991	9.3	12.7	0.44 (0.37, 0.53)
Hispanic	83,242	25.0	17.7	0.77 (0.71, 0.85)	18,952	22.8	18.2	0.65 (0.55, 0.77)
Other	69,817	9.8	16.7	0.68 (0.61, 0.75)	14,086	8.5	22.1	0.81 (0.70, 0.94)
Missing	12,124	2.4	21.1	0.91 (0.79, 1.04)	2538	2.6	21.3	0.77 (0.56, 1.05)
Sex								
Female	255,771	49.2	18.2	1	51,043	46.0	18.0	1
Male	247,383	50.8	20.7	1.10 (1.06, 1.15)	55,082	54.0	28.0	1.85 (1.64, 2.07)
Cigarette use								
No	448,309	84.4	14.3	1	72,080	61.9	20.1	1
Yes	39,000	7.2	73.5	16.69 (15.36, 18.13)	28,168	27.1	32.7	2.09 (1.88, 2.33)
Missing	15,845	8.5	25.4	2.01 (1.72, 2.34)	5877	11.1	19.4	1.09 (0.89, 1.33)
Year								
2015	187,209	27.7	23.0	1	40,148	32.8	13.3	1
2017	165,014	35.5	14.2	0.55 (0.52, 0.60)	25,726	25.9	19.1	1.43 (1.24, 1.66)
2019	150,931	36.8	21.9	1.09 (1.02, 1.17)	40,251	41.4	34.1	3.86 (3.50, 4.25)

[a] Weighted.
[b] Frequent use defined as use on 20+ days per month among e-cigarette users.
[c] State fixed effects are not shown.

Table 3
Marginal effects presented as percentage point changes for the associations between changes in state e-cigarette policies and e-cigarette use and, separately, frequent e-cigarette use (among users) from two-way fixed effects probit regression models.

	MLSA law for e-cigarettes	p-value	Any e-cigarette tax	p-value	Smoke-free legislation for e-cigarettes	p-value
	Percentage point change from marginal effect[b] (95% CI)		Percentage point change from marginal effect[b] (95% CI)		Percentage point change from marginal effect[b] (95% CI)	
E-cigarette use	2.72 (1.29, 4.15)	<0.001	−9.18 (−11.63, −6.73)	<0.001	1.87 (0.23, 3.50)	0.03
Policy x age		0.08		0.4		0.08
Frequent[a] e-cigarette use	−0.48 (−3.14, 2.19)	0.7	−6.45 (−11.03, −1.87)	0.006	−3.30 (−6.83, 0.23)	0.07
Policy x age		0.04		0.8		0.4
14 years	−0.88 (−4.78, 3.03)	0.7				
15 years	−4.36 (−7.83, −0.89)	0.01				
16 years	−3.41 (−7.25, 0.42)	0.08				
17 years	−0.43 (−4.18, 3.32)	0.8				
18 years	3.92 (−2.63, 10.47)	0.2				

[a] Frequent use defined as use on 20+ days per month among e-cigarette users.
[b] Model includes adjustment for age, race and ethnicity, sex, cigarette use, cigarette taxes, smoke-free legislation for cigarettes, and state- and year-fixed effects.

However, demographic patterns varied based on the source (Table 4). Purchasing e-cigarettes from a store increased with age, while obtaining them from someone else decreased with age. Only 16–17-year-olds were more likely to access e-cigarettes from the internet than younger adolescents. There were no racial and ethnic differences in accessing e-cigarettes, except Black adolescents were more likely to obtain them online than White adolescents. Males were more likely to obtain e-cigarettes from a store than females, while they were less likely to obtain them from someone else. Adolescents who used cigarettes were more likely to obtain e-cigarettes online than non-users, but were less likely to obtain them from someone else. Adolescents were less likely to obtain e-cigarettes online in 2019 than 2017, but more likely to obtain them from someone else in 2019 than the prior survey year.

