Chemical Composition of Electronic Vaping Products From School Grounds in California

Ping Wang, PhD[1], **Rebecca J. Williams, DrPH, MPH**[2], **Wenhao Chen, PhD**[1], **Flavia Wang**[1], **Mays Shamout, MD, MPH**[3,4], **Lauren J. Tanz, ScD, MSPH**[4], **Carolyn T.A. Herzig, PhD, MS**[4], **Lisa P. Oakley, PhD, MPH**[4], **Corey M. Peak, ScD, MS**[4], **Amy Heinzerling, MD, MPH**[4,5], **Maeh Al-Shawaf, DrPH, MPH**[3], **Paul Melstrom, PhD**[3], **Kristy Marynak, MPP**[3], **Michael A. Tynan, MPH**[3], **Israel T. Agaku, DMD, PhD**[3], **Kazukiyo Kumagai, PhD**[1]

[1]Air Quality Section, Environmental Health Laboratory, Center for Laboratory Sciences, California Department of Public Health, Richmond, CA, USA

[2]California Tobacco Prevention Program, California Department of Public Health, Sacramento, CA, USA

[3]Office on Smoking and Health, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, Atlanta, GA, USA

[4]Epidemic Intelligence Service, Division of Scientific Education and Professional Development, Center for Surveillance, Epidemiology, and Laboratory Services, Centers for Disease Control and Prevention, Atlanta, GA, USA

[5]Occupational Health Branch, California Department of Public Health, Richmond, CA, USA

Abstract

Introduction: The use of electronic vaping products (EVPs) containing nicotine, marijuana, and/or other substances remains prominent among youth; with EVPs containing nicotine being the most commonly used tobacco product among youth since 2014. However, a detailed understanding of the chemical composition of these products is limited.

Aims and Methods: From February 25th to March 15th, 2019, a total of 576 EVPs, including 233 e-cigarette devices (with 43 disposable vape pens) and 343 e-liquid cartridges/pods/bottled e-liquids, were found or confiscated from a convenience sample of 16 public high schools in California. Liquids inside 251 vape pens and cartridges/pods/bottled e-liquids were analyzed using a gas chromatography/mass spectrometry (GC/MS). For comparison, new JUUL pods, the most commonly used e-cigarette among youth during 2018–2019, with different flavorings and nicotine content were purchased and analyzed.

Results: For e-cigarette cartridges/pods/bottled e-liquids, nicotine was detected in 204 of 208 (98.1%) samples. Propylene glycol and vegetable glycerin were dominant solvents in nicotine-containing EVPs. Among 43 disposable vape pen devices, cannabinoids such as tetrahydrocannabinol (THC) or cannabidiol (CBD) were identified in 39 of 43 (90.1%) samples, of which three contained both nicotine and THC. Differences in chemical compositions were observed between confiscated or collected JUULs and purchased JUULs. Measured nicotine was inconsistent with labels on some confiscated or collected bottled e-liquids.

Conclusions: EVPs from 16 participating schools were found to widely contain substances with known adverse health effects among youth, including nicotine and cannabinoids. There was inconsistency between labeled and measured nicotine on the products from schools.

Implications: This study measured the main chemical compositions of EVPs found at 16 California public high schools. Continued efforts are warranted, including at the school-level, to educate, prevent, and reduce youth use of EVPs.

Introduction

Since 2014, electronic vaping products (EVPs) have been the most commonly used tobacco product among middle and high school students.[1,2] Youth are particularly attracted to the wide variety of flavors available in these products, often have the perception that these products are a less harmful alternative for combustible tobacco, and are drawn to the modern-looking design.[2,3] In 2020, 19.6% of high school students currently used e-cigarettes, with 84.7% reported using flavored e-cigarettes[4]; in 2022, 14.1% of high school students currently used e-cigarettes and 84.9% of those reported the use of flavored e-cigarettes.[1] E-cigarette use among high school students slightly dropped from 2020 to 2022. Among high school current e-cigarette users in 2020, the most commonly used device type was prefilled pods or cartridges (48.5%), followed by disposables (26.5%), and tanks (14.8%),[5] however, by 2022 the most commonly used device types were disposables (57.2%) followed by pods or cartridges (25.7%) and tanks (5.9%).[1] Disposable EVPs instead of prefilled pods or cartridges became the most popular device type among high school students in 2022, while tank type use dropped from 14.8% in 2020 to 5.9% in 2022.[1,5]

Many of these devices deliver nicotine in the form of nicotine salts, which can deliver higher levels of nicotine with less irritation than the free-base form nicotine used in earlier generations of e-cigarettes and conventional tobacco products.[6] The use of nicotine salts could enhance the likelihood of nicotine dependence and addiction, particularly among previously nicotine-naïve populations such as youth.[6] In addition to the risk for addiction, nicotine exposure during adolescence can harm the developing brain and may increase the likelihood of addiction to other tobacco products and other drugs.[6]

E-liquids contain propylene glycol (PG) and vegetable glycerin (VG), which are humectants used to produce the aerosols delivered to the users.[7] Persons who use e-cigarettes have reported that higher levels of PG lead to a better "throat hit" and deliver more flavors, and higher levels of VG produce more exhaled aerosol.[8] It has been found that e-liquids also contain other harmful and potentially harmful ingredients, including flavorants that can cause serious lung damage, volatile organic compounds (VOCs), cancer causing chemicals, and heavy metals.[3]

In addition to nicotine, EVPs can also be used to deliver other substances, including cannabis.[9] In a 2022 study, the past 30-day cannabis vaping among 12th grade students was 14.8%, slightly higher than that reported in 2019 (14.0%).[10,11] Research on the health effects of using cannabis, including in EVPs, is emerging. However, recent studies suggest that using cannabis via an EVP is associated with increased pulmonary irritation in adolescents and increased risk of symptoms from bronchitis and wheezing in young adults.[12,13] During 2019–2020, an outbreak of severe lung injury called E-cigarette, or Vaping, product use Associated Lung Injury (EVALI) occurred, with about half of cases occurring among US youth and young adults. The outbreak, which occurred after this study took place, was linked to an additive, vitamin E acetate, used in some tetrahydrocannabinol (THC) containing EVPs.[14]

