



Electronic Cigarette Use Among Youth: Understanding Unique Risks in a Vulnerable Population

Elisa M. Trucco^{1,2} · Nilofar Fallah-Sohy¹ · Sarah A. Hartmann¹ · Julie V. Cristello¹

Published online: 22 October 2020
© Springer Nature Switzerland AG 2020

Abstract

Purpose of Review This review discusses prevalence rates of electronic (e-)cigarette use among youth and factors that likely contribute to their growing popularity among this population. Trends shaping the e-cigarette landscape, the appeal of e-cigarettes among youth, perceptions contributing to the initiation of e-cigarettes, available assessments capturing the usage of and attitudes towards e-cigarettes, and e-cigarette policies and regulations are reviewed.

Recent Findings E-cigarette use among this vulnerable group may relate to factors associated with the promotion of social status, individuality, and enjoyment, along with low perceptions of risk and harm. Measures assessing factors unique to e-cigarette use among youth (e.g., individuality) still need to be developed and validated. Effects of existing regulations to limit youth access to e-cigarettes may be limited, and shortcomings of current policy measures are discussed with recommendations.

Summary The rise of e-cigarette use among youth culminated through a perfect storm of clever marketing targeting youth appeal, innovations in more effective nicotine delivery systems, capitalizing on increased susceptibility of the adolescent brain, and regulatory gaps. Understanding risk and protective factors specific to this vulnerable group, which can be gleaned in part by psychometrically valid assessments, could inform regulatory strategies and prevention programming efforts. Yet, few validated measures exist that assess attitudes, behaviors, and patterns of e-cigarette use that are specific to youth. Ultimately, it is incumbent upon policymakers to create comprehensive regulations that prioritize harm reduction and can evolve in lockstep with the constantly changing e-cigarette product landscape.

Keywords E-cigarettes · Electronic nicotine delivery systems · Youth · Trends · Appeal · Regulation

This article is part of the Topical Collection on *Tobacco*

✉ Elisa M. Trucco
etrucco@fiu.edu

Nilofar Fallah-Sohy
nfallahs@fiu.edu

Sarah A. Hartmann
sahartma@fiu.edu

Julie V. Cristello
jcristel@fiu.edu

¹ Psychology Department, Center for Children and Families, Florida International University, 11200 SW 8th Street, AHC-1, Miami, FL 33199, USA

² Psychiatry Department, University of Michigan, 4250 Plymouth Road, Ann Arbor, MI 48109, USA

Introduction

Electronic cigarettes (e-cigarettes) are battery-powered devices that generate an aerosol by heating a liquid consisting of propylene glycol (PG) and vegetable glycerin (VG), flavoring agents, and nicotine, without combustion. Accordingly, the production of carcinogens and other toxins is lower in e-cigarettes compared to combustible cigarettes [1]. It is for this reason that e-cigarettes have been widely debated. Some believe that e-cigarettes represent a public health breakthrough, as the transition from combustible cigarettes to e-cigarettes could prevent smoking-related deaths [2]. Opponents raise concerns that marketing of these devices as trendy and harmless targets non-smoking youth among whom e-cigarette use could lead to combustible cigarettes [3]. Given that the adolescent brain is still developing, nicotine's neurotoxic effects can have a negative impact on cognition, attention, mood, and prime the brain for dependence of other substances [4–7]. Thus, the increasing popularity of these

products among youth is alarming, particularly in the United States (US), where estimates indicate that more than one in every four high school students (27.5%) reported using e-cigarettes in the past month in 2019 [8] (see Fig. 1A).

This review focuses on e-cigarette prevalence rates, trends, their appeal, perceptions, and measures used to assess these constructs among youth. Lastly, an overview is provided regarding policies and regulations to reduce e-cigarette use

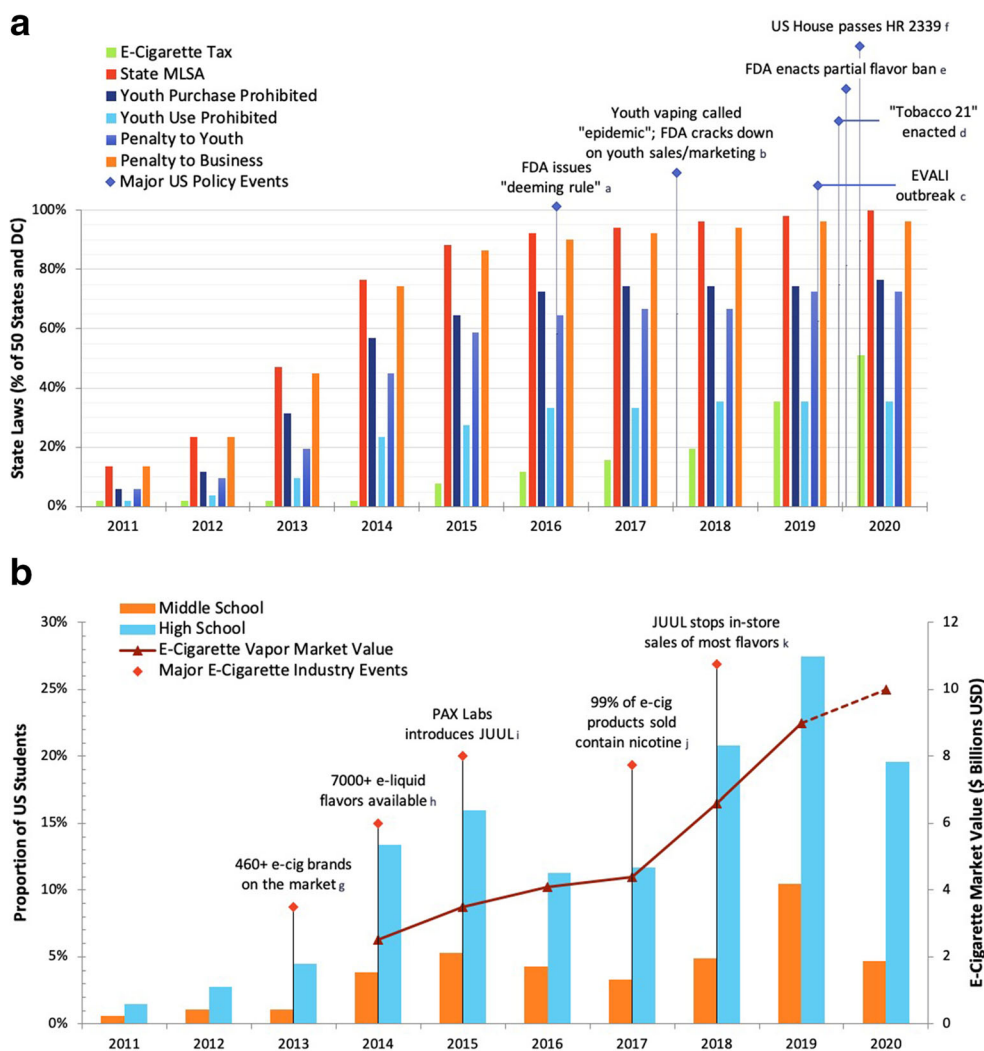


Fig. 1 Timeline of e-cigarette policies, milestones, and youth prevalence rates in the US, 2011–2020. (A) Federal and state policies governing youth access to e-cigarettes. (B) E-cigarette industry milestones and prevalence of current use by US youth. Notable events beginning in 2011 are presented in parallel to available data from the National Youth Tobacco Survey (NYTS) on youth e-cigarette use [8–10]. (A) US Policy Timeline. State policies: Data is from the CDC STATE System database of state-level statutory laws [11] and is current for laws enacted through September 30, 2020 (2020, Q3). Data was aggregated as the percent of the 50 US states and District of Columbia that had a law in place or newly enacted in each year. Local government policies are not reflected. Federal Policy Milestones: (a) The FDA “deeming rule” goes into effect on August 8, expanding the Tobacco Control Act (2009) to regulate e-cigarettes as tobacco products (e.g., MLSA of 18, age verification) [12]. (b) The US Surgeon General and FDA Commissioner declare youth vaping an “epidemic” [13, 14]. In September, the FDA issues warnings and fines to 1300+ retailers and top 5 manufacturers for illegal youth sales and marketing [14]. (c) A national EVALI outbreak peaks in September 2019. The CDC reports 2807 hospitalized cases (including 68 deaths) by February; half of patients are under 24 years old (15% under 18) [15, 16].