We found differential policy effects across the three sources of accessing e-cigarettes (Table 5). State MLSA laws for e-cigarettes were associated with decreases in adolescents purchasing e-cigarettes in a store by 9.50 percentage points, with a significant interaction by age ($p<0.001$) revealing this effect was larger among 18-year-olds (Table 5). Although the effect size was small, there was some evidence that MLSA laws were associated with increases in 14-year-olds obtaining e-cigarettes from stores. While we found no overall associations between smoke-free legislation for e-cigarettes and e-cigarette purchases in stores, a significant interaction ($p<0.001$) indicated that 14-year-olds were less likely to purchase them in stores after their implementation. State e-cigarette taxes were not associated with purchasing e-cigarettes in a store overall or by age.

While we found no overall associations between MLSA laws, smoke-free legislation, or taxes for e-cigarettes and purchasing them online overall, a significant interaction ($p<0.001$) revealed that implementation of smoke-free legislation was associated with increases in 18-year-olds purchasing e-cigarettes online (Table 5).

State MLSA laws for e-cigarettes were associated with increases in adolescents obtaining e-cigarettes from someone else by 13.26 percentage points, with a larger effect among 18-year-olds (interaction $p<0.001$) (Table 5). Although there were no overall associations between smoke-free legislation or taxes for e-cigarettes and obtaining them from someone else, a significant interaction with taxes ($p = 0.05$) revealed that 14-year-olds were more likely to obtain e-cigarettes from someone else after taxes were introduced.

Table 4
Characteristics of how adolescents access e-cigarettes (among e-cigarette users) ($N = 47\,738$), 2017–2019.

		In a store		On the internet		From someone else	
	N	%[a]	%[a]	Adjusted OR[b] (95% CI)	%[a]	Adjusted OR[b] (95% CI)	%[a]	Adjusted OR[b] (95% CI)
Age (years)								
14	5007	8.2	2.6	1	2.7	1	74.5	1
15	11,117	20.6	6.6	2.50 (1.45, 4.32)	3.9	1.51 (0.84, 2.69)	71.8	0.87 (0.65, 1.16)
16	13,006	25.6	12.1	4.75 (3.09, 7.31)	4.9	1.89 (1.02, 3.49)	67.5	0.72 (0.54, 0.96)
17	12,789	27.9	16.4	6.77 (4.24, 10.81)	5.0	1.88 (1.07, 3.28)	66.6	0.71 (0.52, 0.95)
18	5819	17.7	56.3	44.80 (28.59, 70.17)	4.0	1.37 (0.72, 2.60)	31.1	0.16 (0.12, 0.23)
Race and ethnicity								
White	33,024	57.2	20.7	1	3.9	1	63.0	1
Black	3341	7.1	22.1	1.15 (0.71, 1.85)	7.0	1.78 (1.08, 2.94)	58.1	0.77 (0.57, 1.05)
Hispanic	5398	24.9	15.2	0.76 (0.51, 1.12)	4.3	1.40 (0.97, 2.04)	61.4	0.80 (0.60, 1.06)
Other	4950	8.3	17.2	0.79 (0.55, 1.15)	5.0	1.29 (0.81, 2.04)	62.7	0.98 (0.75, 1.27)
Missing	1025	2.5	24.5	0.90 (0.40, 2.02)	6.3	1.53 (0.48, 4.86)	61.3	1.16 (0.69, 1.95)
Sex								
Female	23,293	46.4	13.9	1	2.6	1	71.2	1
Male	24,445	53.6	23.8	1.68 (1.39, 2.03)	5.9	2.25 (0.48, 4.86)	54.4	0.53 (0.47, 0.59)
Cigarette use								
No	34,168	57.3	17.4	1	3.4	1	66.9	1
Yes	12,221	28.0	23.2	1.12 (0.94, 1.33)	5.5	1.45 (1.03, 2.03)	54.0	0.69 (0.59, 0.82)
Missing	1349	14.7	18.7	1.86 (1.14, 3.02)	6.2	2.58 (1.77, 3.75)	59.8	0.54 (0.37, 0.80)
Year								
2017	17,784	38.5	18.7	1	6.0	1	58.9	1
2019	29,954	61.5	19.5	1.13 (0.91, 1.40)	3.4	0.54 (0.39, 0.75)	64.3	1.22 (1.07, 1.39)

[a] Weighted.
[b] State fixed effects are not shown.