To date, many studies have evaluated nicotine content in EVPs available on the market or assessed self-reported youth use of EVPs, including the use of products containing nicotine or cannabis.[15–19] However, no known studies measured the chemical constituents of products from school grounds that may have been used by youth. Further, due to social bias of self-reported information on nicotine or cannabis use, inaccurate ingredient labels, and informal or illicit sources of EVPs, the true nicotine concentration of products may differ from results from self-report surveys and labels from the commercially available products on the market. Therefore, it is necessary to assess chemical constituents in the EVPs found on school grounds and that may be used by youth. This information can help further direct studies on the potential health risks to youth from using these products, as well as strategies to educate, prevent, and reduce use among this population. To address this gap, this study assessed constituents of EVP liquids confiscated from students or from products found on school grounds in a convenience sample of California high schools. This study further compared the levels of nicotine, PG, and VG in the JUULs from the school sample to purchased commercial JUULs, the most prevalent EVP used by adolescents in 2018–2019.[19]

Methods

Electronic Vaping Products Collection

From February 25th to March 15th, 2019, an environmental assessment was conducted among a convenience sample of California public high schools that confiscated EVPs from students or found on school grounds. An e-mail invitation was sent to principals and superintendents of 1456 California public high schools to participate in the assessment. Public high schools were defined as traditional, charter, or magnet schools that serve high school students (Grade level K–12, 7–12, 9–12). High school students in California are typically ages 14–18. A total of 22 schools within the metropolitan areas of San Francisco, Sacramento, Los Angeles, and San Diego voluntarily consented and self-selected for the environmental assessment. Among the 22 schools invited to participate, 16 schools participated and provided 576 EVPs, including 343 cartridges/pods/bottles and 43 vape pens that contained e-liquids. This assessment was reviewed for human subjects determination and was concluded to be exempt from Institutional Review Boards (IRB) approval. A detailed description of this assessment can be found in a previous study.[20]

Sample Sorting and E-Liquid Retrieval

Devices with missing e-liquid cartridges or pods, and those that were empty or had insufficient e-liquid for extraction (ie, <0.3 mL) were excluded for chemical analysis. The remainder of the samples were sorted into three types: e-liquid cartridge or pod, bottled e-liquid, and vape pen, which are manufactured primarily for vaping cannabis.[21] The pods and cartridges were then further separated into subgroups according to brands: JUUL, Suorin, SMOK, and miscellaneous. The miscellaneous category included brands with <10 samples and were batch analyzed together. From this, six analytical categories were created: bottled e-liquid, JUUL pod, Suorin pod, SMOK pod or mod, miscellaneous pod or mod, and vape pen (Table 1). All samples (251 of 386) with a sufficient amount of e-liquid were then retrieved from the original containers. Additional information about extraction techniques for each sample can be found in Section S1. The retrieved e-liquids were stored in amber vials in a refrigerator at 4°C for chemical analysis by a gas chromatography/mass spectrometry (GC/MS). More than 10% of the total samples were randomly chosen for duplicate analysis.

For comparison, new commercially available JUUL pods with different flavorings (five flavors with 3% nicotine and eight flavors with 5% nicotine, purchased online from JUUL. com in May 2019) were also analyzed.

Chemical Analysis by GC/MS

A small portion of each e-liquid was dissolved in isopropanol (IPA, high performance liquid chromatography grade) purchased from Fisher Scientific Co. (Pittsburg, PA, US) to achieve a 10 times dilution. This solution was further diluted with IPA to a 100 times dilution, arriving at a final 1000 (10×100) times dilution for GC/MS analysis. If precipitates were found, the diluted e-liquids were filtered using a 0.45 μm syringe filter (Agilent Technologies Inc., Santa Clara, CA, US), and then transferred into a GC vial for analysis. An Agilent GC/MS (7890/5977) equipped with a liquid autosampler was used to measure

the amount of nicotine, PG, and VG (in mg/mL). Because some nicotine labels were in mg/mL; while some were labeled in percentage for original EVPs, it's inconvenient to compare for one another. For comparison, measured nicotine in mg/mL was converted to weight% based on the density of a synthesized e-liquid: 1.1338 g/mL (an e-liquid with 5% nicotine, 500 mg/mL PG, and 500 mg/mL VG). The actual density for each e-liquid may be slightly different depending on chemical composition (ie, the weight percentage of nicotine, PG, and VG). An Agilent J&W DB-HeavyWAX capillary column (length: 30 m; I.D.: 0.25 mm; film thickness: 0.25 μm) was used in the GC/MS. The GC oven was programmed to optimize the separation of nicotine, PG, VG, and other chemical compounds. Nicotine, PG, and VG were identified and quantified by comparing GC retention time, mass spectra, and selected ions with their analytical standards purchased from Sigma-Aldrich (St. Louis, MO, US). Analytical grade quinoline from Sigma-Aldrich was used as an internal standard for instrument calibration. Method Detection Limit (MDL) was 0.3, 7.4, and 4.1 mg/mL for nicotine, PG, and VG, respectively. More details for the analytical method performance can be found in Table S4. All chemicals were used without further purification. THC and cannabidiol (CBD) were qualitatively identified using an instrument embedded mass spectral database Version14 from the National Institute of Standards and Technology (NIST). Their concentrations were not evaluated because the above GC/MS analytical method was not optimized for their quantification.

The measured concentration of nicotine, PG, and VG from all EVPs from schools was plotted in Figure 1 (nicotine) and Figure 3 (PG and VG), respectively. Measured nicotine from bottled e-liquid from the school sample was also compared with labeled nicotine in Figure 2.

