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REVIEW ARTICLE

Regulatory Strategies for Preventing and Reducing Nicotine Vaping Among Youth: A Systematic Review

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Introduction: Many jurisdictions have implemented different regulatory strategies to reduce vaping among youth. The objective of this systematic review is to synthesize the evidence of the effectiveness of different regulatory strategies for preventing and reducing nicotine vaping among youth.

Methods: Five electronic databases were searched from January 1, 2004 to July 17, 2022 for primary studies examining state/provincial or national regulations targeting vaping among youth (aged 12–21 years) in high-income countries. The primary outcome was vaping prevalence. Included studies were qualitatively synthesized through systematic review.

Results: The systematic review included 30 studies. There was insufficient evidence to recommend age restrictions (n=16), restrictions on location of use (n=1), and mixed/combined regulations (n=3). Flavor bans (n=4), sales licenses (n=2), and taxation (n=2) were generally shown to be associated with decreased rates of youth vaping. Warning labels (n=2) were associated with a decreased desire to initiate vaping. Included studies had moderate-to-serious risks of bias.

Discussion: Although several regulatory interventions have been shown to be effective at reducing vaping among youth, evidence is insufficient to recommend a specific type of regulation. Regulatory authorities could implement various regulations targeting the price, accessibility, and desirability (i.e., flavors and packaging) of E-cigarettes.

INTRODUCTION

Globally, the use of nicotine E-cigarettes (also known as vaping nicotine) has increased substantially over the last decade,[1] and E-cigarettes are the most used substance by 8th and 10th graders in North America.[2] The liquids used in these often sleek and compact electronic vaping devices come in a variety of flavors that are highly appealing to youth.[3] E-cigarettes are commonly used by youth with no history of traditional cigarette use and are associated with respiratory health problems, cognitive impairment, and neurodevelopmental problems.[1] Interventions aimed at preventing nicotine vaping among youth are vital for preventing cigarette initiation and for E-cigarette harm reduction. Countries and states/provinces have introduced regulations that prevent youth access and use of

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these products, including bans on the sale of E-cigarettes to youth and increased taxation on vaping products.[4] To the best of the knowledge of this project's researchers, there has been only one previous knowledge synthesis analyzing the impact of regulatory strategies on youth vaping.[5] Sindelar et al. reported that age restrictions and flavor bans can prevent or reduce vaping among youth. However, this synthesis contained data from the U.S. that examined age restrictions and flavor bans only.[5] In addition, Cann et al. published a systematic review that assessed restrictions on use in public places.[6] However, it did not evaluate the impact of this type of regulation on youth vaping specifically. Klein et al. assessed international E-cigarette regulations and found that regulations such as flavor bans or marketing restrictions could theoretically curb vaping but did not provide evidence on whether these strategies work; their aim was to identify the range of existing interventions and not assess their effectiveness.[4] A recent study published by Taylor et al.[7] assessed regulatory strategies in North America. However, its intent was to synthesize current strategies and make recommendations for new regulations, and it was not a systematic review. There remains a need for a comprehensive systematic review of the effectiveness of such regulations implemented in high-income countries. Therefore, this study synthesized the evidence on the effectiveness of regulations to prevent vaping among youth at provincial/state and national levels in high-income countries.

METHODS

This systematic review follows a prespecified protocol registered in the PROSPERO registry (Number CRD4202126474).[8] It conforms with the PRISMA 2020 statement[9] and the Synthesis without Meta-Analysis guidelines.[10]

This review included both randomized and nonrandomized studies if they featured primary data on the impact of state/provincial or national government regulatory programs (or those affecting a large enough group to be considered comparable with a state), strategies, or policies with at least one element intended to prevent or decrease youth nicotine vaping. Strategies not directly targeting youth but still impacting youth (flavor bans and bans on place of use) were also eligible for inclusion. Abstracts, research letters, and other short communications were excluded because they did not contain enough information to sufficiently determine risk of bias. The eligible population targeted by restrictions was youth aged 12−21 years in high-income countries as defined by the World Bank in 2021 (GNI per capita > $12,695).[11] The review excluded regulations targeting the use of nonvaping tobacco products or tetrahydrocannabinol/marijuana-based vaping products only as were school-, municipal-, and community-based interventions. Eligible comparators included no regulation, previous forms of the same or different regulations, or another type of regulation. Studies with or without external comparators (other jurisdictions) were eligible. Outcomes of interest were (1) the prevalence, change in prevalence, or incidence of vaping among youths; (2) the prevalence, change in prevalence, or incidence of self-reported intention to vape among youths; and (3) the use of tobacco products (cigarettes, cigars, hookah, smokeless tobacco) or intention to use tobacco products among youths. The authors assessed tobacco use as an outcome to determine the impact that E-cigarette restrictions had on traditional cigarette use among youth.

Medline (Ovid), Embase, PsychINFO, Web of Science Core Collection, and ProQuest Public Health were searched from January 1, 2004 to July 17, 2022. Medline and Embase were chosen because of their high number of publications, and PsychINFO, Web of Science, and ProQuest Public Health were chosen because of their public health relevance. A 2004 start date was appropriate because this year was when the first E-cigarette became commercially available.[12] The search included search terms (index terms and keywords) for the following three concepts: *youth/adolescent, e-cigarette/vaping*, and *regulation/law*. An experienced health sciences librarian peer reviewed the search strategy (Appendix Table 1, available online) on the basis of the Peer Review of Electronic Search Strategies guidelines.[13] The authors also performed a gray literature search of the first ten pages of Google Scholar, www.clinicaltrials.gov, and the bibliographies of included studies. Two independent reviewers sequentially screened the publications found through the electronic search in three steps in DistillerSR (Evidence Partners, Ottawa, Canada), including titles, abstracts, and full texts of potentially eligible articles. Any publication deemed potentially relevant by either reviewer during the abstract review was carried forward to full-text review. The reviewers resolved disagreements at the level of the full-text screen by consensus or, if necessary, by consulting a third reviewer.

