HHS Public Access

Author manuscript

Drug Alcohol Depend. Author manuscript; available in PMC 2022 November 01.

Published in final edited form as:

Drug Alcohol Depend. 2021 November 01; 228: 109104. doi:10.1016/j.drugalcdep.2021.109104.

Demographic and substance use-related differences among high school adolescents who vape cannabis versus use other cannabis modalities

Meghan E. Morean[a,*], **Danielle R. Davis**[a], **Grace Kong**[a], **Krysten W. Bold**[a], **Deepa R. Camenga**[b], **Sakinah Suttiratana**[c], **Juhan Lee**[a], **Lavanya Rajeshkumar**[a], **Suchitra Krishnan-Sarin**[a]

[a]Yale School of Medicine, Dept. of Psychiatry, 34 Park Street, New Haven, CT, 06519, USA

[b]Yale School of Medicine, Dept. of Emergency Medicine, 464 Congress Avenue (Suite 260), New Haven, CT, 06519, USA

[c]Yale School of Public Health, Dept. of Chronic Disease Epidemiology, 60 College Street, New Haven, CT, 06520, USA

Abstract

Background.—Vaping is the second most common modality of using cannabis following smoking. We examined differences in demographics and substance use behaviors between adolescent cannabis vapers and those exclusively using other cannabis modalities.

Methods.—In 2019, 4875 students from six Connecticut high schools completed school-wide, online surveys. Past-month cannabis users (n=931; 52.8% female, 16.38(1.27) years old, 44.9% non-Hispanic White) reported on cannabis modalities used (e.g., combustible, vaporizable, edible) and were classified as cannabis vapers or non-vapers. Cannabis vapers reported on device type used to vape cannabis: a cannabis-specific device or modified/hacked e-cigarette. Unadjusted and adjusted relationships were examined to identify demographic and substance-related differences between cannabis vapers and non-vapers.

Results.—56.3% of past-month cannabis users reported vaping cannabis. Cannabis vapers reported using both cannabis-specific vaporizers (91.9%) and modifying/hacking e-cigarettes (23.7%). Cannabis vapers, relative to other cannabis users, were more likely to be male, White, initiate cannabis use at a younger age; endorse past-month use of all cannabis modalities, alcohol,

*Corresponding author: Meghan.Morean@yale.edu.

Contributors

Drs. Morean, Davis, Kong, Bold, Camenga, and Krishnan-Sarin collaborated on the development of the original study and conceptualized the current research question. Dr. Morean completed the statistical analyses and drafted the original version of the manuscript. All other authors, including Drs. Suttiratana, Lee, and Rajesh Kumar, provided substantive feedback on further drafts. All authors approved the submitted manuscript.

Conflict of Interest

Dr. Morean holds a restricted stock agreement with Gofire, Inc.

and e-cigarettes; and report smoking and dabbing cannabis more frequently; consuming more drinks per drinking day; and using e-cigarettes at a younger age and more frequently.

Conclusions.—Relative to other cannabis modalities, vaping was associated with increased use of several cannabis products and other substances. Adolescent past-month cannabis users reported modifying e-cigarettes to vape cannabis. Findings suggest that regulations should be implemented to prevent e-cigarettes from being modifiable for use with cannabis and highlight the importance of assessing different cannabis use modalities, as vaping was associated with distinct substance-related risks.

Keywords

cannabis; marijuana; vape; vaporizer; youth; adolescent

1.0 Introduction

Cannabis continues to be the most commonly used federally illicit substance among youth (MTF, 2020), with underage use prohibited even in states where cannabis is legal for adult use. As of 2020, 21.1% of 12th grade students reported past-month cannabis use (Monitoring the Future [MTF], 2020). Cannabis experimentation is considered normative, with nearly half (43.7%) of 12th grade students reporting lifetime use (MTF, 2020), but it not without consequences. To date, most research on youth cannabis use has focused on combustible cannabis (e.g., smoking joints, bowls, blunts), the most popular use modality of cannabis use among youth. Combustible cannabis use has been linked to a host of negative outcomes (e.g., bronchitis, motor vehicle accidents, cognitive impairment, impulsivity, poorer academic performance, the development or worsening of several mental disorders, dependence on tobacco, alcohol, and other illicit drugs; National Academies of Sciences, Engineering, and Medicine [NASEM], 2017). Unfortunately, risk for negative consequences appears to be exacerbated among individuals who begin smoking cannabis at an early age (NASEM, 2017). Thus, combustible cannabis use during adolescence places youth in a high-risk group. However, the extent to which risks associated with combustible cannabis extend to other cannabis use modalities (e.g., vaporizable, edible cannabis) in not well established in youth.