Results

Electronic Vaping Products for Chemical Analysis

The collected EVPs included a variety of types, brands, models, and flavorings. JUUL (31.7%, 101/319), Suorin (23.5%, 75/319), and vape pen (20.4%, 65/319) were the three most commonly collected brands of cartridges/pods/vape pens, excluding the 67 bottled e-liquids. Among them, 135 cartridges/pods were empty or contained very little e-liquid; while others had varying amounts of extractable levels of e-liquids. Following adherence to the sorting exclusion criteria as mentioned in the methods, a total of 251 e-liquid samples remained for chemical analysis (Table 1).

Nicotine Concentration and/or THC and CBD in Electronic Vaping Products From California Schools

From the 208 e-liquid cartridges/pods/bottles (not including the 43 vape pens), nicotine was detectable in 204 (98%) samples. The measured nicotine concentration was between 0% and 5% (0–56.6 mg/mL) for most (99%) of all chemically analyzed samples from schools (Figure 1). Out of 208 samples, three samples had concentrations higher than 5% (56.6 mg/mL), with the highest one at 6.5% (corresponding to 73.3 mg/mL); two of which were from bottled e-liquids (73.3 and 58.5 mg/mL) and the third was from a JUUL pod from the school sample (5.6%, 63.5 mg/mL). Nicotine was identified in 4 of 43 vape pen

samples. Among these four samples, three contained both nicotine and THC. An example of a GC/MS chromatogram showing nicotine and THC peaks can be found in Section S2. THC was identified in 39 of 43 analyzed vape pens. Among these 39 vape pens, 11 of them were also found to have detectable CBD. No CBD only vape pens were found for the 43 measured samples.

Nicotine in Purchased JUUL Pods Versus JUUL Pods From California Schools

For the purchased nicotine JUUL pods, the average measured nicotine concentration was $3.0 \pm 0.1\%$ (33.5 ± 0.9 mg/mL) for 17 pods (3% nicotine pod) and $4.7 \pm 0.2\%$ (54.9 ± 1.8 mg/mL) for 27 pods (5% nicotine pod). However, for JUUL pods from the 16 California public high schools, the nicotine content ranged between 0.5% and 5.6% (5.3–63.5 mg/mL. Figure 1); concentrations did not cluster around either 3% or 5% nicotine concentrations, the two commercially available nicotine levels of JUUL pod on the US market.

Comparison of Measured Nicotine With Labeled Nicotine in Bottled e-Liquid

Fifty-six of the bottled e-liquids had labels which indicated their nicotine content. Whereas the labeled nicotine content ranged from 0 to 60 mg/mL, the measured nicotine content ranged from 0.3 to 73.3 mg/mL (Figure 2). Three of the 56 bottled e-liquid samples that had labels (labels were missing on some bottled e-liquids) contained detectable nicotine but were labeled as nicotine-free. The measured nicotine concentration was 9.3, 3.2, and 19.6 mg/mL, respectively (green bars in Figure 2). Also, two samples of the 56 had a measured nicotine higher than the labeled concentration (negative blue bars in Figure 2, the difference between measured and labeled nicotine >5%). Since there is no regulated tolerance level for the difference between measured and labeled nicotine currently, we chose 5% as a cutoff value. This included the sample with the highest nicotine amount of 73.3 mg/mL or corresponding to 6.5%. In 42 samples of the 56, the measured nicotine amount was lower than the labeled concentration (positive blue bars in Figure 2, difference >5%). For only nine samples of the 56, the measured nicotine amount was consistent (red bars in Figure 2, difference 5%) with that labeled on the bottle.

PG and VG in Electronic Vaping Products From California Schools

Except for the vape pens, PG and VG total concentration exceeded 800 mg/mL in most of the tested samples, accounting for >70% of the e-liquid (Figure 3). The average carrier amount of PG and VG was 945 ± 132.4 mg/mL, excluding the highest one of around 1800 mg/mL (Figure 3). PG or VG were detectable in 9 of the 43 tested vape pens (21%). In 7 of these 9 samples, the levels of PG/VG amount were comparable to that seen in the nicotine-containing EVPs.

PG and VG in Purchased JUUL Pods Versus JUUL Pods From California Schools

According to the manufacturer,[22] JUUL uses a 30/60 (PG/VG) ratio in their pods and the percentage of PG and VG solvents is >90%. In this investigation, the average measured PG amount was 392.4 ± 23.1 mg/mL and 362.2 ± 23.5 mg/mL in the commercial 3% nicotine and 5% nicotine JUUL pods, respectively. The average VG amount was 724.3 ± 38.9 mg/mL for 3% nicotine and 699.3 ± 32.9 mg/mL for 5% nicotine JUUL pods, respectively. The

ratio of PG/VG is 30/56 (392.4/724.3) for 3% nicotine pods and 30/60 (362.2/724.3) for 5% nicotine pods. The total solvent contributed more than 90% of the JUUL e-liquid. In contrast, JUUL pods from schools had an average of 367.3 ± 63.5 mg/mL PG and 584.8 ± 79.2 mg/mL VG concentrations, respectively. The PG/VG ratio is 30/48 (367.3/584.8).

Discussion

In this work, we assessed the main chemical compositions in EVPs confiscated from youth or found on school grounds in 16 California public high schools. Nicotine was detected in 98% of e-cigarette cartridges/pods and bottled e-liquids, with a nicotine concentration range of 0–73.3 mg/mL. The measured nicotine in bottled e-liquids from schools varied and was not always consistent with labeled concentrations on the bottles. Moreover, the nicotine concentrations in confiscated JUUL pods did not cluster around 3% or 5%, the two commercially available nicotine levels on the US market. PG and VG were predominant solvents in most of the nicotine-containing EVPs. Among the 43 confiscated vape pens, THC or CBD was identified in 91% of samples; 7% of samples contained both nicotine and cannabinoids; PG or VG was detected in only 21% of the vape pens.