(d) The Tobacco 21 law is enacted on December 20, raising the federal MLSA from 18 to 21 for all tobacco products [17]. (e) On January 2, the FDA bans the sale of flavored cartridge-based e-cigarettes (excludes tobacco, menthol) [18, 19]. (f) On February 28, the US House of Representatives passes the Protecting American Lungs and Reversing the Youth Tobacco Epidemic Act (HR 2339). The bill awaits Senate review [20, 21]. (B) US Industry Trends and Prevalence. Youth prevalence rates: Current e-cigarette use (i.e., any use in the past month) rates come from NYTS data, 2011–2020 [8–10]. Annual market value: The annual market value is an industry estimate of the total US sales of e-cigarette and vapor products [22–27]. We were unable to find reports for total market value in years 2011, 2012, and 2013. The annual market value for 2020 is denoted with a dashed line indicating that this was a projected estimate reported in February 2019 [24]. Industry milestones: (g) Over 460 e-cigarette brands on the market [28]. (h) E-liquids available in over 7000 flavors [29]. (i) Pax Labs introduces JUUL, the first pod mod [30]. (j) A total of 99% of e-cigarette products sold in the US contain nicotine [31]. (k) JUUL withdraws in-store sales of flavored pods, excluding tobacco, mint, and menthol flavors [32]

among youth. Given their emergence as the most commonly used tobacco product among US adolescents [33], this review focuses on this population, although international research is also discussed. Here, the term “e-cigarettes” refers to vape pens, cigalikes, mods, or pod mods.

Prevalence

From 2017 to 2019, e-cigarette use with nicotine increased among US 8th, 10th, and 12th graders, by 9.0, 14.9, and 16.5 percentage points, respectively, reflecting the largest increase for any substance in *Monitoring the Future*'s 45-year history [33]. The current annual prevalence rates are 16.5% (8th graders), 30.7% (10th graders), and 35.5% (12th graders) [33]. Most youth (63%) are unsure whether their products contain nicotine [34]. This is problematic, as youth who do not use other tobacco products are now using e-cigarettes [22]. Thus, many are unknowingly exposed to nicotine through the initiation of e-cigarettes [22]. Accordingly, in 2018, the US Surgeon General and Food and Drug Administration (FDA) declared adolescent e-cigarette use an “epidemic” [13, 14] (see Fig. 1A). Understanding why youth use e-cigarettes, and how policies impact use, can help to reduce initiation.

Trends

Since their introduction to the international market in 2004 [35], e-cigarettes have undergone multiple changes [31], evolving from simple, disposable cigarette alternatives, designed to appeal to adult smokers attempting to quit [36•], to sleek and modifiable personal accessories, marketed to youth [36•, 37]. This product evolution contributes to the adolescent e-cigarette epidemic [31, 36•].

The e-cigarette industry has developed four generations of devices [30, 38]. First-generation e-cigarettes, touted as smoking cessation tools, referred to as cigalikes [30], were mostly disposable, closed-systems (i.e., non-refillable) utilizing pre-filled cartridges [2, 38]. Second-generation e-cigarettes, generally referred to as vape pens, were slightly larger, cylindrical models resembling pens [38]. These products contained stronger batteries and utilized refillable tanks (i.e., open-systems), allowing greater variability in throat hit, nicotine concentration, e-liquid flavors, and cloud production [2, 39]. These open-systems, and the wide variety of customizability, may have ignited interest among youth [40, 41].

Third-generation e-cigarettes (i.e., mods) have gained significant popularity among youth [41], likely due to their sleek look and modifiability [2, 41]. Mouthpieces can be specialized [42]; voltage, wattage, and airflow can be programmed [30]; and atomizer coils (i.e., the heating apparatus) and wicks (i.e.,

what carries e-liquid to the coils) can be modified [43]. Customization allows users to increase flavor, nicotine content, and aerosol production (i.e., cloud chasing; sub-ohming) [31, 43], all of which are appealing to youth [29•, 40, 42].

The popularity of mods among youth has been eclipsed by pod mods (e.g., JUUL, Suorin). These fourth-generation devices charge from a USB port and are concealable, reusable, and perceived as more economical than combustible cigarettes [30]. These attributes, alongside JUUL Lab's courting of youth through social media and advertising [36•], have set these devices apart from other e-cigarettes. In fact, JUUL has become so popular among youth that the term “JUULing” has often replaced (e-cigarette) “smoking/vaping” in adolescent lexicon [36•, 44].

The newest type of e-cigarette is the disposable pod [45]. These products resemble rechargeable pod mods but are disposable after use, and markedly cheaper. These new disposables gained popularity after the federal ban on flavored vape pods [46]. Disposable pods, which skirt the federal ban and are still available in multiple flavors, may appeal to youth as they are more convenient and economical than rechargeable pods, but remain highly concealable.

E-liquid types and levels of nicotine have also evolved [47]. Early generations of e-cigarettes utilized e-liquids composed of freebase nicotine (i.e., nicotine solution added to PG/VG) [48]. Recently, pod mods utilize nicotine salts (i.e., benzoic acid added to raise pH) [30]. This neutralizes the alkaline activation of protective mechanisms in the throat, allowing for a more subtle throat hit [48]. This innovation addresses consumer complaints of throat irritation [36•] while producing products with three times the amount of nicotine [48]. Reports indicate that nicotine salts may be a leading contributor to the high rates of e-cigarette dependence among youth [49].

The PG/VG ratio of e-liquid solvents has also evolved. E-liquids designed for later generation products are often higher in VG. VG-heavy solvents produce larger vapor clouds, as well as a milder throat hit [30]. Such changes in solvent ratio hold appeal for youth who report interest in producing large clouds with decreased throat irritation [47].

Appeal

Research has shown that youth report flavor variety [37], device modifiability [40], the ability to perform tricks [47], and concealment from authority figures [50] to be among the primary appeals of e-cigarettes. Youth find the availability of e-liquid flavors alluring [40, 51]. Over 7000 e-liquids are available to appeal to each user's taste [52]. Over 30% of middle school e-cigarette users endorsed initiation due to flavoring, 85% of 12–17-year-old users reported their first use was with a flavored e-liquid, and 90% of adolescent users reported

current use of flavored e-liquids [29•, 31, 53]. Consistent with chemosensory science, indicating that youth generally have a strong preference for sweet flavorings [54], adolescent e-cigarette users report a preference for fruit and dessert flavored e-liquids [51]. Moreover, research indicates that preferring sweet e-liquids is associated with more frequent usage among youth [55]. Youth also report using e-cigarettes for appetite control, as many flavored e-liquids mimic high calorie foods and beverages [56] and provide a nicotine “buzz” thought to quell food cravings [57]. Furthermore, youth endorse the nicotine “buzz” as appealing [29•].

The introduction of mods created a hobbyist appeal for the e-cigarette enthusiast [58]. Many adolescent e-cigarette users devote time and money to customize devices [59] to reflect their individuality. E-liquids can also be modified in a do-it-yourself (DIY) fashion, allowing customization of nicotine content, PG/VG ratios, and flavoring [43]. Reasons for engaging in DIY practices among adolescent e-cigarette users include the following: the ability to increase nicotine concentrations above what is available commercially, lower costs, personal oversight of quality control, and the creative outlet provided through design and construction [43].

Performing tricks (e.g., creating smoke shapes) is also appealing for youth and is often cited as a reason for initiation [47]. Sponsored competitions and YouTube channels devoted to such tricks have become popular among youth [47]. To create the large vapor clouds necessary to perform these tricks, many adolescent e-cigarette users report dripping e-liquid directly onto the coil [29•]. This is especially concerning given that “dripping” elevates nicotine and toxicant levels [29•].