Table 5
Marginal effects presented as percentage point changes for the associations between changes in state e-cigarette policies and how adolescents access e-cigarettes (among e-cigarette users) from two-way fixed effects probit regression models.

	MLSA law for e-cigarettes	p-value	Any e-cigarette tax	p-value	Smoke-free legislation for e-cigarettes	p-value
	Percentage point change from marginal effect[a] (95% CI)		Percentage point change from marginal effect[a] (95% CI)		Percentage point change from marginal effect[a] (95% CI)	
In a store	−9.50 (−18.21, −0.79)	0.03	−7.62 (−19.98, 4.73)	0.2	−4.06 (−11.51, 3.39)	0.3
Policy x age		<0.001		0.2		<0.001
14 years	2.74 (1.50, 3.97)	<0.001			−5.62 (−8.78, −2.47)	<0.001
15 years	3.20 (−0.37, 6.76)	0.08			−2.43 (−7.75, 2.89)	0.4
16 years	4.49 (−1.54, 10.53)	0.1			−5.36 (−13.02, 2.29)	0.2
17 years	0.03 (−7.87, 7.93)	1.0			−5.33 (−13.43, 2.77)	0.2
18 years	−38.49 (−49.46, −27.53)	<0.001			−2.31 (−18.05, 13.44)	0.8
On the internet	1.98 (−0.57, 4.53)	0.1	2.40 (−1.93, 6.74)	0.3	2.28 (−1.63, 6.18)	0.3
Policy x age		0.2		0.6		<0.001
14 years					−1.94 (−5.78, 1.90)	0.3
15 years					−1.29 (−5.49, 2.91)	0.5
16 years					3.91 (−2.41, 10.24)	0.2
17 years					−1.51 (−5.16, 2.14)	0.4
18 years					8.36 (0.85, 15.87)	0.03
From someone else	13.26 (4.10, 22.42)	0.005	7.45 (−6.68, 21.59)	0.3	1.44 (−8.88, 11.76)	0.8
Policy x age		<0.001		0.05		0.1
14 years	−1.32 (−13.69, 11.02)	0.8	16.90 (5.40, 28.40)	0.004		
15 years	1.78 (−8.85, 12.41)	0.7	6.85 (−6.58, 20.27)	0.3		
16 years	−4.17 (−15.34, 7.00)	0.5	8.82 (−7.89, 25.53)	0.3		
17 years	2.01 (−9.95, 13.97)	0.7	2.44 (−11.32, 16.21)	0.7		
18 years	26.92 (16.13, 37.70)	<0.001	2.71 (−12.62, 18.04)	0.7		

[a] Model includes adjustment for age, race and ethnicity, sex, cigarette use, cigarette taxes, smoke-free legislation for cigarettes, and state- and year-fixed effects.

4. Discussion

We found evidence that e-cigarette-related policies had conflicting short and longer-term associations with e-cigarette use and unintended consequences on how adolescents access e-cigarettes. Statewide MLSA laws which increased the legal sales age of e-cigarettes to 18 years or older were associated with slight increases in adolescent use immediately after they were implemented. Smoke-free legislation that prohibits e-cigarettes indoors were also associated with slight increases in current use. However, after policies were implemented for at least 1 year, these effects were altered in their magnitude and direction. MLSA laws were no longer associated with current use and smoke-free legislation was associated with decreases in current and frequent use. The introduction of any e-cigarette taxes was associated with decreases in current and frequent use (among users) immediately and over time, but there were limited associations with how adolescents accessed e-cigarettes. MLSA laws were associated with decreases in purchases of e-cigarettes in stores and increases in acquiring them from someone else, particularly among 18-year-olds. Smoke-free legislation was also associated with decreases in purchases in stores by 14-year-olds, but increases in online purchases by 18-year-olds. Our findings highlight the importance of understanding the immediate and longer-term consequences of recent e-cigarette policies as reducing e-cigarette use without simultaneously addressing how adolescents access these products may not achieve the desired goal.