Many studies about nicotine or cannabis use among youth rely on student self-reported data.[17,23,24] However, in some cases, adolescents may not know whether their EVPs contain nicotine or cannabis.[25] Some additives, such as flavors, can mask or reduce the harshness of nicotine or cannabis, potentially increasing unintentional nicotine or cannabis use among youth.[26] "Do-it-yourself" (DIY) e-liquid videos can be found on many social media platforms using materials obtained from informal or illicit sources such as friends, family, and online retailers, often without any ingredient information.[27–29] Even though many commercial EVPs are sold as "closed" systems, they can be manipulated by consumers to alter their contents.[20,22] In addition to the health risks from harmful and potentially harmful substances in EVPs, filling "closed" EVPs with additional externally acquired substances can be dangerous if those substances are not safe for inhalation. Characterization of chemical compositions and their amount in the EVPs found on school grounds or confiscated from youth is important in understanding youth's potential exposure to modified products, as well as to psychoactive substances and other chemicals.

Laboratory assessments of nicotine concentration in e-liquids can facilitate understanding of the scope of exposure to nicotine levels in EVPs. This is of particular importance among youth as they are especially susceptible to nicotine addiction and can show signs of dependence quickly, even before the onset of regular use.[6,30–32] Nicotine exposure can also harm adolescent brain development and may prime the brain for addiction to other substances.[6] In 2016, the European Union issued regulations limiting nicotine to 20 mg/mL in commercial e-liquid to allow "for a delivery of nicotine that is comparable to the permitted dose of nicotine derived from a standard cigarette."[33] Sales of e-cigarettes with the highest levels of nicotine (5% or greater nicotine strength) increased nearly 15-fold in 5 years, from 5% of total e-cigarette sales in 2017 to 81% in 2022.[34] Our finding that nicotine was found in 98% of analyzed non-vape pen products is consistent with sales data showing that almost all EVPs sold in US retail outlets (excluding vape shops and online retailers) contain nicotine.[35] Nicotine was undetectable (<MDL, 0.3 mg/mL) in only four samples. In

some samples, the nicotine concentration was as high as 6.5% and was inconsistent with the labeled information (5%) on the e-liquid bottle.

THC or CBD was identified in 39 of 43 (91%) vape pens from schools. Four vape pens had detectable nicotine, all with concentrations 1%. Unlike conventional e-cigarettes, these devices were designed and sold primarily for cannabis vaping.[18,21] We were unable to determine whether the nicotine was intentionally added to those vape pens by the manufacturer or added by consumers. Three vape pens contain both nicotine and THC; more information is needed to understand the potential health effects of inhaling nicotine and cannabinoids simultaneously. The risks of using inhaling nicotine through devices designed to vape THC are unknown because coil temperatures for such devices are usually higher than those designed for nicotine vaping,[36,37] and which may emit more degradation chemicals.[38]

The most recently reported top brands of EVPs used among youths included Puff Bar, VUSE, SMOK, and JUUL.[1] During the time of this study, JUUL was the most commonly used device type used by adolescents (2018–2019).[19] These e-devices are disposable and prefilled with a solution containing nicotine salt, which usually has a higher concentration of nicotine than solutions with free-base nicotine. Many of them are non-refillable and not intended to be reused according to the manufacturers. However, counterfeit pods can be purchased, and the original pods can be opened and refilled with other e-liquids containing nicotine, THC, CBD, or other substances.[22,39] It is important to raise youth awareness of the potential risks of changing e-liquid composition, especially considering the modifiable nature of some e-cigarette products, which includes some products that were not intended to be modified after sale and that can be used to deliver illicit substances in addition to nicotine.

Some previous studies have found there is consistency between measured nicotine and what is reported on vape product labels, while others showed wide inconsistencies between the labeled and measured nicotine concentration.[15,40] We also observed some discrepancies between labeled and measured nicotine content on confiscated bottled e-liquids. As the origin of the bottled e-liquids found or confiscated at these schools wasn't clear, we are not able to determine if these differences were due to inconsistencies or errors in labeling or due to manipulation by the user. Another possibility for the lower nicotine levels and altered PG/VG ratio could be due to nicotine oxidation or evaporation. Regardless, this could be a health concern, especially for youth, particularly for those products labeled as nicotine-free. On the other hand, we found that some e-liquid bottle labels only indicated the presence or absence of nicotine without further information about concentration. Additionally, some nicotine labels on the e-liquid bottles contained contradictions. For example, in two samples, the product's general description indicated "no" nicotine, but the nicotine level was labeled as "11 mg/mL and 24 mg/mL," respectively. For another sample, the nicotine amount was labeled as "12 mg/15 mL," which could be misinterpreted by consumers because the nicotine strength is 12 mg/mL, and the total volume of e-liquid is 15 mL. A recent study has shown that young adults have difficulty understanding nicotine concentrations labeled using the two most common metrics (mg/mL and percent nicotine).[41] An easy-to-understand,

standardized labeling system for EVPs may be warranted to convey accurate information about nicotine strength.

PG and VG are two of the most common solvents used in e-liquids. Both are listed as generally recognized as safe (GRAS) by the Food and Drug Administration (FDA) for use in foods.[42] However, GRAS determinations pertain only to ingestion, not inhalation. Besides PG and VG, some other solvents such as ethylene glycol (EG), polyethylene glycol (PEG), medium chain triglyceride (MCT) oil, and vitamin E have also been identified in e-liquids.[43] The carrier concentration varies among different EVPs, between approximately 80% and 97% of the e-cigarette liquid.[44] Our results were consistent as PG and VG were dominant carriers in 208 nicotine-containing EVPs; while they were detected in only 9 of 43 vape pens, which are designed mainly for cannabis vaping. Whether there exist other carriers in the cannabis vape pens warrants further analysis. Because of the lipophilic nature of cannabis oils, some other alternative solvents such as MCT oil, or terpene oils are commonly used as thinning agents in vape pens.[43] The health consequences of vaping these solvents are not known. Additionally, vitamin E acetate was reported to be strongly associated with the outbreak of EVALI in the US which had a peak of hospitalized cases in September 2019 and a total of 2807 hospitalized cases reported.[14,45] Carrier or solvent labels on EVPs may be warranted. Additionally, our results suggest that consumers may manipulate the "closed" pods, such as by refilling them with liquids containing different nicotine concentrations or other substances (eg, THC) as well as carriers. It has been found that changing the PG/VG ratio in e-liquids can affect the formation of harmful degradation products such as formaldehyde.[46] Modification of the PG/VG ratio can also alter the nicotine delivery efficiency in fine aerosols.[47]

Our results for chemical compositions demonstrate the prevalence of nicotine and cannabinoids in EVPs found or confiscated among 16 participating California public high schools. We've identified the possibility that manipulation of devices and liquids may be occurring either by the youth themselves or prior to their purchase. This indicates the necessity of education programs among youth to improve their knowledge about e-cigarette contents, perceptions of harm and addiction, and the dangers of manipulation.