Concealment is another draw of e-cigarettes for youth [44]. E-cigarette vapor does not linger on the breath, clothes, or environment; thus, its odor is not readily identifiable [50]. JUUL and other pod-type devices (e.g., MarkTen Elite), furthered concealment by designing a device shaped like a USB [36••]. Given work demonstrating that most parents and school personnel have difficulty identifying JUULs in photos, the widespread use of e-cigarettes is unsurprising [30].

Youth Perceptions

The popularity of e-cigarette products among youth warrants an examination of perceptions that underlie their use. Understanding how youth perceptions impact e-cigarette use may help to inform public health messaging.

Positive Expectancies

Positive expectancies such as personal enjoyment, social benefits, and perceived safety, all contribute to adolescent e-cigarette use [60]. Youth also report e-cigarettes as safe, convenient, and socially acceptable alternatives to combustible

cigarettes [60, 61]. Moreover, studies find that enjoyment of flavored e-cigarettes [55, 62•] and perceptions that sweet flavored e-liquids are less harmful than tobacco flavored products [40, 51, 63] contribute to greater odds of use.

Social influences are primary drivers of positive youth perceptions of e-cigarettes [36••, 62•]. Youth frequently endorse perceptions of e-cigarettes as “cool” and an expectancy of social enhancement [37, 47]. E-cigarette users and susceptible never users were more likely to report perceived social benefits of e-cigarette use, such as having more friends and fitting in socially [64]. Yet, other findings suggest that the effects of positive social expectancies on e-cigarette use are diminished when controlling for other outcome expectancies (e.g., stress relief) [62•].

Positive perceptions also reflect e-cigarettes as a stress relief tool among youth [60, 62•]. One study found that while only a minority of youth endorsed social benefits of e-cigarette use, up to one-third endorsed e-cigarettes as a means of stress relief [64]. Findings could guide intervention efforts aimed at providing at-risk youth with alternative outlets to achieve stress relief.

Negative Expectancies

Youth endorse lower negative expectancies for e-cigarettes compared to combustible cigarettes [36••, 65••]; with greater than 40% of youth in one study stating that e-cigarettes are safer alternatives [64]. Given their relatively short time on the market, little research exists on the long-term health effects of e-cigarettes, which may lead to misperceptions regarding their harm and contents. For example, about 1 in 5 adolescents believed that e-cigarette vapor is comprised of water [66]. Pod-based e-cigarette systems were also viewed as less harmful than both combustible cigarettes and other ENDS, even among nicotine-dependent e-cigarette users [67]. Additionally, while the majority of youth believe that JUUL products are somewhat risky, a significant minority believe they are risk-free (5.8%) and will not lead to addiction (7.3%) [68]. Lower perceptions of risk also extend to lower perceived addictiveness, with fewer than two-thirds of high school students reporting the possibility of e-cigarette addiction [64]. Furthermore, lower perceived addictiveness of e-cigarettes predicted e-cigarette use among youth [69]. Youth e-cigarette users tend to hold lower risk perceptions than non-users [64, 66, 68, 69].

Yet, there is a promising shift in risk perceptions. Earlier studies have found that, among both adolescent e-cigarette users and non-users, e-cigarettes were perceived as less harmful than combustible cigarettes, while recent research finds them to be perceived as equally or more harmful [60]. Nevertheless, investigations regarding how e-cigarette risk perceptions contribute to actual use are mixed. That is, some find that while perceptions of e-cigarette harm may be present,

harm perceptions alone are not enough to deter youth [62•, 70].

Measurement

Given that the appeal and attitudes toward e-cigarette use is unique to adolescents, measures capturing these nuances are critical. Yet, assessing e-cigarette use among youth is challenging. This is likely due to evolving terminology, the speed at which new products develop, and the variations in language used by consumers versus researchers [71]. Given these considerations, it is not only important that measures reflect constructs specific to youth, but including pictures may ensure that respondents have a clear understanding of what is being assessed [65••, 71].

Measuring frequency and quantity of e-cigarette use has been difficult, as use can range from one puff to more continuous daily use. Prior work finds that most researchers only assess number of days used per month [72], and not number of sessions per day or length of each session [73]. Assessing both days and daily sessions may provide a more accurate report of frequency [73] and distinguish experimentation from regular use [74]. In contrast, quantity is often not assessed given variations in e-cigarette terminology, device type, and use patterns (e.g., sharing devices) [75–77].

Few validated measures assessing adolescent e-cigarette behaviors and related constructs exist (see Table 1). Dependence has been challenging to assess due to various nicotine concentrations across devices. Interestingly, prior research has found signs of dependence among users who report using zero nicotine e-liquids [72]. This may be due to a strong affiliative attachment to e-cigarettes, the mislabeling of products, or the tendency for youth to erroneously conclude that their own or shared devices are nicotine-free [84].

Measuring e-cigarette attitudes and expectancies among youth may help inform prevention programming and policies. While e-cigarettes were initially advertised as cessation tools for adult cigarette smokers [30], attitudes and expectancies among youth are more varied. Additionally, adolescents endorsing positive outcome expectancies are more likely to initiate use compared to those who endorse negative outcome expectancies [62•, 80]. Thus, measures capturing adolescent outcome expectancies, such as the Adolescent E-Cigarette Consequences Questionnaire (AECQ) [79], could identify youth that are vulnerable to e-cigarette use. One outcome expectancy unique to e-cigarette use and key to adolescent e-cigarette curiosity are taste/sensory experiences [82], such as flavoring (e.g., fruit) [77, 85] and cloud production [82]. While prior research indicates that sensory expectancies are especially salient among youth [86], few measures assess this construct with one notable exception, i.e., the Sensory E-cigarette Expectancies Scale [82].

Measures assessing e-cigarette attitudes can also provide information regarding adolescent vulnerability to e-cigarette use initiation [65••]. Namely, assessing perceptions of benefits (e.g., social status), harm (e.g., health risks), addiction potential, and social norms (e.g., injunctive and descriptive) should be tailored to adolescents [65••]. The Electronic Cigarette Attitude Survey (ECAS) [83], which assesses attitudes towards e-cigarettes, has been validated among adolescents.

Policy

Due to the potential adverse health consequences of e-cigarette use, government regulations are needed to mitigate youth access to e-cigarettes. Much like those enacted in response to the tobacco industry, policies sanctioned across the globe to combat youth e-cigarette use include sales restrictions, minimum legal sales age (MLSA) laws, marketing restrictions, and product regulations [87]. The World Health Organization (WHO)'s 2014 report on e-cigarettes recommended that regulation is needed to prevent initiation by non-smokers, minimize potential health risks until greater clarity in research is achieved, prohibit unsubstantiated health claims about their utility, prevent the influence of tobacco industry on policy, and expand availability of cessation programs [88]. Even with mounting research on e-cigarette health risks, the degree of government regulation varies across countries, ranging from no oversight to complete prohibition ([87, 89], see Table 2).

Until recently, e-cigarettes remained largely exempt from the Food and Drug Administration (FDA)'s federal regulation of tobacco products. Recognition of youth e-cigarette use as an epidemic [8, 13], catalyzed by the emergence of e-cigarette, or vaping, product use-associated lung injury (EVALI) in 2019 [15, 16], provided a critical call-to-action for policymakers to enact legislation to mitigate adolescent e-cigarette use harms. Within the US, federal and state regulations have built on existing laws that govern traditional tobacco products. Thus, e-cigarette policies are framed within existing cigarette policies with a focus on efforts to curb accessibility and appeal by regulating youth sales, marketing/advertising, and flavoring [90].