Two independent reviewers extracted data, with disagreements resolved by consensus or by consulting a third reviewer. Extracted study characteristics included title, first author, journal, publication year, study period, funding source, study design, location, unit of analysis, follow-up period, and outcome assessment method. Extracted population characteristics included country, age, sex, ethnicity, SES, educational level, sample size (overall and by intervention), vaping prevalence, and

conventional cigarette smoking prevalence. Extracted intervention characteristics included name of regulation, type of regulation, year of enactment, year of data collection, setting, target population (if applicable), and duration of intervention. The reviewers also extracted primary and secondary outcomes as they were reported in studies.

Two reviewers independently assessed the risk of bias in eligible studies using the ROBINS-I (Risk of Bias in Nonrandomized Studies - of Interventions) tool,[14] resolving any discrepancies through consensus or consultation with a third reviewer. To assess the risk of bias from confounding, the authors considered age and sex (if comparing multiple jurisdictions), SES, implementation date of policies, presence of other tobacco or marijuana policies, and cigarette smoking rates as the prespecified potential confounders that needed to be addressed (either by design or analytically). For each outcome of interest extracted from an included study, the risk of bias is reported within each of the seven domains as low, moderate, serious, critical, or no information. This review includes studies regardless of their assessed risk of bias; however, authors considered a risk of bias when drawing conclusions. The search found no randomized studies; therefore, it was not necessary to use the Cochrane Risk of Bias tool.

Results are grouped alphabetically by regulation type (e.g., taxation, restriction, and ban). The studies featured a variety of different interventions, which they separated into seven broad categories: taxation/price increases, age restrictions, flavor bans, limitations on the location of use, warning labels/packaging modifications, E-cigarette sales licenses, and mixed/combined interventions. Because included studies were heterogeneous in terms of study design, interventions, and outcomes, the authors synthesized findings qualitatively.

RESULTS

The database search generated 6,793 nonduplicate potentially eligible publications (Figure 1). A total of 183 publications underwent full-text review, of which 27 met the inclusion criteria. The reviewers identified 1 publication in the gray literature. Hand searching the bibliographies of included articles identified 2 additional eligible studies. Therefore, the systematic review included 30 publications.

A total of 27 studies described regulations in various U.S. states,[15−40,] 1 article described British regulations,[41] 1 article described Canadian regulations,[42] and 1 article compared regulations between 2 countries (the U.S. and the Republic of Korea)[43] (Table 1). Twenty-seven studies reported data exclusively on youth. Three studies included both adults and youth,[32,38,39] with mean ages ranging from 12 to 21 years. Study designs included 22 repeated cross-sectional studies,[11,15−20,23−26,28−30,32−34,37,38,41,44] 4 cross-sectional studies,[21,22,31,43] 2 cohort studies,[36,41] 1 pretest/post-test study,[36] and 1 quasiexperimental study.[42]

A total of 21 studies[15−28,44] exclusively evaluated laws involving age restrictions implemented at a variety of legislative levels, with the majority (n=11)[15,17−19,21,23−25,27,28,42] implemented at the provincial/state level (Table 1). Most studies in this category had a serious risk of bias; 5 had a moderate risk of bias (Appendix Table 2, available online).[18,19,22,26,40,42] Included studies reported a variety of outcomes. Thirteen reported the impacts of age restrictions on the prevalence of youth vaping, and 12 reported the impacts on traditional cigarette use. Seven[16,20,22,25,27,28,42] studies reported that increasing the legal age to purchase vaping products was associated with decreased use of vaping products, 5 studies[15,17,19,21,26] reported no significant change in vaping prevalence, and 1 study[44] reported that it was associated with increased rates of vaping. Of the 5 studies in this category with a moderate risk of bias that evaluated E-cigarette use, 2 found no change, with Ferrell et al. reporting an OR of 1.049 (95% CI=0.778, 1.416) and Schiff et al. finding a nonsignificant relative change of −3.5% in current E-cigarette use.[19,26] Macinko et al. found a significant difference when comparing a jurisdiction with an age restriction (New York City, 15.86% current users) with one without (Florida, 20.74% current users).[22] Overall, it was found that age restrictions were not strongly associated with either an increase or decrease in youth vaping.

Twelve[15,17−28,30,41] studies reported the impacts of E-cigarette age restrictions on cigarette smoking (i.e., to assess whether restricted access to E-cigarettes is associated with changes in the use of traditional tobacco products). Five studies reported that E-cigarette legislation decreased youth smoking.[15,18,22,25,28] Three[17,23,24] studies reported that the prevalence of cigarette smoking showed an absolute increase between 0.6% and 1.0% (Appendix Table 3 and 5, available online). Five studies[20,21,26,27,30] reported no significant change in tobacco use.