Limitations

Our findings are subject to some limitations. First, this study used a convenience sample of 16 public high schools, so the results may not be representative of other schools in California or elsewhere in the US. Second, we only measured nicotine, PG, and VG quantitatively, and screened cannabinoids in e-cigarette liquids without quantitation of them individually. The psychoactive THC delta 9 and the less psychoactive THC delta 8 were not chromatographically separated. The chemical compositions in corresponding aerosols (ie, the substances inhaled and exhaled by users) were not assessed. Third, we were unable to evaluate all of the collected e-liquid cartridges/pods/bottles because there was not enough liquid for chemical analysis in some devices. Further, any products that were not confiscated by staff or discarded in trash or removed from school property prior to our study, but nonetheless used at schools were unable to be tested and may have different characteristics than those analyzed. As such, the confiscated products and

products collected on school grounds might not be representative of constituents from all products. Given complex e-liquid formulas, more continued work is warranted to better understand what chemicals the youth are vaping. Fourth, while the devices confiscated from students were used by students, devices found on school grounds could include products used by adults and that were discarded on school property. Fifth, the differences in nicotine and PG/VG levels in confiscated JUUL versus purchased JUUL could arise from counterfeit use, consumer refilling of pods, or less likely, chemical degradation or other environmental factors such as rain or water that could also potentially dilute the e-liquid.[48] Only confiscated JUUL products were compared with commercially available products. It is not possible to determine whether there was post-manufacturer manipulation from other brands.

Conclusions

EVPs confiscated from students or collected on school grounds in 16 California public high schools were found to contain substances that can adversely impact the health of youth, including nicotine and cannabinoids. The measured nicotine concentration for most samples was between 0% and 5% for the confiscated nicotine-containing EVPs, with the highest one at 6.5%. Both nicotine and cannabinoids were detected in some collected vape pens. The inconsistency of measured nicotine, PG, and VG in confiscated JUUL pods with new commercial JUUL pods indicates the "closed" EVPs may be manipulated. The detailed results have been specifically reported before.[20] Inconsistencies between labeled and measured nicotine on collected bottled e-liquids were also observed. Although it is unknown whether these discrepancies are due to inaccurate manufacturer labels or manipulation, our results demonstrate the importance of continued efforts to prevent youth access to and use of e-cigarettes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Data availability

All data relevant to the study are included in the article or uploaded as Supplementary Information.

References

1. Cooper M, Park-Lee E, Ren C, et al. Notes from the field: e-cigarette use among middle and high school students—United States. MMWR Morb Mortal Wkly Rep. 2022;71(40):1283–1285. [PubMed: 36201370]

2. Arrazola RA, Singh T, Corey CG, et al. ; Centers for Disease Control and Prevention (CDC). Tobacco use among middle and high school students—United States, 2011–2014. MMWR Morb Mortal Wkly Rep. 2015;64(14):381–385. [PubMed: 25879896]

3. Cullen KA, Gentzke AS, Sawdey MD, et al. E-cigarette use among youth in the United States, 2019. JAMA. 2019;322(21):2095–2103. [PubMed: 31688912]

4. Gentzke AS, Wang TW, Jamal A, et al. Tobacco product use among middle and high school students —United States, 2020. MMWR Morb Mortal Wkly Rep. 2020;69(50):1881–1888. [PubMed: 33332300]

5. Wang TW, Neff LJ, Park-Lee E, et al. E-cigarette use among middle and high school students —United States, 2020. MMWR Morb Mortal Wkly Rep. 2020;69(37):1310–1312. [PubMed: 32941408]

6. Office of the U.S. Surgeon General. Surgeon General's Advisory on E-cigarette Use Among Youth. 2018. https://www.cdc.gov/tobacco/basic_information/e-cigarettes/surgeon-general-advisory/index.html

7. Spindle TR, Talih S, Hiler MM, et al. Effects of electronic cigarette liquid solvents propylene glycol and vegetable glycerin on user nicotine delivery, heart rate, subjective effects, and puff topography. Drug Alcohol Depend. 2018;188(Jul 1):193–199. [PubMed: 29778773]

8. Li Q, Zhan Y, Wang L, Leischow SJ, Zeng DD. Analysis of symptoms and their potential associations with e-liquids' components: a social media study. BMC Public Health. 2016;16(1):1–2. [PubMed: 26728978]

9. Watson CV, Alexander DS, Oliver BE, Trivers KF. Substance use among adult marijuana and nicotine e-cigarette or vaping product users, 2020. Addict Behav. 2022;132(Sep 1):107349. [PubMed: 35580371]

10. Miech RA, Johnston LD, Patrick ME, O'Malley PM, Bachman JG, Schulenberg JE. Monitoring the Future National Survey Results on Drug Use, 1975–2022: Secondary School Students. Institute for Social Research. 2023. https://isr.umich.edu

11. Miech RA, Patrick ME, O'Malley PM, Johnston LD, Bachman JG. Trends in reported cannabis vaping among US adolescents, 2017–2019. JAMA. 2020;323(5):475–476. [PubMed: 31848566]

12. Boyd CJ, McCabe SE, Evans-Polce RJ, Veliz PT. Cannabis, vaping, and respiratory symptoms in a probability sample of US youth. J Adolesc Health. 2021;69(1):149–152. [PubMed: 33676824]

13. Braymiller JL, Barrington-Trimis JL, Leventhal AM, et al. Assessment of nicotine and cannabis vaping and respiratory symptoms in young adults. JAMA Netw Open. 2020;3(12):e2030189. [PubMed: 33351085]

14. King BA, Jones CM, Baldwin GT, Briss PA. E-cigarette, or vaping, product use-associated lung injury: looking back, moving forward. Nicotine Tob Res. 2020;22(Supplement_1):S96–S99. [PubMed: 33320257]

15. Raymond BH, Collette-Merrill K, Harrison RG, Jarvis S, Rasmussen RJ. The nicotine content of a sample of e-cigarette liquid manufactured in the United States. J Addict Med. 2018;12(2):127–131. [PubMed: 29280749]

16. Marsot A, Simon N. Nicotine, and cotinine levels with electronic cigarette: a review. Int J Toxicol. 2016;35(2):179–185. [PubMed: 26681385]

17. Pepper JK, Ribisl KM, Brewer NT. Adolescents' interest in trying flavoured e-cigarettes. Tob Control. 2016;25(Suppl 2):iiii62–iiii66.