Federal and State Regulations

FDA regulations of e-cigarettes expanded upon the authority of the 2009 Family Smoking Prevention and Tobacco Control Act, which granted the FDA authority over the sales and distribution of tobacco products, and, most notably, first established a national MLSA law of 18 years for combustible cigarette and smokeless tobacco [91]. FDA regulations of e-cigarettes began in 2016 with the “deeming rule” determination that the sale and distribution of e-cigarette products fall

Table 1 Validated measures to assess e-cigarette dependence, outcome expectancies, and attitudes

Construct	Measure	Target population	Number of items	Sample items
Dependence	Patient-Reported Outcomes Measurement Information System Nicotine Dependence Item Bank for E-Cigarettes (PROMIS-E) [78]	Adolescents	4	“I find myself reaching for my e-cigarette without thinking about it.” “I vape more before going into a situation where vaping is not allowed.”
	Penn State E-Cigarette Dependence Index (PS-ECDI) [72]	Adults	10	“How many times per day do you usually use your electronic cigarette?” “Do you sometimes awaken at night to use your electronic cigarette?”
Outcome expectancies	Adolescent E-Cigarette Consequences Questionnaire (AECQ) [79]	Adolescents	28	“Smoking e-cigarettes will help calm an angry person down.” “E-cigarettes taste good.”
	Untitled measure [62•]	Adolescents and young adults	19	“If I were to use an e-cigarette or other vaping device, I would like it.” “If I were to use an e-cigarette or other vaping device, I would worry about my health.”
	Revised youth e-cigarette outcome expectancies measure [80]	Young adults	55	“E-cigarettes hurt your lungs.” “E-cigarettes smell good.”
	Short Form Vaping Consequences Questionnaire (S-VCQ) [81]	Adults	21	“By vaping I risk heart disease and lung cancer.” “I will enjoy feeling an e-cigarette on my tongue and lips.”
	Sensory E-Cigarette Expectancies Scale (SEES) [82]	Adults	9	“I like the smell of vapor.” “I like how vaping makes me feel good physically.”
Perceptions/attitudes	Electronic Cigarette Attitudes Survey (ECAS) [83]	Adolescents	12	“E-cigarettes are less harmful to a person than regular cigarettes.” “E-cigarettes allow people to show their individuality and personality by customizing their products.”

under the agency’s current authority [12]. Recently, the FDA announced its intent to limit unauthorized cartridge-based e-cigarette flavoring [90] and marketing strategies promoting adolescent e-cigarette use [18]. Despite its progress, the FDA’s role has remained limited in the face of litigation by the tobacco industry [20, 92], and their regulatory efforts continue to lag behind e-cigarette use trends. For example, current FDA regulation does not apply to menthol, refillable, or sealed disposable products [20]. Accordingly, policymakers have undertaken the responsibility of regulating youth e-cigarette use at the state and local level. For instance, state-level MLSA legislation began in 2010, driving a public health initiative adopted by 48 states in advance of the FDA’s 2016 deeming rule expansion [93]. While state-by-state variation in specific legislation remains significant (see Fig. 1B) [11], stricter MLSA regulation, flavor bans, and marketing and sales restrictions have become pillars of a policy approach designed to reduce access and the appeal of e-cigarettes.

Major Policy Types and Effectiveness

Sales Age Restrictions

Some posit that increased control of e-cigarette sales may limit youth accessibility. Accordingly, in 2019, Tobacco 21

legislation made the sale of any tobacco product, including e-cigarettes, illegal to anyone under 21 across the US [17]. This legislation has become the topic of much investigation. For example, one study found that MLSA laws enacted through 2015 were associated with an increase in youth combustible cigarette smoking [93]. This increase may represent an unintentional post-policy consequence of restricting youth e-cigarette access [93]. Yet, other studies found no association between e-cigarette use and state-level MLSA, and even higher rates of e-cigarette use in states with smoke-free tobacco legislation [94, 95]. Thus, limiting youth access to e-cigarettes alone may inadvertently redirect behavior to other tobacco products.

Restrictions on Flavoring

The rise in youth e-cigarette use is largely attributed to the appeal of flavored products [40, 51]. Though the Tobacco Control Act banned flavored cigarettes (excluding menthol) in 2009 [12], this legislation did not cover other tobacco products and left open a loophole in which the e-cigarette industry came to thrive among youth [96, 97]. Amidst building pressure, in 2018, JUUL Lab halted in-store sales of all flavors excluding tobacco, menthol, and mint [32]. Subsequently, sales of their menthol and mint products increased

Table 2 Overview of laws currently implemented globally to regulate e-cigarette products

Category	Description	Country-level implementation	
		No. of countries [89]	US Federal Law?
MLSA	Where sales are legal, minimum age to purchase e-cigarettes (between 18 and 21 years)	45	Yes – “Deeming rule” (2016) set MLSA to 18 [12] – “Tobacco 21” (2019) raised it to 21 [17]
Sales	Regulation on sales (i.e., pre-marketing authorization required, restrictions on sales across border and in specific locations)	49	Yes – “Deeming rule” (2016) [12, 22]
	Sales ban for all e-cigarette products (<i>*only nicotine-containing products</i>)	30 (*4)	No
Marketing	Ban or regulation of advertising and promotion (<i>*only nicotine-containing products</i>)	69 (*8)	Yes
Packaging	Requirements for child-resistant packaging	32	Yes – Child Nicotine Poisoning Prevention Act (2015) [22]
	Required health warnings (i.e., “This product contains nicotine”)	40	Yes – 2016 “deeming rule” [12]
E-liquid product regulation	Regulations of nicotine concentration	35	No
	Ban of other harmful e-liquid ingredients	33	No
	Regulation of quality of ingredients, required safety and quality evaluations, flavor ban or regulation	33	No* – <i>*FDA partial flavor ban of cartridge-based products only</i> [19]
Reporting/notification	Pre-marketing notification, annual sales reports required	35	Yes* – “Deeming rule” (2016); announced as enforcement priority in 2020 [12, 19] – <i>*Federal Trade Commission requested sales, marketing reports from manufacturers in October 2019</i> [34]
E-cigarette tax	Any tax on e-cigarette sales (e.g., based on amount of e-liquid, nicotine, price)	16	No
Smoke-free air policy	Ban or restriction of e-use in public areas or workplaces	55	No

Country-level policies regulating e-cigarettes are aggregated by the Institute for Global Tobacco Control, current as of May 18, 2020 [89]

significantly [32]. As such, “self-regulation” efforts by the e-cigarette industry may be insufficient and point to the need for policy measures, such as a ban on all flavored e-cigarette products.

Effective February of 2020, the FDA took action by issuing a ban on all non-tobacco and non-menthol-flavored cartridge-based e-cigarette systems [90]. However, the ban notably omits e-liquids and disposable devices, raising concerns that youth may simply switch to other products not covered by the partial ban [98]. Independent of the FDA, nine states instituted actions to halt the retail of *all* flavored e-cigarettes, which were met with legal opposition and overruling in district courts [90].

Marketing and Advertising

The e-cigarette industry has spent hundreds of millions of US dollars on marketing and advertising in stores, online, and through media outlets, using appealing flavors, attractive

product labels, and branding to appeal to youth [22, 23]. A lack of early regulation of e-cigarette marketing likely contributed to widespread youth uptake [22, 96]. In 2016, over three-quarters of US youth reported exposure to e-cigarette advertising [99]. Unlike heavy restrictions in place governing the marketing of traditional tobacco products, equivalent federal-level regulations governing e-cigarette marketing have not been implemented [34]. Thus, the WHO and other public health officials recommended strict regulation of advertising/marketing.

Sales Taxes

Due to adolescents’ sensitivity to pricing, sales taxes on other tobacco products have been effective in reducing youth purchasing [22]. Yet, tobacco companies have responded to these mandates by reducing the baseline costs of cigarettes [22]. The Surgeon General and the WHO similarly recommend an e-cigarette sales tax [22, 87, 100]. However, e-cigarettes

regulated by the FDA as tobacco products are not subject to the federal tax code for tobacco products, which falls under the regulatory authority of the Department of Treasury's Alcohol and Tobacco Tax and Trade Bureau [22, 98]. E-cigarette taxes have not yet been widely adopted internationally (see Table 2) [89] and are only enforced in half of US states (see Fig. 1B) [11].

Sales

Restrictions to govern in-person e-cigarette sales to underage youth vary in severity across the US, including penalties to businesses (i.e., monetary fines) and laws that ban and/or penalize youth for e-cigarette purchase, possession, or use (see Fig. 1B) [101]. The federal response to the youth vaping epidemic notably included a crackdown by the FDA, with thousands of citations submitted to retailers [14]. Nevertheless, retailers have violated these laws, with one study finding that over 40% of vape shops in California sold e-cigarettes to underage buyers [101].