Recently, increases in the use of non-combustible cannabis modalities (e.g., vaporizable concentrates, edibles) have been observed (Fataar and Hammond, 2019; Giroud et al., 2015; Knapp et al., 2018, Miech et al., 2021; Patrick et al., 2020; Struble et al., 2019). Research indicates that using a greater number of cannabis modalities is associated with increased negative outcomes among youth (e.g., the use of more other substances including alcohol, nicotine, and other illicit drugs; Knapp et al., 2019), but there is reason to believe that demographic-, health-, and addiction-related risk also may be modality-specific. With regard to demographics, research on adolescents has suggested that boys are more likely than girls to have used vaporizable cannabis but not combustible or edible cannabis (Peters et al., 2018). Further, youth from lower socioeconomic status backgrounds are more likely to have used combustible and edible cannabis, but not vaporizable cannabis (Peters et al., 2018). Prior research also has suggested disparities in blunt use, a means of combustible cannabis delivery that traditionally involves smoking cannabis wrapped in a tobacco cigar, such that

Black and Hispanic youth are more likely to use blunts than white, non-Hispanic youth. (Eggers et al., 2017).

Although a complete review of the literature is beyond the scope of the current study, differences in broader health and addiction-related risk across cannabis use modalities also have been observed. For instance, combustible cannabis uniquely produces carbon monoxide and combustion-related carcinogens (Solowij, 2018). Further, the onset and resolution of psychoactive effects differs across modalities, with a faster onset and resolution of effects associated with combustible and vaporizable cannabis compared to cannabis that is consumed (Barrus et al., 2016). The delayed onset and longer duration of effects associated with edible use can lead to inadvertent over-ingestion of THC and is thought to be responsible for a disproportionate number of adult hospital visits that are characterized by cannabis intoxication and psychiatric symptoms (Monte et al., 2019). This pattern likely extends to youth, given that young people (ages 15 to 24 years) are most likely to present to the hospital for cannabis-related reasons (Maloney-Hall et al., 2020). Risk for addiction also may vary by modality; research comparing dabbing to combustible cannabis use in adults indicates that dabs may be associated with increased tolerance and withdrawal (Loflin & Earleywine, 2014). In addition, subjective drug effects, which have been shown to relate to risk for addiction, vary by modality; in youth, the strongest positive subjective effects were associated with combustible cannabis and the strongest negative subjective effects with edible use (Boisveryt, 2020). There also is evidence that risk may vary even within a modality of use. For instance, combustible cannabis delivered via blunts carries added risk related to the co-use of cannabis and nicotine/tobacco (Dharmapuri, Miller, & Klein, 2020). Given the focus of the study, several additional modality-specific differences that are linked to vaping cannabis concentrates are reviewed below.

Cannabis vaping is the second most common modality of use among youth (Fataar and Hammond, 2019; Giroud et al., 2015; Knapp et al., 2018); lifetime, past-year, and past-month cannabis vaping more than doubled from 2017 to 2020 among 10^{th} and 12^{th} grade students (MTF, 2020). As of 2020, past-month rates of vaping cannabis were 11.3% among 10^{th} grade students and 12.2% among 12^{th} grade students (MTF, 2020). While both cannabis flower and concentrates can be vaporized, vaping concentrates like hash oil is most popular among adolescents (Knapp et al., 2019). Vaporizing concentrates compared to using other cannabis modalities may be especially concerning for several reasons. First, concentrates can be very potent, with levels of tetrahydrocannabinol (THC) that often are 2 to 3 times stronger than high-THC flower strains (Orens et al., 2018); in 2017 the average THC content in flower sold in Colorado was 19.6%, while the average THC content in concentrates was 68.6% (Orens et al., 2018). However, concentrates can contain THC concentrations exceeding 92% (e.g., Grape Ape, Strawberry Cough; https://herb.co/learn/strongest-dabs/). Research on adult cannabis users suggests that vaporized concentrates also may increase subjective drug effects, dry mouth, eye irritation, cognitive/psychomotor impairment, paranoia, and peak blood THC levels relative to combustible cannabis at equal THC concentrations (Spindle et al., 2018). Among other negative consequences associated with exposure to high THC levels like increased risk for psychosis (Di Forti et al., 2019), using high-THC concentrates also may increase risk for cannabis use disorder (Bidwell et al., 2018).