18. Frohe T, Leeman RF, Patock-Peckham J, et al. Correlates of cannabis vape-pen use and knowledge among US college students. Addict Behav Rep. 2018;7(Jun 1):32–39. [PubMed: 29450254]

19. Wang TW, Gentzke AS, Creamer MR, et al. Tobacco product use and associated factors among middle and high school students—United States, 2019. MMWR CDC Surveill Summ. 2019;68(12):1.

20. Shamout M, Wang P, Wong F, et al. Chemical composition of JUUL pods collected from students in California high schools. J Adolesc Health. 2021;69(2):342–345. [PubMed: 33712386]

21. Giroud C, De Cesare M, Berthet A, et al. A review of new trends in cannabis use. Int J Environ Res Public Health. 2015;12(8):9988–10008. [PubMed: 26308021]

22. JUUL Labs. JUULpod basics. Available at: https://www.juul.com/age-gate?redirect=%2Fsupport. Accessed: August 28, 2018.

23. Farsalinos K, Barbouni A, Niaura R. Changes from 2017 to 2018 in e-cigarette use and in ever marijuana use with e-cigarettes among US adolescents: analysis of the National Youth Tobacco Survey. Addiction. 2021;116(1):139–149. [PubMed: 32533631]

24. Miech R, Patrick ME, O'Malley PM, Johnston LD. What are kids vaping? Results from a national survey of US adolescents. Tob Control. 2017;26(4):386–391. [PubMed: 27562412]

25. Pepper JK, Farrelly MC, Watson KA. Adolescents' understanding and use of nicotine in e-cigarettes. Addict Behav. 2018;82(Jul 1):109–113. [PubMed: 29518664]

26. 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. [PubMed: 31453046]

27. Kong G, Schott AS, Lee J, Dashtian H, Murthy D. Understanding e-cigarette content and promotion on YouTube through machine learning. Tob Control. 2022;32(Nov 1):739–746. doi:10.1136/tobaccocontrol-2021-057243 [PubMed: 35504690]

28. Vassey J, Galimov A, Kennedy CJ, Vogel EA, Unger JB. Frequency of social media use and exposure to tobacco or nicotinerelated content in association with e-cigarette use among youth: a cross-sectional and longitudinal survey analysis. Prev Med Rep. 2022;30(Dec 1):102055. [PubMed: 36531097]

29. Cox S, Leigh NJ, Vanderbush TS, et al. An exploration into "do-it-yourself" (DIY) e-liquid mixing: users' motivations, practices and product laboratory analysis. Addict Behav Rep. 2019;9(Jun 1):100151. [PubMed: 31193745]

30. US Department of Health and Human Services. "The health consequences of smoking—50 years of progress: a report of the Surgeon General." 2014.

31. DiFranza JR, Rigotti NA, McNeill AD, et al. Initial symptoms of nicotine dependence in adolescents. Tob Control. 2000;9(3):313–319. [PubMed: 10982576]

32. DiFranza JR, Savageau JA, Fletcher K, et al. Symptoms of tobacco dependence after brief intermittent use: the development and assessment of nicotine dependence in youth–2 study. Arch Pediatr Adolesc Med. 2007;161(7):704–710. [PubMed: 17606835]

33. European Union. Directive 2014/40/EU of the European Parliament and of the Council of 3 April 2014 on the approximation of the laws, regulations and administrative provisions of the Member States concerning the manufacture, presentation and sale of tobacco and related products and repealing Directive 2001/37/EC. 2015 Retrieved 4/8, 2020, from. Available: http://data.europa.eu/eli/dir/2014/40/2015-01-06

34. Ali FR, Seaman EL, Crane E, Schillo B, King BA. Trends in US e-cigarette sales and prices by nicotine strength, overall and by product and flavor type, 2017–2022. Nicotine Tob Res. 2023;25(5):1052–1056. [PubMed: 36580384]

35. Marynak KL, Gammon DG, Rogers T, et al. Sales of nicotine-containing electronic cigarette products: United States, 2015. Am J Public Health. 2017;107(5):702–705. [PubMed: 28323467]

36. Lynch J, Lorenz L, Brueggemeyer JL, et al. Simultaneous temperature measurements and aerosol collection during vaping for the analysis of δ9-tetrahydrocannabinol and vitamin e acetate mixtures in ceramic coil style cartridges. Front Chem. 2021;9(Aug 9):734793. [PubMed: 34434923]

37. Zhao T, Shu S, Guo Q, Zhu Y. Effects of design parameters and puff topography on heating coil temperature and mainstream aerosols in electronic cigarettes. Atmos Environ. 2016;134(Jun 1):61–69.