Online Sales

Online access to tobacco products represents another regulatory loophole, which has inadvertently resulted in an increase in online sales to youth [32, 102, 103]. A 2015 study found that, of 98 attempts by youth to purchase e-cigarettes online, only five were rejected due to age verification [103]. A study conducted in 2017 found that, of 68 youth online cigarette purchase attempts, none were rejected [102]. Despite policies in place to regulate internet tobacco sales (i.e., age verification), enforcement remains difficult, as the majority of online vendors are overseas [102, 103].

Policy Considerations and Future Directions

Despite their shortcomings, there is evidence suggesting that regulations targeting youth e-cigarette access have been effective. Still, policymakers must take into consideration possible adverse consequences of over-regulation. Additional measures, such as the Protecting American Lungs and Reversing the Youth Tobacco Epidemic Act of 2020 (HR 2339), seek to curb youth nicotine addiction by expanding FDA regulations to cover e-cigarettes and imposing several restrictions on tobacco (including e-cigarette) products and sales [20, 21]. The legislation would prohibit all flavoring (excluding tobacco) in tobacco products, ban online sales of all tobacco products, and impose nicotine taxes for e-cigarettes [20]. Yet, advocacy organizations express concern that proposed restrictions via HR 2339's expanded flavor ban may disproportionately affect communities of color, who use mostly menthol-flavored tobacco products, by emphasizing criminalization over harm

reduction [104]. Thus, lawmakers should prioritize targeting the manufacture and sale, not the use, of illegal e-cigarette products.

Conclusions

The rise in youth e-cigarette use has been staggering, especially in the US [8]. Although e-cigarette companies firmly assert that their primary mission is to provide a safer alternative to adult cigarette smokers, the industry has seized the opportunity to hook a younger, more vulnerable generation on nicotine who have previously evidenced historically low smoking rates. E-cigarette companies have appealed to youth through marketing reflecting messages that their products deliver a harm-free sensory experience through a multitude of e-liquid flavorings and the ability to perform tricks, offer an opportunity to promote one's individuality through customization, and provide an effective method to gain social status. This range of appealing features presents a challenge for researchers wanting to assess e-cigarette behaviors and attitudes, which has contributed to a lack of validated measures specific to adolescent e-cigarette use. Moreover, innovations in more effective nicotine delivery systems that increase nicotine concentration levels while minimizing throat irritation have also contributed to increased rates of nicotine dependence. This is especially concerning given that low levels of nicotine exposure during adolescence can have a profound impact on neurochemistry and behavior (e.g., decreased cognitive function, enhanced drug reward), which contribute to the development of nicotine dependence, as well as substance use disorders [4, 6].

Notable gaps in regulation also contribute to the rise of e-cigarette use among youth. Namely, e-cigarette companies profited by open loopholes that circumvented policies restricting access to these products among youth, such as sales age restrictions and marketing. Research indicates that countries that extensively regulate e-cigarettes through policies focused on taxation, requiring warning labels, and prohibiting sales to minors demonstrate remarkably low prevalence rates among youth compared to the rapid escalation seen among US counterparts [87, 105]. If left unchecked, the rates of e-cigarette use among this vulnerable population are likely to continue rising and undo previous successes in reducing rates of adolescent cigarette use. Moving forward, it is paramount that regulatory gaps are addressed through targeted legislation focused on governing product flavoring, prohibiting advertisements and promotions, and enforcing e-cigarette taxes and smoke-free indoor air policies. Policymakers should consider comprehensive regulations that prioritize harm reduction while harmonizing with the evolving e-cigarette product landscape.

Funding This publication was supported by the National Institute on Minority Health and Health Disparities (U54 MD012393 to E. M. Trucco), the National Institute on Alcohol Abuse and Alcoholism (K08 AA023290 to E. M. Trucco), and the National Institute on Drug Abuse (T32 DA043449 to W. E. Pelham) of the National Institutes of Health. In addition, this publication was supported by the University Graduate School's Presidential Fellowship at Florida International University (to S. A. Hartmann). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health or Florida International University.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent All reported studies/experiments with human or animal subjects performed by the authors have been previously published and complied with all applicable ethical standards (including the Helsinki declaration and its amendments, institutional/national research committee standards, and international/national/institutional guidelines).

References

Papers of particular interest, published recently, have been highlighted as:

- Of importance
- Of major importance

1. Glantz SA, Bareham DW. E-cigarettes: use, effects on smoking, risks, and policy implications. *Annu Rev Public Health*. 2018;39(1):215–35. <https://doi.org/10.1146/annurev-publhealth-040617-013757>.
2. Dawkins L, Kimber C, Puwanesarasa Y, Soar K. First- versus second-generation electronic cigarettes: predictors of choice and effects on urge to smoke and withdrawal symptoms. *Addiction*. 2015;110(4):669–77. <https://doi.org/10.1111/add.12807>.
3. Schneider S, Diehl K. Vaping as a catalyst for smoking? An initial model on the initiation of electronic cigarette use and the transition to tobacco smoking among adolescents. *Nicotine Tob Res*. 2016;18(5):647–53. <https://doi.org/10.1093/ntr/ntv193>.
4. Yuan M, Cross SJ, Loughlin SE, Leslie FM. Nicotine and the adolescent brain. *J Physiol*. 2015;593(16):3397–412. <https://doi.org/10.1113/JP270492>.
5. Moylan S, Jacka FN, Pasco JA, Berk M. Cigarette smoking, nicotine dependence and anxiety disorders: a systematic review of population-based, epidemiological studies. *BMC Med*. 2012;10:123. <https://doi.org/10.1186/1741-7015-10-123>.
6. Treur JL, Willemsen G, Bartels M, Geels LM, van Beek JH, Huppertz C, et al. Smoking during adolescence as a risk factor for attention problems. *Biol Psychiatry*. 2015;78(9):656–63. <https://doi.org/10.1016/j.biopsych.2014.06.019>.
7. Squeglia LM, Gray KM. Alcohol and drug use and the developing brain. *Curr Psychiatry Rep*. 2016;18(5):46. <https://doi.org/10.1007/s11920-016-0689-y>.
8. Cullen KA, Gentzke AS, Sawdey MD, Chang JT, Anic GM, Wang TW, et al. E-cigarette use among youth in the United States, 2019. *JAMA*. 2019;322(21):2095–103. <https://doi.org/10.1001/jama.2019.18387>.
9. Cullen KA, Ambrose BK, Gentzke AS, Apelberg BJ, Jamal A, King BA. Notes from the field: use of electronic cigarettes and any tobacco product among middle and high school students - United States, 2011–2018. *MMWR Morb Mortal Wkly Rep*. 2018;67(45):1276–7. <https://doi.org/10.15585/mmwr.mm6745a5>.
10. Wang TW, Neff LJ, Park-Lee E, Ren C, Cullen KA, BA K. E-cigarette use among middle and high school students — United States. *MMWR Morb Mortal Wkly Rep*. 2020. <https://doi.org/10.15585/mmwr.mm6937e1>.
11. Centers for Disease Control and Prevention (CDC). State Tobacco Activities Tracking and Evaluation (STATE) System. In: State Tobacco Activities Tracking and Evaluation (STATE) System. CDC. 2020. <https://www.cdc.gov/statesystem>. Accessed April 15 2020.
12. Food and Drug Administration, Department of Health and Human Services. Deeming tobacco products to be subject to the Federal Food, Drug, and Cosmetic Act, as Amended by the Family Smoking Prevention and Tobacco Control Act; restrictions on the sale and distribution of tobacco products and required warning statements for tobacco products. Final rule. *Fed Regist*. 2016;81(90):28973–9106.
13. Office of the Surgeon General. Surgeon general's advisory on e-cigarette use among youth. 2018.
14. Food and Drug Administration, Department of Health and Human Services. FDA takes new steps to address epidemic of youth e-cigarette use, including a historic action against more than 1,300 retailers and 5 major manufacturers for their roles perpetuating youth access. 2018.
15. Office on Smoking and Health, National Center for Chronic Disease Prevention and Health Promotion. Outbreak of lung injury associated with the use of e-cigarette, or vaping, products. Centers for Disease Control and Prevention (CDC). 2020. https://www.cdc.gov/tobacco/basic_information/e-cigarettes/severe-lung-disease.html. Accessed June 30 2020.
16. Perrine CG. Characteristics of a multistate outbreak of lung injury associated with e-cigarette use, or vaping — United States, 2019. *Morb Mortal Rep* 2019.
17. Food and Drug Administration, Department of Health and Human Services. Newly signed legislation raises federal minimum age of sale of tobacco products to 21. Food and Drug Administration. 2020. <https://www.fda.gov/tobacco-products/ctp-newsroom/newly-signed-legislation-raises-federal-minimum-age-sale-tobacco-products-21>. Accessed June 30 2020.
18. Zeller M. Youth e-cigarette use and the Food and Drug Administration's multifaceted approach. *Am J Public Health*. 2020;110(6):772–3. <https://doi.org/10.2105/AJPH.2020.305680>.
19. Food and Drug Administration, Department of Health and Human Services. Enforcement priorities for electronic nicotine delivery system (ENDS) and other deemed products on the market without premarket authorization. *Fed Regist*. 2020.
20. Gee RE. Shortcomings of the Food and Drug Administration Guidance Addressed by Congress 2020 HR 2339. *Am J Public Health*. 2020;110(6):776–7. <https://doi.org/10.2105/AJPH.2020.305679>.
21. Protecting American Lungs and Reversing the Youth Tobacco Epidemic Act of 2020, 116th Congress, 2d Sess. (2020).
22. Office of the Surgeon General. E-cigarette use among youth and young adults. A report of the surgeon general. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health; 2016.
23. Ali FRM, Marynak KL, Kim Y, Binns S, Emery SL, Gomez Y et al. E-cigarette advertising expenditures in the United States,