Second, devices designed specifically to vaporize cannabis concentrates are often indistinguishable from e-cigarettes for use with nicotine or nicotine-free e-liquids and produce less odor than smoking marijuana, making them easier to conceal (Morean et al., 2017). Also linking cannabis and nicotine vaporizers, the devices function identically: a battery-powered, electronic heating element vaporizers a liquid. Although cannabis concentrates and nicotine e-liquids have different optimal vaporization temperatures, nicotine e-cigarettes can be hacked or modified for use with cannabis (Ibara, 2018; Morean et al., 2015) and there are numerous online tutorials for how to do so. Hacking e-cigarettes for use with cannabis is of particular concern among youth given that e-cigarettes continue to be the most popular nicotine product used by this age group (Miech et al., 2021). However, little is known about the prevalence of hacking e-cigarettes for cannabis use.

Third, informally-sourced, unregulated vaporizable cannabis concentrates can contain constituents with undetermined health risks and/or contaminants. Cannabis concentrates may increase exposure to toxins including acetaldehyde and formaldehyde which can be byproducts of heating additives like propylene glycol and polyethylene glycol (Trout and Dindanato, 2017). Further, the 2019 outbreak of e-cigarette or vaping product use-associated lung injury (EVALI; CDC, 2019) was deemed to be caused primarily by vitamin E acetate, an additive used to thicken THC concentrates. EVALI sickened over 2,800 people, causing 68 deaths (CDC, 2019); 16% of reported EVALI cases occurred in youth ages 13–17 years (Lozier et al., 2019). The lack of regulation over the production of illicit concentrates may put users of these products at increased risk, whether they contain vitamin E acetate or other additives that are not safe for inhaling (King et al., 2020).

Fourth, there is evidence that youth cannabis vapers compared to non-vapers may disproportionately engage in antisocial behaviors and use other substances. Using data from the 2017 MTF study, Jackson and colleagues (2019) found that youth cannabis vapers were more likely to engage in violent behavior, property-related deviance, and other deviant behaviors like running away from home. Using data from the 2018 MTF survey, Kritikos and colleagues (2021) found that youth cannabis vapers were more to report past-month use of alcohol, cigarettes, and other illicit drugs including misuse of prescription drugs. Although these studies do not demonstrate causal relationships, they suggest that cannabis vaping may be associated with unique risks. However, neither study directly compared vaping cannabis to the use of other cannabis modalities. Jackson and colleagues (2019) collapsed non-vaporized use of nicotine or cannabis into two categories (i.e., no vaping of any substance plus either nicotine or cannabis use; flavor-only vaping with other nicotine or cannabis use), and Kritikos and colleagues (2021) used a reference group of cannabis non-vapers that included both cannabis non-users and users who reported using cannabis in other modalities.

Given the high rates of youth cannabis vaping; the high potency of cannabis concentrates; the concealability of vaporizing cannabis concentrates; and the links between cannabis vaping and negative outcomes, it is critical to better understand risk that is uniquely associated with vaping cannabis versus using other cannabis modalities. We address this gap by examining how cannabis vaping (relative to the use of other non-vaporized cannabis modalities) is related to demographics and substance use. Specifically, we 1)

identified demographic characteristics that differentiated adolescent (grades 9–12) past-month cannabis vapers from past-month users of other cannabis modalities and 2) examined incremental risk for substance use outcomes associated with cannabis vaping. We also examined the type(s) of devices that youth reported using to vape cannabis: vaping devices manufactured specifically for use with cannabis versus hacked/modified e-cigarettes.

2.0 Materials and Methods

In 2019, before cannabis became legal for adult recreational use in Connecticut, school-wide surveys were conducted in six high schools. To ensure a socio-demographically diverse sample, the schools were selected from different district reference groups, which reflect school groupings based on similar family income levels, parental education/occupation, and use of a non-English language at home (School and State Finance Project, 2016). The Yale University Institutional Review Board, the school boards, and each school approved the study procedures. Two weeks prior to survey administration we sent information letters to guardians describing the study. Guardians could refuse their child's participation by contacting us. We informed all eligible students that participation was voluntary and anonymous. In total, 4875 students used handheld tablets distributed by the study staff to complete the 20-minute Qualtrics survey. The analytic sample comprised 931 students (47.2% male, M = 16.38[SD=1.27] years old, 44.9% non-Hispanic White) who reported past-month cannabis use and endorsed using at least one cannabis modality (i.e., smoking, vaping, dabbing, eating edibles, using tinctures, using topicals, consuming raw or juiced cannabis). Please see Figure 1 for a simplified depiction of the general study flow.