38. Sleiman M, Logue JM, Montesinos VN, et al. Emissions from electronic cigarettes: key parameters affecting the release of harmful chemicals. Environ Sci Technol. 2016;50(17):9644–9651. [PubMed: 27461870]

39. JUUL Labs. Protecting youth from illegal, unregulated, and harmful counterfeit and infringing products. Available at: https://www.juullabs.com/juul-action-plan-update-protecting-youth-from-illegal-unregulated-and-harmful-counterfeit-and-infringing-products/

40. Etter JF, Zäther E, Svensson S. Analysis of refill liquids for electronic cigarettes. Addiction. 2013;108(9):1671–1679. [PubMed: 23701634]

41. Morean ME, Wackowski OA, Eissenberg T, Delnevo CD, Krishnan-Sarin S. Adolescents and young adults have difficulty understanding nicotine concentration labels on vaping products presented as mg/ml and percent nicotine. Nicotine Tob Res. 2021;23(8):1389–1397. [PubMed: 33433626]

42. Park-Lee E, Ren C, Sawdey MD, et al. Notes from the field: e-cigarette use among middle and high school students—National Youth Tobacco Survey, United States, 2021. MMWR Morb Mortal Wkly Rep. 2021;70(39):1387–1389. [PubMed: 34591834]

43. Smith DM, Goniewicz ML. The role of policy in the EVALI outbreak: solution or contributor? Lancet Respir Med. 2020;8(4):343–344. [PubMed: 32043987]

44. Han S, Chen H, Zhang X, Liu T, Fu YN. Levels of selected groups of compounds in refill solutions for electronic cigarettes. Nicotine Tob Res. 2016;18(5):708–714. [PubMed: 26568061]

45. Blount BC, Karwowski MP, Shields PG, et al. ; Lung Injury Response Laboratory Working Group. Vitamin E acetate in bronchoalveolar-lavage fluid associated with EVALI. N Engl J Med. 2020;382(8):697–705. [PubMed: 31860793]

46. Wang P, Chen W, Liao J, et al. A device-independent evaluation of carbonyl emissions from heated electronic cigarette solvents. PLoS One. 2017;12(1):e0169811. [PubMed: 28076380]

47. Li L, Lee ES, Nguyen C, Zhu Y. Effects of propylene glycol, vegetable glycerin, and nicotine on emissions and dynamics of electronic cigarette aerosols. Aerosol Sci Technol. 2020;54(11):1270–1281. [PubMed: 33116348]