Regulations that ban or limit flavored E-cigarette products were evaluated in 4 studies,[29−32] of which 3[29,30,32] showed that such regulations decreased youth vaping (Table 1). One study showed no change in vaping prevalence in the jurisdiction with the flavor restriction, whereas a neighboring jurisdiction reported an increase.[30] One study showed no change (Table 3, Appendix Table 3 and 4, available online).[31] Included studies varied both in the type of ban implemented and the jurisdictional level of implementation. Two studies[30,32] assessed a flavor ban implemented by a

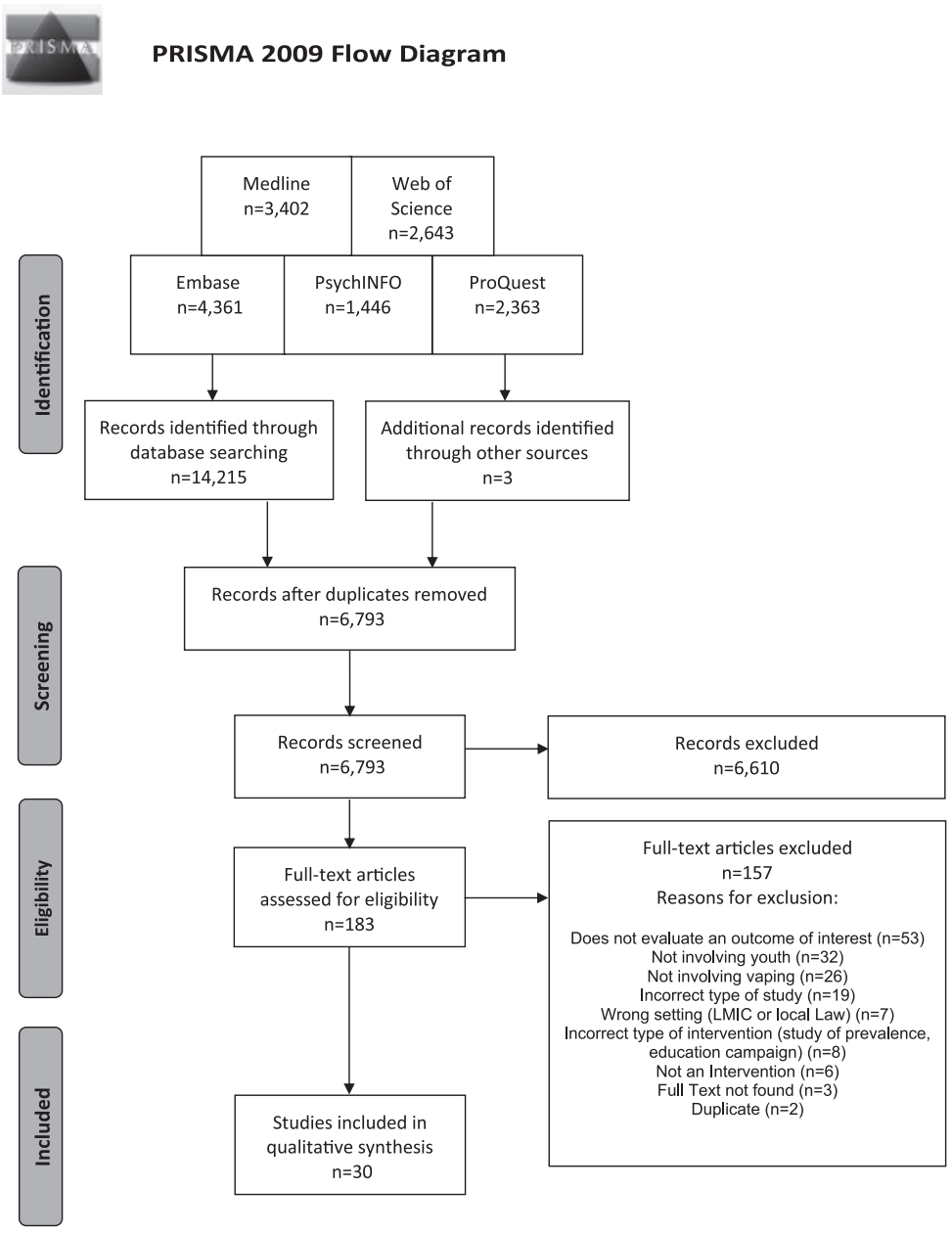

Figure 1. Prisma flow diagram of included studies. LMIC, lower-middle income countr.

government; 1 study assessed sales restrictions by local governments,[31] and 1 study[29] examined a self-imposed sales restriction by a corporation (Juul) (Table 3). The exact flavors banned varied by jurisdiction and study. All studies featured restrictions that banned various sweet flavors but retained flavors such as menthol and tobacco. Three studies[29,30,32] reported that flavor restrictions were associated with decreased use of vaping products in youth. Interestingly, 1 study found that banning flavors increased the use of a nonbanned flavor (mint).[29] It should be noted that since the publication of these studies, the U.S. Food and Drug Administration (FDA) has restricted some flavored disposable E-cigarettes, and a ban has been proposed in Canada, whereas the average monthly nicotine strength of E-cigarettes has continued to rise since 2017.[45] The FDA ban was also associated with a change in youth E-cigarette habits, with many teens/young adults using cartridge-based E-cigarettes soon after implementation of the ban and disposable E-cigarettes becoming more common during the pandemic lockdown of 2020.[46] Most studies in this category found an association between flavor bans and a reduced rate of

Table 1. Study and Population Characteristics of Included Studies Detailing Regulatory Strategies Aimed at Youth Vaping