States have been encouraged to adopt comprehensive tobacco control policies to address the high levels of adolescent e-cigarette use (US Department of Health and Human Services, 2016). Prior to the federal T21 law in December 2019, 49 states and DC had increased the MLSA for e-cigarettes to age 18, 19, or 21 years (CDC, 2021b). As of June 2022, 30 states and DC had legislation requiring a tax on e-cigarettes, including 12 states taxing per milliliter of liquid or consumable material and 15 states taxing a percentage of a specified cost (CDC, 2022). As of June 2022, 17 states and DC had passed smoke-free indoor air laws that prohibit e-cigarette use in worksites, restaurants, and bars (CDC, 2021b). As the tobacco control policy landscape for e-cigarettes evolves, our findings highlight the importance of continuing to monitor and evaluate the effects of these policies on adolescent e-cigarette use and access.

While state MLSA laws for e-cigarettes were superseded by federal laws, nearly all states and DC had previously enacted legislation to raise the MLSA of e-cigarettes to align with other tobacco products. In our sample, Pennsylvania was the only state without a MLSA for e-cigarettes by the end of the study period. We found that MLSA laws for e-cigarettes slightly increased use immediately, but had no effect on use after they were implemented for at least one year. In a sensitivity analysis, MLSA laws for e-cigarettes were not effective at curbing adolescent e-cigarette use even after excluding the four states with prior T21 laws. Similar to Choi et al. (2021), we found that MLSA laws for e-cigarettes decreased adolescent purchases of e-cigarettes in stores, but increased acquiring them from someone else, with the strongest effects among 18-year-olds. These results suggest that access to e-cigarettes may be maintained even with the introduction of new laws if they do not also help restrict access to products across multiple sources.

Seventeen states and DC enacted their own T21 law prior to the federal law and 24 states have since enacted one (Preventing Tobacco Addiction Foundation, 2022). Early evaluations of T21 laws on adolescent e-cigarette use have reported mixed results (Choi et al., 2021; Grube et al., 2021; Schiff et al., 2021). However, Schiff et al. (2021) found that after the enactment of the California T21 law, underage participants reported that it felt harder to purchase e-cigarettes, but few were unable to purchase them. Other studies have also reported minimal barriers for underage adolescents to purchase e-cigarettes in stores or online, further demonstrating the limited compliance with local laws (Cwalina et al., 2021; Meyers et al., 2017; Williams et al., 2015). In conjunction with our findings, this suggests that the compliance and enforcement of T21 laws in addition to adolescent access to e-cigarettes will be critical components to understanding their breadth and effectiveness.

Increasing tobacco taxes and prices are the most effective policies to reduce tobacco use (World Health Organization, 2021) and adolescents are price sensitive (Chaloupka et al., 2012). Although Choi et al. (2021) found that states with any e-cigarette tax had higher increases in the prevalence of adolescent e-cigarette use than those without, it was not possible to separate the policy effects from the state policy context since other tobacco policies were not controlled for in their models. In contrast, we found that the introduction of e-cigarette taxes decreased

current use by 9.18 percentage points with similar effects among frequent users, and some evidence that higher taxes increased accessing e-cigarettes from someone else among 14-year-olds. A continued challenge is the limited comparability of e-cigarette taxes across states due to differences in the components taxed and tax structure (CDC, 2022). Other studies have examined prices using retail scanner data and found that higher disposable e-cigarette prices reduced e-cigarette use (Pesko et al., 2018), but not rechargeable e-cigarette prices (Cantrell et al., 2020; Pesko et al., 2018), which likely reflects the products preferred by adolescents. While these findings together suggest that e-cigarette taxes and prices are likely effective, further research is needed on the most appropriate tax structures and amounts as well as the mechanisms for influencing adolescent e-cigarette use and accessing e-cigarettes.