- 2014–2018. Tobacco Control. 2020:tobaccocontrol. <https://doi.org/10.1136/tobaccocontrol-2019-055424>.
24. Herzog B. Wall street tobacco industry update. National Association of Tobacco Outlets (NATO) Education Seminar – February 11, 2019.
 25. Wells Fargo Securities, Equity Research. Nielsen: Tobacco “All Channel” Data Cig Pricing Remains Strong; E-Cig \$ Sales Growth Re-Accelerates. . San Francisco (CA): Wells Fargo Securities, March 31, 2015.
 26. Wells Fargo Securities, Equity Research. Nielsen: Tobacco “All Channel” Data Marlboro Volume & Share Pressures Continue. San Francisco (CA): Wells Fargo Securities, February 8, 2018.
 27. Wells Fargo Securities, Equity Research. Nielsen: Tobacco All Channel Data Thru 8/11 - Cig Vol Decelerates. San Francisco (CA): Wells Fargo Securities, August 21, 2018.
 28. Zhu SH, Sun JY, Bonnevie E, Cummins SE, Gamst A, Yin L, et al. Four hundred and sixty brands of e-cigarettes and counting: implications for product regulation. *Tob Control*. 2014;23(suppl 3):iii3–9. <https://doi.org/10.1136/tobaccocontrol-2014-051670>.
 29. Kong G, Krishnan-Sarin S. A call to end the epidemic of adolescent e-cigarette use. *Drug Alcohol Depend*. 2017;174:215–21. <https://doi.org/10.1016/j.drugalcdep.2017.03.001> **This review provides a summary of e-cigarette devices and e-liquids, prevalence rates of adolescent e-cigarette use, e-cigarette safety and health effects. In addition, the effectiveness of e-cigarettes as smoking cessation aids and e-cigarette regulations within the United States are reviewed.**
 30. Galstyan E, Galimov A, Sussman S. Commentary: the emergence of pod mods at Vape shops. *Eval Health Prof*. 2019;42(1):118–24. <https://doi.org/10.1177/0163278718812976>.
 31. McMillen R, Tanski S, Wilson K, Klein JD, Winickoff JP. Adolescent use of different e-cigarette products. *Pediatrics*. 2018;142(4):e20180260. <https://doi.org/10.1542/peds.2018-0260>.
 32. Liber A, Cahn Z, Larsen A, Drope J. Flavored e-cigarette sales in the United States under self-regulation from January 2015 through October 2019. *Am J Public Health*. 2020;110(6):785–7. <https://doi.org/10.2105/AJPH.2020.305667>.
 33. Johnston LD, Miech RA, O’Malley PM, Bachman JG, Schulenberg JE, Patrick ME. Monitoring the future National Survey Results on drug use 1975–2019: overview, key findings on adolescent drug use. Ann Arbor: Institute for Social Research, University of Michigan; 2020.
 34. Truth Initiative. E-cigarettes: facts, stats and regulations. Truth Initiative, Washington, DC. 2019. https://truthinitiative.org/sites/default/files/media/files/2020/02/Truth_E-Cigarette_FactSheet%202019_Update_010920.pdf. Accessed June 23 2020.
 35. Dawkins L, Turner J, Roberts A, Soar K. ‘Vaping’ profiles and preferences: an online survey of electronic cigarette users. *Addiction*. 2013;108(6):1115–25. <https://doi.org/10.1111/add.12150>.
 36. Faddus MC, Smith TT, Squeglia LM. The rise of e-cigarettes, pod mod devices, and JUUL among youth: factors influencing use, health implications, and downstream effects. *Drug Alcohol Depend*. 2019;201:85–93. <https://doi.org/10.1016/j.drugalcdep.2019.04.011> **This review article provides an overview of e-cigarette use among youth. The authors provide answers to commonly asked questions regarding e-cigarettes as a resource for clinicians, educators, youth, and family members.**
 37. Kong G, Morean ME, Cavallo DA, Camenga DR, Krishnan-Sarin S. Reasons for electronic cigarette experimentation and discontinuation among adolescents and young adults. *Nicotine Tob Res*. 2015;17(7):847–54. <https://doi.org/10.1093/ntr/ntu257>.
 38. Hsu G, Sun JY, Zhu SH. Evolution of electronic cigarette brands from 2013–2014 to 2016–2017: analysis of brand websites. *J Med Internet Res*. 2018;20(3):e80. <https://doi.org/10.2196/jmir.8550>.
 39. Etter JF. Characteristics of users and usage of different types of electronic cigarettes: findings from an online survey. *Addiction*. 2016;111(4):724–33. <https://doi.org/10.1111/add.13240>.
 40. Shang C, Huang J, Chaloupka FJ, Emery SL. The impact of flavour, device type and warning messages on youth preferences for electronic nicotine delivery systems: evidence from an online discrete choice experiment. *Tob Control*. 2018;27(e2):e152–e9. <https://doi.org/10.1136/tobaccocontrol-2017-053754>.
 41. Laestadius LI, Wahl MM, Pokhrel P, Cho YI. From apple to werewolf: a content analysis of marketing for e-liquids on Instagram. *Addict Behav*. 2019;91:119–27. <https://doi.org/10.1016/j.addbeh.2018.09.008>.
 42. Chen C, Zhuang YL, Zhu SH. E-cigarette design preference and smoking cessation: a U.S. population study. *Am J Prev Med*. 2016;51(3):356–63. <https://doi.org/10.1016/j.amepre.2016.02.002>.
 43. Cox S, Leigh NJ, Vanderbush TS, Choo E, Goniewicz ML, Dawkins L. An exploration into “do-it-yourself” (DIY) e-liquid mixing: Users’ motivations, practices and product laboratory analysis. *Addict Behav Rep*. 2019;9:100151. <https://doi.org/10.1016/j.abrep.2018.100151>.
 44. Kong G, Bold KW, Morean ME, Bhatti H, Camenga DR, Jackson A, et al. Appeal of JUUL among adolescents. *Drug Alcohol Depend*. 2019;205:107691. <https://doi.org/10.1016/j.drugalcdep.2019.107691>.
 45. Delnevo C, Giovenco DP, Hrywna M. Rapid proliferation of illegal pod-mod disposable e-cigarettes. *Tobacco Control*. 2020:tobaccocontrol-2019-055485. <https://doi.org/10.1136/tobaccocontrol-2019-055485>.
 46. Williams R. The rise of disposable JUUL-type e-cigarette devices. *Tobacco Control*. 2019:tobaccocontrol-2019-055379. <https://doi.org/10.1136/tobaccocontrol-2019-055379>.
 47. Kong G, LaVallee H, Rams A, Ramamurthi D, Krishnan-Sarin S. Promotion of vape tricks on YouTube: content analysis. *J Med Internet Res*. 2019;21(6):e12709. <https://doi.org/10.2196/12709>.
 48. Hajek P, Pittaccio K, Pesola F, Myers Smith K, Phillips-Waller A, Przulj D. Nicotine delivery and users’ reactions to Juul compared with cigarettes and other e-cigarette products. *Addiction*. 2020;115(6):1141–8. <https://doi.org/10.1111/add.14936>.
 49. Creswell J, Kaplan S. New York Times (Online): How Juul hooked a generation on nicotine; 2019.
 50. Hammig B, Daniel-Dobbs P, Blunt-Vinti H. Electronic cigarette initiation among minority youth in the United States. *Am J Drug Alcohol Abuse*. 2017;43(3):306–10. <https://doi.org/10.1080/00952990.2016.1203926>.
 51. Meernik C, Baker HM, Kowitt SD, Ranney LM, Goldstein AO. Impact of non-menthol flavours in e-cigarettes on perceptions and use: an updated systematic review. *BMJ Open*. 2019;9(10):e031598. <https://doi.org/10.1136/bmjopen-2019-031598>.
 52. Groom AL, Vu TT, Kesh A, Hart JL, Walker KL, Giachello AL, et al. Correlates of youth vaping flavor preferences. *Prev Med Rep*. 2020;18:101094. <https://doi.org/10.1016/j.pmedr.2020.101094>.
 53. Li Q, Wang C, Liu R, Wang L, Zeng DD, Leischow SJ. Understanding users’ vaping experiences from social media: initial study using sentiment opinion summarization techniques. *J Med Internet Res*. 2018;20(8):e252. <https://doi.org/10.2196/jmir.9373>.
 54. Goldenson NI, Leventhal AM, Simpson KA, Barrington-Trimis JL. A review of the use and appeal of flavored electronic cigarettes. *Curr Addict Rep*. 2019;6(2):98–113. <https://doi.org/10.1007/s40429-019-00244-4>.
 55. Morean ME, Butler ER, Bold KW, Kong G, Camenga DR, Cavallo DA, et al. Preferring more e-cigarette flavors is associated with e-cigarette use frequency among adolescents but not adults.