Study	Study period, years	Mean/median age, years	Survey or sample used	Study design	Participants, number
Age restrictions					
Abouk and Adams[15] The U.S.	2007–2014	Not reported, ranging between 15 and 18 years	MTF	Repeated cross-sectional	Around 50,000
Dai et al.[16] The U.S.	2018–2019	Not reported, 29.1% Grade 6, 28.6% Grade 8, 24.0% Grade 10, and 18.3% Grade 12	KCTC (6th, 8th, 10th, and 12th grade students)	Repeated cross-sectional	132,803
Dave et al.[17] The U.S.	2005–2015	Not reported, ranging between 12 and 21 years	YRBSS	Repeated cross-sectional	Not stated, but 800,000 person-years were included
Debchoudhury et al.[44] The U.S.	2014–2018	Not reported, Grades 6–12	New York State Tobacco Survey	Repeated cross-sectional	12,545
Dutra et al.[18] The U.S.	2009–2014	2009 (14.54), 2011 (14.50), 2012 (14.51), 2013 (14.53), 2014 (14.51)	NYTS	Repeated cross-sectional	85,861
Ferrell et al.[19] The U.S.	2014–2015	14.65	FYTS	Repeated cross-sectional	82,215
García-Ramírez et al.[20] The U.S.	2013–2019	Not reported, Grades 7, 9, and 11	California Healthy Kids survey	Repeated cross-sectional	2,229,401
Hawkins et al.[21] The U.S.	2015	Not reported, range between 14 and 18 years	YRBSS	Cross-sectional	938,486
Macinko and Silver[22] The U.S.	2008–2016 for the whole study, 2014–2016 for E-cigarettes	Not reported, Grades 7–12	New York Youth Tobacco Survey for New York participants and YRBSS for others	Cross-sectional	33,039
Nguyen[42] Canada	2013–2017	DD Sample (SD): 16.4 (1.1) provinces with a ban; 16.5 (1.1) provinces without a ban DDD Sample: 20.3 (3.2) provinces with a ban; 20.2 (3.1) provinces without a ban	CTADS and CSTADS	Quasiexperimental difference-in-differences and triple-differences	107,796
Pesko and Currie[23] The U.S.	2010–2016	Not reported, in the full treatment group 3.6% are aged ≤14 years, 11.6 are aged 15 years, 29.2% are aged 16 years, and 55.6% are aged 17 years.	Participants were selected through administrative birth records with geocoded information provided by the NCHS	Repeated cross-sectional	326,892
Pesko et al.[24] The U.S.	2007–2013	Not reported	YRBSS	Repeated cross-sectional	Not reported
Roberts et al.[25] The U.S.	2016–2018	18.6	Undergraduate students surveyed at a large public university	Repeated cross-sectional	1,140
Schiff et al.[26] The U.S.	2015–2017	Before implementation: 18.9 After implementation: 20.2	Southern California CHS, participants selected in Kindergarten	Repeated cross-sectional	Before implementation: 1,609 After implementation: 1,502
Trapl et al.[27] The U.S.	2013–2019	Not reported, Grades 9–12	YRBS	Repeated cross-sectional	12,616
Wilhelm et al.[28] The U.S.	2016–2019	Not reported, Grades 8, 9, and 11	Minnesota student survey	Repeated cross-sectional	210,177
Flavor bans					
Morean et al.[29] The U.S.	2018–2019	Before implementation: 15.87 After implementation: 15.99	Participants came from 4 Connecticut high schools representing a convenience sample	Repeated cross-sectional	6,244
Olson et al.[30] The U.S.	2016–2019	Not reported, Grades 5–12	Minnesota Youth Tobacco Survey and the Minnesota Student Survey	Repeated cross-sectional	Over 210,000
Vogel et al.[31] The U.S.	September–November 2020	17.7	ASPiRE consortium	Cross-sectional	900
Yang et al.[32] The U.S.	November 9–23, 2019	21.47	Study-specific MTurk survey	Repeated cross-sectional	247
Mixed/combined regulations					
Cho et al.[43] The U.S./Korea	2011 and 2015	Not reported, range between 12–18 years in the U.S. and 9–21 years in South Korea	KYRBS in Korea NYTS in the U.S.	Cross-sectional	Not reported Number ranged from 67,671 in 2015 to 75,643 in 2011 for the Korean survey. Number ranged from 15,664 in 2013 to 21,560 in 2012 for the U.S. study
Hawkins et al.[47] The U.S.	2011–2017	16.1	Massachusetts Youth Health Survey (YHS)—high school	Repeated cross-sectional	10,168
Moore et al.[41] Wales, England, Scotland	2013–2017	Not reported, range between 11 and 16 years	SHRN and HBSC	Repeated cross-sectional	59,234

(*continued on next page*)

Table 1. Study and Population Characteristics of Included Studies Detailing Regulatory Strategies Aimed at Youth Vaping (*continued*)

Study	Study period, years	Mean/median age, years	Survey or sample used	Study design	Participants, number
E-cigarette sales license					
Astor et al.[33] The U.S.	January–June of 2014, follow up January 2015–June 2016	17.3	Southern California CHS[a]	Repeated cross-sectional	1,553
Azagba et al.[34] The U.S.	2015–2017	Not reported, 10th–12th grade	YRBSS	Repeated cross-sectional	37,797
Warning labels					
Katz et al.[35] The U.S.	Not reported	15.91	Students were selected from 4 different high schools	Multiarm randomized (no control)[b]	657
Li et al.[36] The U.S.	Early 2019	20.9	Participants were current JUUL users without a history of chronic disease and did not have concurrent use of >5 cigarettes per day	Pre/post intervention design	26
Taxation					
Anderson et al.[37] The U.S.	2015–2017	Not reported, ranges between 14 and 18 years	YRBSS	Repeated cross-sectional	Not reported
Han et al.[38] The U.S.	2014–2019	21.2	TUSCPS	Repeated cross-sectional	17,896
Restriction of location of use					
Friedman et al.[39] The U.S.	2014–2018	21.5	NHIS	Observational study[c]	87,334 total, 15,830 aged 18–24.