48. Martinez RE, Dhawan S, Sumner W, Williams BJ. On-line chemical composition analysis of refillable electronic cigarette aerosol—measurement of nicotine and nicotyrine. Nicotine Tob Res. 2014;17(10):1263–1269. [PubMed: 25542921]
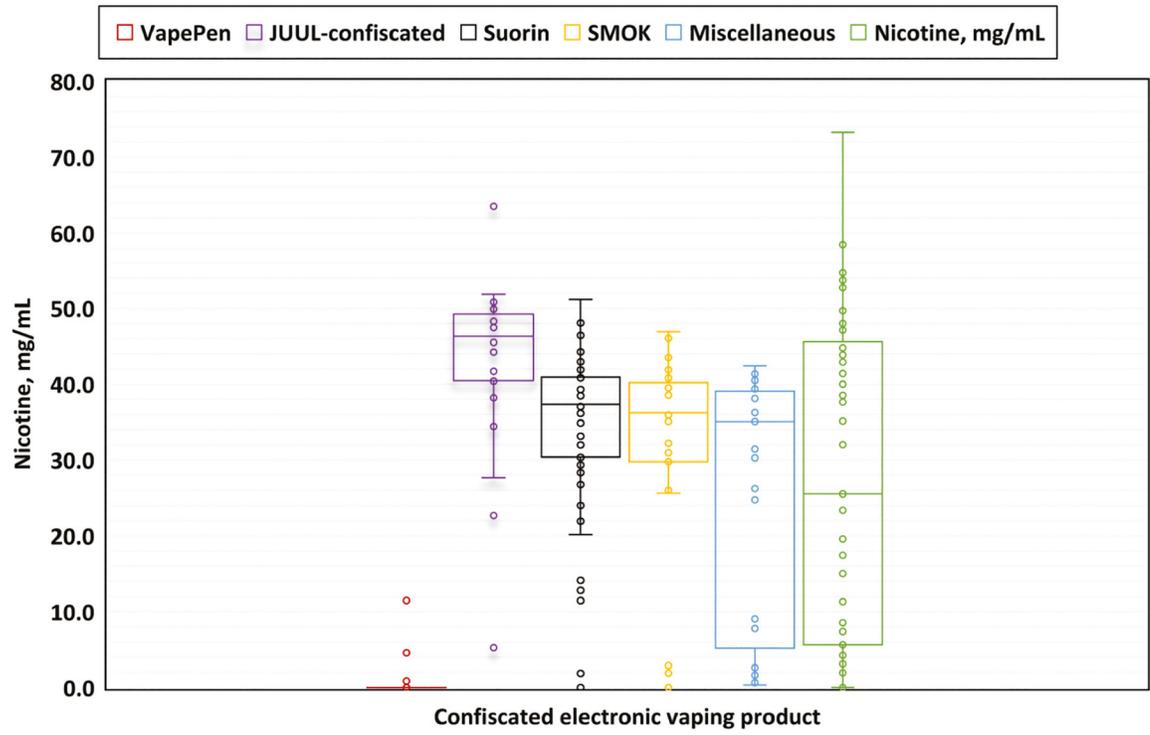
Figure 1.
Nicotine amounts in electronic vaping products confiscated by California School Administrators or found on school grounds.
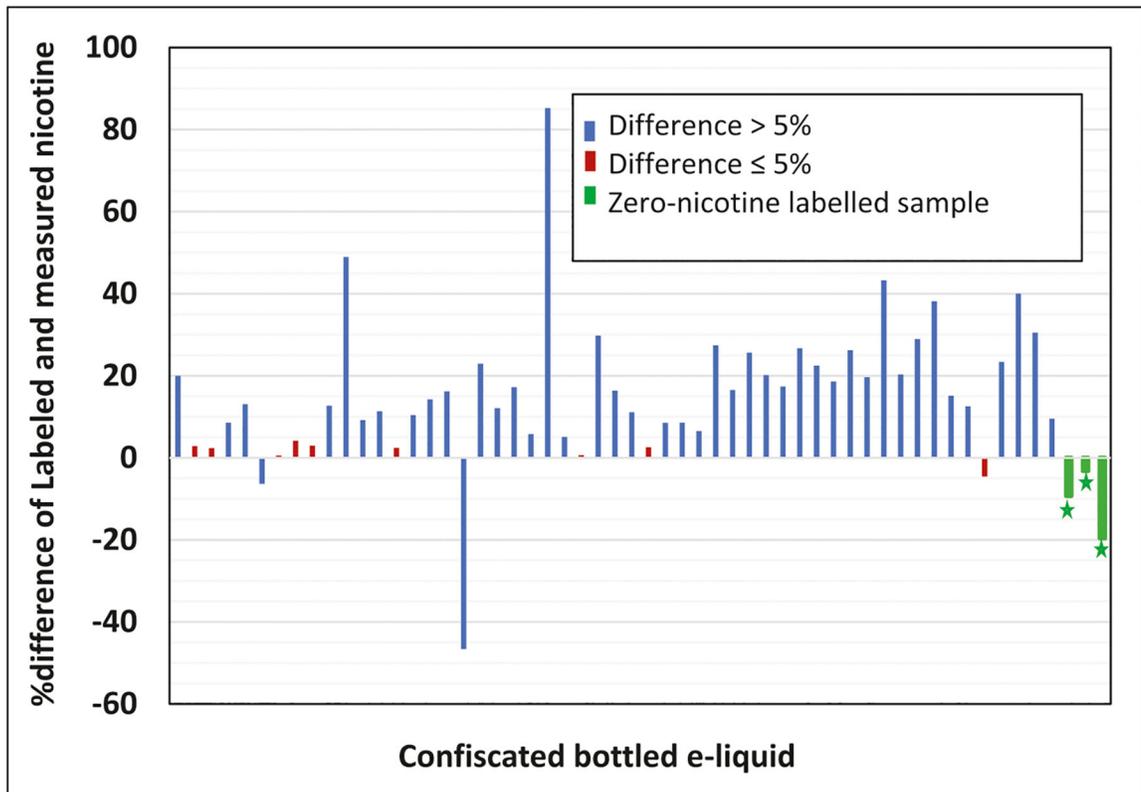
Figure 2.
Percentual discrepancies between labeled and measured nicotine on bottled e-liquid
confiscated by California School Administrators or found on school grounds.
Note: ★Zero-nicotine labeled samples with measured amounts in mg/mL.
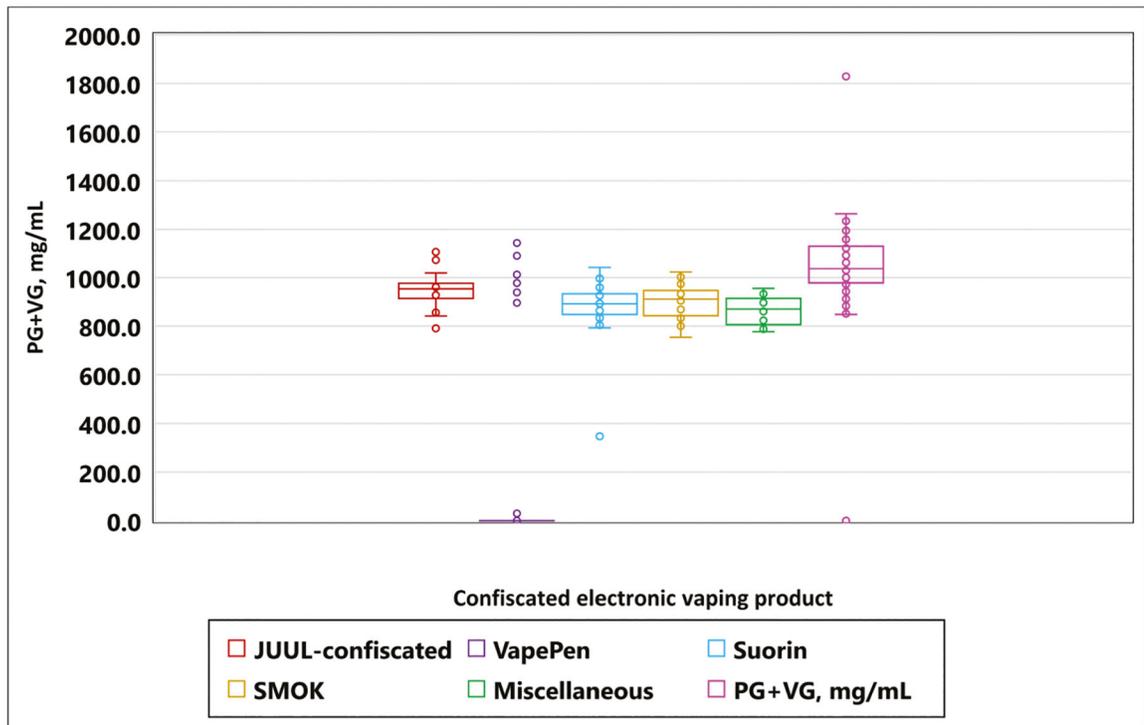
Figure 3.
The concentration of propylene glycol and vegetable glycerol in e-cigarette liquid from products confiscated by California School Administrators or found on school grounds.

Table 1.

Chemical Analysis of Electronic Vaping Products Confiscated by California School Administrators or Found on School Grounds[*]

(Total = 251 samples)			
Category or brand	Number of samples	Labeled nicotine	Type[1]
Bottled e-liquid (various brands)	67	0–60 mg/mL	e-liquid in bottle
Vape pen[2] (various brands)	43	N/A	disposable
JUUL	26	N/A	pod
Suorin	59	N/A	pod
SMOK	31	N/A	pod or mod
Miscellaneous brand	25	N/A	pod or mod

N/A: not available.

[*] All these products were collected from schools, they may or may not be actual JUUL, Suorin, or SMOK products due to counterfeit or manipulation after sale.

[1] See definition at https://www.cdc.gov/tobacco/basic_information/e-cigarettes/pdfs/ecigarette-or-vaping-products-visual-dictionary-508.pdf.

[2] Device primarily for cannabis vaping.