- PLoS One. 2018;13(1):e0189015. <https://doi.org/10.1371/journal.pone.0189015>.
56. Morean ME, Bold KW, Kong G, Camenga DR, Simon P, Jackson A, et al. High school students' use of flavored e-cigarette e-liquids for appetite control and weight loss. *Addict Behav.* 2020;102:106139. <https://doi.org/10.1016/j.addbeh.2019.106139>.
 57. French SA, Perry CL, Leon GR, Fulkerson JA. Weight concerns, dieting behavior, and smoking initiation among adolescents: a prospective study. *Am J Public Health.* 1994;84(11):1818–20. <https://doi.org/10.2105/ajph.84.11.1818>.
 58. Farrimond H. A typology of vaping: identifying differing beliefs, motivations for use, identity and political interest amongst e-cigarette users. *Int J Drug Policy.* 2017;48:81–90. <https://doi.org/10.1016/j.drugpo.2017.07.011>.
 59. Yule JA, Tinson JS. Youth and the sociability of "Vaping". *J Consum Behav.* 2017;16(1):3–14. <https://doi.org/10.1002/cb.1597>.
 60. Romijnders K, van Osch L, de Vries H, Talhout R. Perceptions and reasons regarding e-cigarette use among users and non-users: a narrative literature review. *Int J Environ Res Public Health.* 2018;15(6). <https://doi.org/10.3390/ijerph15061190>.
 61. McKeganey N, Barnard M, Russell C. Vapers and vaping: e-cigarettes users views of vaping and smoking. *Drugs: Education, Prevention and Policy.* 2017;25(1):13–20. <https://doi.org/10.1080/09687637.2017.1296933>.
 62. Barker JO, Kelley DE, Noar SM, Reboussin BA, Cornacchione Ross J, Sutfin EL. E-cigarette outcome expectancies among nationally representative samples of adolescents and young adults. *Subst Use Misuse.* 2019;54(12):1970–9. <https://doi.org/10.1080/10826084.2019.1624773> **This study measures outcome expectancies of e-cigarette use among a nationally representative sample of adolescents (ages 14–17) and young adults (ages 18–25), as well as the association between varying positive and negative outcome expectancies and e-cigarette use.**
 63. Zare S, Nemati M, Zheng Y. A systematic review of consumer preference for e-cigarette attributes: flavor, nicotine strength, and type. *PLoS One.* 2018;13(3):e0194145. <https://doi.org/10.1371/journal.pone.0194145>.
 64. Bernat D, Gasquet N, Wilson KO, Porter L, Choi K. Electronic cigarette harm and benefit perceptions and use among youth. *Am J Prev Med.* 2018;55(3):361–7. <https://doi.org/10.1016/j.amepre.2018.04.043>.
 65. Gibson LA, Creamer MR, Breland AB, Giachello AL, Kaufman A, Kong G, et al. Measuring perceptions related to e-cigarettes: important principles and next steps to enhance study validity. *Addict Behav.* 2018;79:219–25. <https://doi.org/10.1016/j.addbeh.2017.11.017> **This article provides comprehensive guidance regarding how to assess e-cigarette perceptions. It is suggested that measures cover four areas of perception: 1) benefits, 2) harm, 3) addiction, and 4) social norms. Measures on e-cigarette use perceptions could help inform why youth initiate and continue the use of these products.**
 66. Gorukanti A, Delucchi K, Ling P, Fisher-Travis R, Halpern-Felsher B. Adolescents' attitudes towards e-cigarette ingredients, safety, addictive properties, social norms, and regulation. *Prev Med.* 2017;94:65–71. <https://doi.org/10.1016/j.ypmed.2016.10.019>.
 67. McKelvey K, Baiocchi M, Halpern-Felsher B. Adolescents' and young adults' use and perceptions of pod-based electronic cigarettes. *JAMA Netw Open.* 2018;1(6):e183535. <https://doi.org/10.1001/jamanetworkopen.2018.3535>.
 68. Russell C, Katsampouris E, McKeganey N. Harm and addiction perceptions of the JUUL e-cigarette among adolescents. *Nicotine Tob Res.* 2020;22(5):713–21. <https://doi.org/10.1093/ntr/ntz183>.
 69. Rohde JA, Noar SM, Horvitz C, Lazard AJ, Cornacchione Ross J, Sutfin EL. The role of knowledge and risk beliefs in adolescent e-cigarette use: a pilot study. *Int J Environ Res Public Health.* 2018;15(4). <https://doi.org/10.3390/ijerph15040830>.
 70. Manzione LC, Shan L, Azagba S. Associations between risk perceptions and cigarette, e-cigarette, and dual-product use among Canadian adolescents. *Tob Use Insights.* 2020;13:1179173X20903784. <https://doi.org/10.1177/1179173X20903784>.
 71. Weaver SR, Kim H, Glasser AM, Sutfin EL, Barrington-Trimis J, Payne TJ, et al. Establishing consensus on survey measures for electronic nicotine and non-nicotine delivery system use: current challenges and considerations for researchers. *Addict Behav.* 2018;79:203–12. <https://doi.org/10.1016/j.addbeh.2017.11.016>.
 72. Foulds J, Veldheer S, Yingst J, Hrabovsky S, Wilson SJ, Nichols TT, et al. Development of a questionnaire for assessing dependence on electronic cigarettes among a large sample of ex-smoking e-cigarette users. *Nicotine Tob Res.* 2015;17(2):186–92. <https://doi.org/10.1093/ntr/ntu204>.
 73. Vogel EA, Prochaska JJ, Rubinstein ML. Measuring e-cigarette addiction among adolescents. *Tob Control.* 2020;29(3):258–62. <https://doi.org/10.1136/tobaccocontrol-2018-054900>.
 74. Amato MS, Boyle RG, Levy D. How to define e-cigarette prevalence? Finding clues in the use frequency distribution. *Tob Control.* 2016;25(e1):e24–9. <https://doi.org/10.1136/tobaccocontrol-2015-052236>.
 75. Cooper M, Harrell MB, Perry CL. A qualitative approach to understanding real-world electronic cigarette use: implications for measurement and regulation. *Prev Chronic Dis.* 2016;13:E07. <https://doi.org/10.5888/pcd13.150502>.
 76. Hinds JT III, Loukas A, Chow S, Pasch KE, Harrell MB, Perry CL, et al. Using cognitive interviewing to better assess young adult e-cigarette use. *Nicotine Tob Res.* 2016;18(10):1998–2005.
 77. Kim H, Davis AH, Dohack JL, Clark PI. E-cigarettes use behavior and experience of adults: qualitative research findings to inform e-cigarette use measure development. *Nicotine Tob Res.* 2017;19(2):190–6. <https://doi.org/10.1093/ntr/ntw175>.
 78. Morean ME, Krishnan-Sarin S, SOM S. Assessing nicotine dependence in adolescent e-cigarette users: the 4-item Patient-Reported Outcomes Measurement Information System (PROMIS) nicotine dependence item bank for electronic cigarettes. *Drug Alcohol Depend.* 2018;188:60–3. <https://doi.org/10.1016/j.drugalcdep.2018.03.029>.
 79. Cristello JV, Sutherland MT, Trucco EM. A preliminary validation of the adolescent e-cigarette consequences questionnaire. *Drug Alcohol Depend.* 2020;213:108118. <https://doi.org/10.1016/j.drugalcdep.2020.108118>.
 80. Pokhrel P, Lam TH, Pagano I, Kawamoto CT, Herzog TA. Young adult e-cigarette use outcome expectancies: validity of a revised scale and a short scale. *Addict Behav.* 2018;78:193–9. <https://doi.org/10.1016/j.addbeh.2017.11.019>.
 81. Morean ME, L'Insalata A. The short form vaping consequences questionnaire: psychometric properties of a measure of vaping expectancies for use with adult e-cigarette users. *Nicotine Tob Res.* 2017;19(2):215–21. <https://doi.org/10.1093/ntr/ntw205>.
 82. Morean ME, Krishnan-Sarin S, Sussman S, Foulds J, Fishbein H, Grana R, et al. Development and psychometric validation of a novel measure of sensory expectancies associated with e-cigarette use. *Addict Behav.* 2019;91:208–15. <https://doi.org/10.1016/j.addbeh.2018.08.031>.
 83. Diez SL, Cristello JV, Dillon FR, De La Rosa M, Trucco EM. Validation of the electronic cigarette attitudes survey (ECAS) for youth. *Addict Behav.* 2019;91:216–21. <https://doi.org/10.1016/j.addbeh.2018.11.022>.
 84. Bold KW, Sussman S, O'Malley SS, Grana R, Foulds J, Fishbein H, et al. Measuring e-cigarette dependence: initial guidance. *Addict Behav.* 2018;79:213–8. <https://doi.org/10.1016/j.addbeh.2017.11.015>.