[a]A grade required adequate annual retail license fees, which were paid by all tobacco retailers (including gas stations, convenience stores, larger grocery stores, and pharmacies), to cover the administration of an enforcement program and regular compliance checks in each store. An A grade also required (1) an annual renewal of this local license; (2) a provision that any violation of local, state, or federal law is a violation of the license; and (3) a graduated penalty system for violators, including financial deterrents such as fines or other penalties such as license revocation or suspension. The remaining study jurisdictions were assigned an F grade (8) or a D grade (1). An F grade indicated either (1) no local ordinance mandating a license fee or (2) a fee insufficient to fund administrative and compliance checks as well as none of the 3 other provisions for an A grade. The jurisdiction with the D grade had a licensing fee that was insufficient to cover administration and compliance checks, but it had at least 1 of the other 3 provisions listed earlier that were needed for an A grade.

[b]Five hundred and twenty-three students were included in the study. The students were randomized into groups as follows: DA warning/no MRS/no flavor (*n*=51), FDA/MRS/no flavor (*n*=52), FDA/no MRS/flavor (*n*=52), FDA/MRS/flavor (*n*=50), MarkTen/no MRS/no flavor (*n*=50), MarkTen/MRS/no flavor (*n*=51), Markten/no MRS/flavor (*n*=50), MarkTen/MRS/flavor (*n*=52), abstract/no MRS/no flavor (*n*=49), abstract/MRS/no flavor (*n*=48), abstract/no MRS/flavor (*n*=49), and abstract/MRS/flavor (*n*=53).

[c]Observational study of nationally representative data from 2014–2018. National Health Interview Survey.

ASPiRE, Advancing Science & Practice in the Retail Environment; CHS, Children's Health Study; CSTADS, Canadian Student Tobacco, Alcohol and Drugs Survey; CTADS, Canadian Tobacco, Alcohol, and Drugs Survey; DD, difference in difference analysis; DDD, triple difference analysis; FDA, U.S. Food and Drug Administration; FYTS, Florida Youth Tobacco Survey; HBSC, Health Behaviour in School-aged Children Survey; KCTC, Kansas Communities that Care; KYRBS, Korean Youth Risk Behavior Web-based Survey; MTF, Monitoring the Future; MRS, Modified Risk Statememt; NCHS, National Center for Health Statistics; NYTS, National Youth Tobacco Survey; SHRN, School Health Research Network; TUSCPS, Tobacco Use Supplement to the Current Population Survey; YHS, Youth Health Survey; YRBS, Youth Risk Behaviour Survey, YRBSS, Youth Risk Behavior Surveillance survey.

youth vaping. Three studies[29,31,32] in this category had a moderate risk of bias, whereas 1 had a serious risk of bias.[30,]

The effectiveness of E-cigarette sales licenses was evaluated in 2 studies, both of which reported that it was effective in reducing youth vaping (Table 2, Appendix Table 5 and 6, available online).[33,34] These regulations were implemented at the state level, with stores in these states required to have a permit to sell vaping products, which greatly reduced the number of stores allowed to sell such products. One study compared Pennsylvania (where a licensing policy was implemented) with New York (where a policy was not implemented) and found that vaping in Pennsylvania decreased by 5.2% compared with that in New York.[34] The second study reported that the odds of E-cigarette initiation were lower (OR=0.74; 95% CI=0.55, 0.99) in areas with tougher licensing laws (A grade locations) (Appendix Table 5 and 6, available online).[33] The reviewers deemed both studies in this category to have a serious risk of bias. Thus, although this type of regulation appears promising, the lack of high-quality evidence prohibits definitive conclusions.

Two studies theoretically evaluated warning labels using focus-group methodology to garner youths' opinions and to determine the impact of such labels on their intention to initiate vaping (Table 3).[35,36] One study found that warning labels were associated with decreased intentions to vape, whereas the other found no significant association (Table 2, Appendix Table 4 and 6, available online). The investigated labels, proposed by the FDA, featured a warning that nicotine is addictive. Li et