There is evidence that the benefits of smoke-free legislation extend to adolescents by reducing current use of combustible cigarettes (Garritsen et al., 2022; Hawkins et al., 2016). Although legislation itself can reduce opportunities for use, decrease visibility of use, and alter social norms (Garritsen et al., 2022), there is limited known whether these effects also extend to legislation prohibiting indoor use of e-cigarettes. Choi et al. (2021) found the prevalence of e-cigarette use declined in states with e-cigarette-inclusive smoke-free legislation compared to those without, but challenges remain in identifying the effects of policies versus these states more broadly. We found that the implementation of smoke-free legislation for e-cigarettes was associated with increases in e-cigarette use immediately, but after at least 1 year, was associated with decreases in current and frequent use. Smoke-free legislation for e-cigarette was also associated with decreases in e-cigarette purchases in stores among 14-year-olds, but increases in online purchases among 18-year-olds. These results may signal that indoor e-cigarette restrictions reduce opportunities for use, but additional evaluation is needed as states continue to extend indoor smoke-free legislation to prohibit e-cigarettes.

4.1. Limitations

There are limitations to our study. The YRBS introduced e-cigarette questions in 2015, so there are only 3 survey periods available to examine the associations between e-cigarette policies and use and only 2 survey periods to examine e-cigarette access. It will be important to further evaluate e-cigarette policies, including the federal T21 law, as additional YRBS data are available in order to determine how they influence use and access over time. Although there are municipalities with local e-cigarette polices without state-wide legislation (American Nonsmokers' Rights Foundation, 2022), more granular geographical information is not available in the YRBS nor is the YRBS representative at these lower levels. The YRBS only asks about using e-cigarettes and related devices without collecting information on the frequency of use per day, the type of device, what is vaped and if nicotine, the concentration of nicotine. Although adolescents may have accessed e-cigarettes through multiple sources, they could only select one response from a list of potential sources that may not have been exhaustive. As the YRBS is based on self-report, there is also the potential for reporting bias. Although we tried to identify potential mechanisms for how e-cigarette policy changes influence adolescent use by examining sources of accessing e-cigarettes, the YRBS is cross-sectional and does not follow adolescents longitudinally to more fully understand the process of how policy changes alter patterns of use.

5. Conclusions

As states continue to restrict e-cigarettes through legislative and fiscal measures, our results provide evidence for the complexities and potentially unintended consequences of these relatively nascent policies. Our findings demonstrate that e-cigarette taxes and smoke-free legislation are likely effective at reducing adolescent use and frequent use among e-cigarette users in the longer-term. In contrast, statewide MLSA laws for e-cigarettes could have no effect on use over time. MLSA laws could also reduce purchases of e-cigarettes in stores, but increase access to these products from someone else. This suggests that adolescents will continue accessing e-cigarettes across varying sources if measures are not taken to address access alongside policies aimed at reducing use. Although we found few associations between e-cigarette policies and accessing e-cigarettes online, this source needs to be continually monitored as patterns may shift over time. The tobacco control policy landscape is evolving rapidly and as policies and products change, continued evaluation is needed to achieve the broader goal of reducing adolescent e-cigarette use.

Contributors

Ms. Pastrana participated in data collection, analysis, and interpretation and drafted the initial manuscript. Dr. Hawkins conceptualized and designed the study, participated in data collection, analysis, and interpretation, and drafted the initial manuscript. Dr. Baum participated in data analysis and interpretation, and reviewed and revised the manuscript. All authors approved the final manuscript as submitted.

Declaration of Competing Interest

The authors have no conflicts of interest to declare.

Funding

Ms. Pastrana was supported by a Boston College Global Public Health internship.

Role of Funding Source

The funder had no role in the study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.dadr.2023.100157.

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