85. Barrington-Trimis JL, Berhane K, Unger JB, Cruz TB, Huh J, Leventhal AM, et al. Psychosocial factors associated with adolescent electronic cigarette and cigarette use. *Pediatrics*. 2015;136(2):308–17. <https://doi.org/10.1542/peds.2015-0639>.
86. Pokhrel P, Little MA, Fagan P, Muranaka N, Herzog TA. Electronic cigarette use outcome expectancies among college students. *Addict Behav*. 2014;39(6):1062–5. <https://doi.org/10.1016/j.addbeh.2014.02.014>.
87. World Health Organization (WHO). WHO TobReg: report on the scientific basis of tobacco product regulation: 7th report of a WHO study group. 2019.
88. World Health Organization (WHO). Electronic nicotine delivery system 2014 July 21.
89. Institute for Global Tobacco Control. Country laws regulating e-cigarettes: a policy scan. Johns Hopkins Bloomberg School of Public Health, Baltimore, MD. 2020. <https://www.globaltobaccocontrol.org/home>. Accessed September 1 2020.
90. King BA. Flavors are a major driver of the youth e-cigarette epidemic. *Am J Public Health*. 2020;110(6):773–4. <https://doi.org/10.2105/AJPH.2020.305670>.
91. Family Smoking Prevention and Tobacco Control Act, Pub. L. No. 111–31, Stat. H.R.1256 (2009).
92. Berman ML, Yang YT. E-cigarettes, youth, and the US Food and Drug Administration’s “deeming” regulation. *JAMA Pediatr*. 2016;170(11):1039–40. <https://doi.org/10.1001/jamapediatrics.2016.2255>.
93. Dave D, Feng B, Pesko MF. The effects of e-cigarette minimum legal sale age laws on youth substance use. *Health Econ*. 2019;28(3):419–36. <https://doi.org/10.1002/hec.3854>.
94. Hawkins SS, Ghiani M, Baum CF. Associations between state tobacco control policies and adolescent ENDS use. *J Public Health Manag Pract*. 2019;25(6):529–36. <https://doi.org/10.1097/PHH.0000000000000859>.
95. Dutra LM, Glantz SA, Arrazola RA, King BA. Impact of e-cigarette minimum legal sale age laws on current cigarette smoking. *J Adolesc Health*. 2018;62(5):532–8. <https://doi.org/10.1016/j.jadohealth.2017.11.302>.
96. Livingston CJ, Freeman RJ, Costales VC, Westhoff JL, Caplan LS, Sherin KM, et al. Electronic nicotine delivery systems or e-cigarettes: American College of Preventive Medicine’s practice statement. *Am J Prev Med*. 2019;56(1):167–78. <https://doi.org/10.1016/j.amepre.2018.09.010>.
97. Stone E, Marshall H. Tobacco and electronic nicotine delivery systems regulation. *Transl Lung Cancer Res*. 2019;8(Suppl 1):S67–76. <https://doi.org/10.21037/tlcr.2019.03.13>.
98. Sindelar JL. Regulating Vaping - policies, possibilities, and perils. *N Engl J Med*. 2020;382(20):e54. <https://doi.org/10.1056/NEJMp1917065>.
99. Marynak K, Gentzke A, Wang TW, Neff L, King BA. Exposure to electronic cigarette advertising among middle and high school students - United States, 2014–2016. *MMWR Morb Mortal Wkly Rep*. 2018;67(10):294–9. <https://doi.org/10.15585/mmwr.mm6710a3>.
100. World Health Organization (WHO). WHO report on the global tobacco epidemic 2019: Offer help to quit tobacco use 2019.
101. Roeseler A, Vuong TD, Henriksen L, Zhang X. Assessment of underage sales violations in tobacco stores and vape shops. 2019. p. 795–7.
102. Williams RS, Derrick J, Phillips KJ. Cigarette sales to minors via the internet: how the story has changed in the wake of federal regulation. *Tob Control*. 2017;26(4):415–20. <https://doi.org/10.1136/tobaccocontrol-2015-052844>.
103. Williams RS, Derrick J, Ribisl KM. Electronic cigarette sales to minors via the internet. *JAMA Pediatr*. 2015;169(3):e1563. <https://doi.org/10.1001/jamapediatrics.2015.63>.
104. American Civil Liberties Union (ACLU). Coalition Letter of Criminal Justice Concerns with H.R. 2339, Reversing the Youth Tobacco Epidemic Act. 2020. <https://www.aclu.org/letter/coalition-letter-criminal-justice-concerns-hr-2339-reversing-youth-tobacco-epidemic-act>. Accessed 26 June 2020.
105. Jun J, Kim JK. Do state regulations on e-cigarettes have impacts on the e-cigarette prevalence? *Tob Control*. 2020;tobaccocontrol. <https://doi.org/10.1136/tobaccocontrol-2019-055287>.

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.