Table 2. Summary of Effects of Vaping Regulations on Various Target Outcomes

Study	Change in prevalence of youth E-cigarette use	Change in the prevalence of self-reported tobacco product use	Change in E-cigarette practices	Prevalence (or change of prevalence) of intention to initiate vaping
Age restriction				
Abouk and Adams[15]	(=)[a]	(−)[b]	X	X
Dai et al.[16]	(−)	X	X	X
Dave et al.[17]	(=)	(+)	X	X
Debchoudhury et al.[44]	(+)[c]	X	X	X
Dutra et al.[18]	X	(−)	X	X
Ferrell et al.[19]	(=)	X	X	X
García-Ramírez et al.[20]	(−)	(−)	X	X
Hawkins et al.[21]	(=)	(=)	X	X
Macinko and Silver[22]	(−)	(−)	X	X
Nguyen[42]	(−)	X	X	X
Pesko et al.[24]	X	(+)	X	X
Pesko and Currie[23]	X	(+)	X	X
Roberts et al.[25]	(−)	(+)	X	X
Schiff et al.[26]	(=)	(=)	X	X
Trapl et al.[27]	(−)	(−)	X	X
Wilhelm et al.[28]	(−)	(−)	X	X
Flavor bans				
Morean et al.[29]	(−)	X	(−)	X
Olson et al.[30]	(−)	(−)	X	X
Vogel et al.[31]	(=)	X	(=)	X
Yang et al.[32]	(−)	(=)	(−)	X
E-cigarette sales licenses				
Astor et al.[33]	(−)	(−)	X	X
Azagba et al.[34]	(−)	(−)	X	X
Mixed/combined regulations				
Cho et al.[43]	(−)	(=)	X	X
Hawkins et al.[40]	(=)	X	X	X
Moore et al.[41]	(=)	X	X	X
Warning labels				
Katz et al.[35]	X	X	X	(=)
Li et al.[36]	X	X	X	(−)
Taxation				
Anderson et al.[37]	(−)	(=)	X	X
Han et al.[38]	(−)	X	X	X
Restriction of location of use			X	X
Friedman et al.[39]	(=)	(=)	X	X

Note: X outcome was not assessed.
[a](=) denotes no statistically significant change.
[b](+) denotes a statistically significant increase in the prevalence of smoking, vaping, or intention to use.
[c](−) denotes a statistically significant decrease in the prevalence of smoking/vaping or intention to use.

al. reported that warning labels decreased youth's intention to initiate vaping—the score for motivation for future use was 50 among those exposed to a Graphic Health Warning label, compared with 65 among those not exposed to it (Appendix Table 4 and 6, available online).[36] Katz et al. found no significant association between warning labels and intention to initiate vaping.[35] This group also reported that having an MRS (Modified Risk Statement) (i.e., a statement educating the user on the potential harms of E-cigarettes) was more beneficial in increasing harm perception among youth than having either an FDA label or no label at all.

Table 3. Characteristics of Included Vaping Regulations and Their Year of Enactment

Study Location	Name of regulation	Level of regulation	Year of enactment
Age restriction			
Abouk and Adams[15] The U.S.	Bans on E-cigarette sales to minors (age <18 years)	Provincial/state	2010–2014 (varies by state)
Dai et al.[16] The U.S.	Tobacco 21	National	Between November 2015 and March 2019 (gradual implementation)
Dave et al.[17] The U.S.	MLSA laws (aged <18 or 19 years depending on the state)	Provincial/state	Varies by state, first law implemented in 2010
Debchoudhhury et al.[44] The U.S.	Tobacco 21	Provincial/state	2018
Dutra et al.[18] The U.S.	MLSA laws (age <18 or 19 years depending on the state)	Provincial/state	Varied by state, beginning in May 2016
Ferrell et al.[19] The U.S.	Florida's minimum age policy (age <18 years)	Provincial/state	2014
García-Ramírez et al.[20] The U.S.	Tobacco 21	Provincial/state	2016
Hawkins et al.[19] The U.S.	Tobacco control policies (age <18 or 19 depending on the state)	Provincial/state	2010–2014 (depending on the state)
Macinko and Silver[22] The U.S.	New York City's increased minimum legal purchase age (age <21 years)	Municipal	2014
Nguyen[42] Canada	Canada's provincial E-cigarette age restrictions (age <18 or 19 depending on the province)	Provincial/state	2015–2017, depending on the province
Pesko and Currie[23] The U.S.	ENDS MLSA (see abbreviations) Law (age <18 years)	Provincial/state	Varies by state, beginning in 2010
Pesko et al.[24] The U.S.	ENDS MLSA law (age <18 or 19 years depending on state)	Provincial/state	2011–2013 (2013 is the end of the study)
Roberts et al.[25] The U.S.	Tobacco 21	Provincial/state	2017
Schiff et al.[26] The U.S.	Tobacco 21	National	June 2016
Trapl et al.[27] The U.S.	Tobacco 21	Provincial/state	2016
Wilhelm et al.[28] The U.S.	Tobacco 21	Provincial/state	2017
Flavor bans			
Morean et al.[29] The U.S.	JUUL self-imposed flavor ban on mango, fruit medley, crème brulee pods	International (JUUL operates worldwide)	November 2018
Olson et al.[30] The U.S.	Minneapolis and St Paul menthol flavored tobacco ban	Provincial/state	2016
Vogel et al.[31] The U.S.	Sales restriction on flavored E-cigarettes	Municipal (30 cities)	Variable
Yang et al.[32] The U.S.	San Francisco flavored tobacco ban	Municipal	Voted in 2018, implemented in February 2019
Mixed/combined regulations			
Cho et al.[43] Korea/U.S.	Korean and American E-cigarette regulations	National	2008 (Korea) Beginning in 2010 (U.S.)
Hawkins et al.[33] The U.S.	Flavored tobacco product restriction	Provincial/state	Around 2019, varies on the basis of regulation
Moore et al.[41] United Kingdom	EU Tobacco Products Directive regulations	International	2016
E-cigarette sales licenses			
Astor et al.[33] The U.S.	Tobacco retail licensing (Grades A [high]–F [low])[a]	Provincial/state	Not reported, study was in 2014
Azagba et al.[34] The U.S.	Pennsylvania E-cigarette licensing law	Provincial/state	2016
Warning labels			
Katz et al.[35] The U.S.	FDA warning label with and without modified risk statement	National	Experimental study, so no year of enactment
Li et al.[36] The U.S.	Graphic health warning labels	Provincial/state	Experimental study, so no year of enactment
Taxation			
Anderson et al.[37] The U.S.	E-cigarette tax (CA, PA, and WV)	Provincial/state	2010–2017