2.1 Measures

2.1.1 Demographics—Participants reported on age, sex at birth, ethnicity (Hispanic/Latino/a/x vs. not), and race. Given insufficient sample sizes for certain racial groups (e.g., Asian, Native American, Pacific Islander, Middle Eastern), a four-level variable was created reflecting white, Black, multiracial, and other.

We also assessed socioeconomic status (SES) via the four-item Family Affluence Scale (FAS), which prior research has demonstrated is both reliable and valid for measuring SES in youth (e.g., Boyce et al., 2006). The FAS also previously been used with adolescents in the context of substance-related research (e.g., Simon et al., 2018). The FAS was scored via summary score (Simon et al., 2018), with higher values equating to higher SES.

2.1.2 General cannabis use—Participants reported on lifetime use (no/yes) of blunts ("a cigar, cigarillo, little cigar, or blunt wrap filled with marijuana") and marijuana in any form other than a blunt ("some examples include smoking joints, bongs, or pipes; vaping dried bud or concentrates like hash oil, shatter, or butter; or eating brownies or candies that contain marijuana"). Participants who endorsed lifetime cannabis use reported on age of cannabis use onset and lifetime use of seven cannabis modalities: combustible cannabis, vaporizable cannabis, dabs, edibles, tinctures, topicals, and raw/juiced cannabis. Vaping and dabbing were considered as separate modalities because, although dabbing can result in vaporization especially when a dab-pen is used, dabbing with a torch and nail often results in combustion given the high temperature to which the concentrate is exposed (Hädener et al.,

2019). Participants who endorsed lifetime use of a given modality reported on past-30-day use and frequency. Tinctures, topicals, and raw/juice cannabis were combined into a single category due to expected low endorsement rates. A variable was created to reflect the total number of past-month cannabis modalities used.

2.1.3 Cannabis vaping modalities—Past-month cannabis vapers were asked to identify the ways in which they had ever vaped cannabis: an e-cigarette or vape-pen filled with oil, an e-cigarette or vape-pen filled with wax, an e-cigarette or vape-pen filled with dry marijuana/flower/bud, a portable vaporizer filled with dried marijuana/flower/bud, a disposable joint, a tabletop vaporizer (e.g., the Volcano), dabs, and I don't know. Participants also were asked whether they used "a device that was made specifically for vaping marijuana" and/or if they "made changes to a device, like an e-cigarette, so that it could be used to vape marijuana."

2.1.4 Tobacco product use—Participants reported on lifetime use (no/yes) of "e-cigarettes (i.e., disposable e-cigarette, cig-a-like, or e-hookah; vape-pen; JUUL; any pod system other than JUUL; a mod or an advanced personalized vaporizer); heated tobacco (like IQOS); cigarettes; hookah (a waterpipe used to smoke tobacco); smokeless tobacco (like chew, snuff, or dip); cigarillos or little cigars (without marijuana); large cigars (without marijuana); and blunts (a cigar, cigarillo, little cigar, or blunt wrap filled with marijuana)." Participants who endorsed lifetime tobacco product use reported age of onset and frequency of use in the past 30 days. Note that past-month e-cigarette users reported total past 30-day vaping frequency inclusive of all devices used. Variables were created to reflect the total number of traditional tobacco products used (i.e., combustible + smokeless tobacco products), the total number of e-cigarette products used (i.e., the sum of all e-cigarette devices), and the total number of all tobacco products used (i.e., traditional tobacco products + total e-cigarette devices used). Heated tobacco use was excluded given the low rate of endorsement (1.7%) and the fact that heated tobacco is a cross-over between traditional tobacco use and vaping. Dichotomous variables were created to reflect any past-month use of each product (e.g., past-month e-cigarette use coded as no/yes).

2.1.5 Alcohol use—Participants reported on lifetime use of alcohol. Lifetime drinkers reported on age of alcohol use onset, past-30-day frequency of use, and typical number of drinks consumed per drinking day. A variable also was created reflecting any past-month alcohol use.

2.2. Analytic plan

Analyses were run using SPSS 27. Descriptive statistics for methods of cannabis vaping (e.g., oil, wax, flower) and device use (i.e., cannabis-specific device versus a modified/hacked e-cigarette) were run within the subsample of cannabis vapers. Descriptive statistics for study variables that were relevant to all participants (e.g., demographic characteristics, any past-month use of tobacco products, alcohol use) were run within the total analytic sample and within the subsamples of past-month cannabis vapers and past-month users of other cannabis modalities. Descriptive statistics that were substance-specific (e.g., age of onset of a substance, past-month frequency of use of a substance, typical drinks per drinking

day) were run within the subsamples who endorsed past-month use of that product, and, within each subsample, by cannabis vaping status. For example, age at alcohol use onset was calculated within the subsample of all students who endorsed drinking in the past month, and, subsequently, differences in age of alcohol onset were examined by cannabis vaping status.