(*continued on next page*)

Table 3. Characteristics of Included Vaping Regulations and Their Year of Enactment (*continued*)

Study Location	Name of regulation	Level of regulation	Year of enactment
Han et al.[38] The U.S.	E-cigarette product excise tax policy	Provincial/state	Variable, before 2018.
Restriction of location of use			
Friedman et at.[39] The U.S.	Vape-free air laws	National	Beginning in 2010, but data were collected in 2014–2018

[a]A grade required adequate annual retail license fees, which were paid by all tobacco retailers (including gas stations, convenience stores, larger grocery stores, and pharmacies), to cover the administration of an enforcement program and regular compliance checks in each store. An A grade also required (1) an annual renewal of this local license; (2) a provision that any violation of local, state, or federal law is a violation of the license; and (3) a graduated penalty system for violators, including financial deterrents such as fines or other penalties such as license revocation or suspension. The remaining study jurisdictions were assigned an F grade (8) or a D grade (1). An F grade indicated either (1) no local ordinance mandating a license fee or (2) a fee insufficient to fund administrative and compliance checks as well as none of the 3 other provisions for an A grade. The jurisdiction with the D grade had a licensing fee that was insufficient to cover administration and compliance checks, but it had at least 1 of the other 3 provisions listed earlier that were needed for an A grade.
CA, California; EU, European Union; FDA, U.S. Food and Drug Administration; MLSA, minimum legal sale age; PA, Pennsylvania; WV, West Virginia.

Furthermore, although not an outcome of interest, both studies reported that the labels increased the perception of harm associated with E-cigarettes. In the study by Katz et al., perceived harm led to a decreased intention to try vaping.[35] The study assessed neither label in a real-life context. Both studies had a moderate risk of bias. Both studies in this category found that warning labels are strongly correlated with a decreased intention to vape.

Two studies assessed taxation or price increases for E-cigarettes (Table 3).[37,38] Anderson et al. reported an overall decrease in vaping use (average marginal effect [SE]= −0.013 [0.012]), with no increase in marijuana or tobacco use.[37] Han et al. reported that jurisdictions that implemented an E-cigarette tax had a significantly smaller increase in vaping than those that did not (AOR=0.57; 95% CI=0.35, 0.91) (Table 2).[38] The reviewers found the studies to have serious and moderate risks of bias, respectively (Appendix Table 2, available online). Both studies associated taxation with decreased prevalence of vaping.

A single study evaluated the impact of legally restricting locations where vaping products can be used, reporting no effect on youth vaping (Table 3).[39] The study assessed a nationwide ban on the use of E-cigarettes in restaurants and in workplaces in the U. S. Overall, the addition of vaping-free laws to already existing smoke-free laws had no additional impact on vaping prevalence (correlation coefficient was 0.001 in 2014 vs 0.005 in 2018) (Table 2, Appendix Table 3 and 5, available online). The study had a serious risk of bias.

Three studies investigated jurisdictions where a variety of different vaping regulations were implemented concurrently (Table 3).[41,43,47] One study[43] reported reductions in youth vaping, whereas 2 found no difference (Table 2).[41,47] The regulations varied across studies but encompassed age restrictions, restrictions in place of use, taxation, and nicotine restriction (Table 3). Cho et al. found significant differences when studying a Korean jurisdiction with multiple regulations compared with the U.S., which had only an age restriction implemented (Table 1).[43] During the same period, vaping decreased by 0.7% among Korean youth compared with a relative increase of 10.3% among U.S. youth. Both Moore et al. and Hawkins et al. found no association between mixed regulations and youth vaping (OR=0.96; 95% CI=0.91, 1.01)[41] and (coefficient= −0.87; 95% CI= −1.68 to −0.06).[47] All 3 studies in this category had a serious risk of bias.

Nineteen studies evaluated the relationship between E-cigarette regulations and youth tobacco use, reporting heterogeneous results.[9,15,17,18,20–22,23,25–28,30,32–34,37,39,41] A common argument against E-cigarette regulations is that youth will turn to traditional tobacco products or illicit substances in its place. Most studies reported that limiting the availability of E-cigarettes either decreased youth tobacco use or caused no change, suggesting that youth will not switch to combustible tobacco cigarettes if E-cigarettes are not available.[15,18,20–22,26–28,30,32–34,37] In addition, although not an evaluated outcome in this systematic review, studies that evaluated the impacts of E-cigarette regulations on other substances found that they did not increase marijuana use or drinking among youth.[24,30]

Despite these positive results, 4 studies did report an increase in cigarette smoking once E-cigarettes were restricted among youth.[17,23–25] A study by Pesko and Currie evaluated whether pregnant teenagers quit smoking before and after restricting the purchase age of E-cigarettes and found that banning E-cigarette sales to minors decreased the ability of teens living in rural areas to quit smoking.[23] E-cigarette regulations should ideally target youth non-users while still having the products

available for cigarette users who wish to switch to vaping.

DISCUSSION

This systematic review synthesized the evidence on the effectiveness of regulatory strategies intended to reduce or prevent the use of E-cigarettes among youth. The studies found that flavor bans, sales licenses, warning labels, and taxation were all associated with a positive impact on youth vaping. Age restrictions were the most frequently implemented regulation across studies but had heterogeneous results; thus, this study is unable to recommend them. Key findings also include that there is insufficient evidence to recommend any single intervention. Overall, the results suggest that regulatory authorities could implement a variety of regulations aimed at targeting the price, accessibility, and desirability (i.e., flavors and packaging) of E-cigarettes.

Evidence on the effectiveness of laws restricting the legal age of E-cigarettes purchase is inconclusive, both in this review and in that by Taylor et al.[7] However, despite the lack of evidence, it is the most commonly implemented regulatory strategy.[7] Sindelar et al. argued that although numerous vaping regulations (particularly T21) in the U.S. have a potential to be effective, they fall short when it comes to feasibility.[5] For example, restricting the age of purchase to 21+ years could be effective because nicotine addiction often begins by age 19. However, implementation of age restrictions is challenging because it requires compliance by both retailers and local governments. In a recent study, 72% of online vendors were noncompliant with measures such as identification checks for E-cigarette purchasing.[48] Furthermore, youth may also get access to E-cigarettes through older individuals, which could bypass any age restrictions. Macinko et al. postulated that inconsistent implementation of policies could underpin the inconclusive results regarding this intervention.[22] Cultural norms, governmental surveillance, and youth E-cigarette trends have an impact on the effectiveness of age restrictions. Despite problems with the implementation of E-cigarette regulation, there is a large amount of evidence demonstrating that both parents[49] and youth[41,50] support it.

One study evaluating the impact of mixed regulations on youth vaping found promising results. Cho et al. found that a mixed regulation approach may be superior to the implementation of any one regulation alone.[43] However, E-cigarettes were regulated in the Republic of Korea far earlier than in the U.S., and cultural differences between the two countries represent an important unmeasured confounder. In addition, the regulatory landscape in the Republic of Korea is stricter than in the U.S., which may also contribute to the difference in E-cigarette use.[51] Hawkins et al. reported that a variety of regulations (age restrictions, flavor bans, and bans on place of use) contributed to a decrease in youth vaping, although the change was not statistically significant.[47] Moore et al. analyzed the impacts of the mixed EU E-cigarette regulations (packet warnings, advertisement bans, and regulated nicotine strength) and found that they helped to decrease youth vaping, although to a non-statistically significant degree.[41] The evidence put forth by Cho et al. demonstrates that implementing regulatory strategies soon after E-cigarettes come on the market can help reduce youth vaping.[43] Given that E-cigarettes have already penetrated the market in most high-income countries, a combination of regulations could be an effective strategy to reduce their use. Not all youth are deterred by flavor bans or price hikes alone; however, combining multiple types of regulations may impact a wider group of youth.

Finally, although the evidence on certain regulatory strategies for E-cigarettes may be lacking, similar interventions have long been implemented for tobacco products. The FDA banned flavored cigarettes (other than menthol) in 2009, which prompted a reduction in youth smoking by 43%.[52] Similarly, taxation has also been highly effective in reducing smoking among youth.[53] Furthermore, warning labels have already been implemented on Canadian cigarette packages and have been associated with a higher desire to quit among adults who smoke combustible cigarettes.[54] In line with this study's findings, a large-scale study evaluating the impacts of cigarette age restrictions on youth smoking in Europe found that there was no discernible effect on tobacco use.[55] Although age restrictions may be the most popular and potentially easiest regulatory strategy to implement, data on their effectiveness are inconclusive. Simply restricting the legal age of E-cigarette purchase beyond when nicotine addictions begin does not appear to be sufficient to curb the vaping epidemic.[5] Wakefield et al. demonstrated that comprehensive tobacco policies (involving taxation, price increases, and social programs) were more effective in reducing youth tobacco use than any strategy alone.[56] A similar strategy could possibly be applied to vaping with success.

Limitations

To ensure greater applicability to the North American context, this systematic review was restricted to studies in high-income countries. Consequently, the reviewers may not have captured the full range of regulatory strategies that aim to prevent youth vaping. In addition, because of the nature of the regulations (i.e., large, population-level regulations) assessed

and the study designs used, all included studies had an elevated (i.e., moderate-to-serious) risk of bias. This high risk of bias was largely driven by the potential risk of confounding, which is inherent in such studies. Cultural norms, previous smoking practices, and the time of implementation all vary between jurisdictions and confound the impact of any studied regulation. It is also difficult to ensure that no additional policy changes occurred at the same time as the interventions of interest, and the evolving availability of different vaping products can also potentially impact the prevalence of vaping.

CONCLUSIONS

This systematic review synthesized the evidence on regulatory strategies aimed at preventing or reducing youth vaping in high-income countries. The aim was to assess whether taxation/price increases, age restrictions, flavor bans, warning labels/packaging modifications, retail sales licenses, and mixed/combined regulations were effective at lowering the prevalence of vaping among youths. Flavor bans, sales licenses, warning labels, and taxation were all found to reduce the prevalence of youth vaping, youth tobacco use, or intention to initiate vaping. Age restrictions were the most frequently evaluated regulation; however, variability of results suggests that the quality of implementation and contextual factors such as cultural norms may impact the effectiveness of such policies. Overall, current evidence does not support a specific type of regulation for reduction of youth vaping, although implementing multiple, varied types of regulations could be the key to reducing youth vaping.

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SUPPLEMENTAL MATERIAL

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