To examine unadjusted differences between cannabis vapers and users of all other non-vaporized cannabis modalities, chi-squares (for categorical variables) and independent samples t-tests (for continuous variables) were run. For tobacco product types and alcohol, we examined differences in age of onset and frequency of past-month use by cannabis vaping status only for products for which significant unadjusted differences ($p < .05$) in any past-month use were observed.

To examine adjusted relationships, a binary logistic regression was run predicting any past-month cannabis vaping (no/yes) within the total analytic sample. School was included as a covariate to account for the fact that students came from six high schools; multilevel was not deemed appropriate because clustering by school would be unreliable due to the limited number of schools/clusters. The following independent variables were included in the model: age, sex, Hispanic/Latino/a/x ethnicity, race, SES, age of cannabis use onset, and past-month use (no/yes) of e-cigarettes, cigarettes, cigarillos, cigars, blunts, hookah, smokeless tobacco, alcohol, cannabis dabs, combustible cannabis, edible cannabis, and other cannabis modalities (i.e., cannabis tinctures, topicals, and/or raw/juiced cannabis). Again, heated tobacco products were excluded from the model due to an insufficient sample size (1.7% of total sample). We also ran sensitivity analyses checking results in the model excluding blunts given that blunts represent both a tobacco product and a combustible cannabis product. However, given that some blunt users do not consider themselves to be tobacco users (Delnevo et al., 2011) and the pattern of findings was the same whether blunts were included or excluded, we chose to present findings from the more inclusive model accounting for blunt use. Of note, to support the final binary logistic regression model presented below, we also ran a linear regression model in which variance inflation factors (VIF) were requested to explore whether there was multicollinearity among variables. The highest VIF was 1.53, which is below the threshold for multicollinearity as defined by Akinwande and colleagues (2015).

3.0 Results

3.1 Descriptive findings

Of past-month cannabis users (N=931), 56.3% endorsed past-month cannabis vaping. Average cannabis vaping frequency was 10.29(10.24) days out of the past 30 days. Cannabis vapers endorsed lifetime use of 2.39 (SD = 1.63) modalities of vaporizing cannabis, with vaping oils using a vape-pen as the most common method (76.8%) followed by doing dabs (46.7%; Figure 2). Among cannabis vapers, 91.9% reported using a vaping device made specifically for vaping cannabis and 23.7% reported hacking/modifying an e-cigarette for use with cannabis.

Unadjusted findings showed that cannabis vapers were significantly more likely than users of any other non-vaporized cannabis modalities to be male, White, and endorse any past-month use of e-cigarettes (including higher rates of use for each of the five devices assessed), alcohol, cannabis dabs, cannabis edibles, and other cannabis modalities (comprising tinctures, topicals, and raw/juiced cannabis; Table 1). Cannabis vapers also were more likely than were users of non-vaporized cannabis modalities to report initiating cannabis use at an earlier age and using a greater total number of cannabis modalities, e-cigarette devices, and tobacco product types in the past month. In contrast, cannabis vapers were less likely than were users of non-vaporized cannabis modalities to be Black and to endorse past-month combustible cannabis use (Table 1).

3.2 Adjusted Findings

The logistic regression model (χ^2 [25] = 204.76, Nagelkerke R^2 = 0.27, p < .001) correctly classified 81.5% of cannabis vapers. Cannabis vapers were more likely than users of other non-vaporized cannabis modalities to be male, White (vs. Black), to initiate cannabis use earlier, and to report past-month use of e-cigarettes, alcohol, cannabis edibles, and other non-combustible cannabis modalities (i.e., tinctures, topicals, or raw/juiced cannabis). Cannabis vapers were less likely to report past-month use of smokeless tobacco and combustible cannabis than were users of non-vaporized cannabis modalities (Table 2).

3.3 Frequency of Cannabis and Other Substance Use

Cannabis vapers reported vaping cannabis on 10.29 (10.24) days in the past month. Compared to all users of other, non-vaporized cannabis modalities, cannabis vapers reported more frequent cannabis dabbing (8.73 [9.41] vs. 6.24 [8.67] days in the past month), more frequent cannabis smoking (13.95 [11.22] vs. 8.13 [9.30] days in the past month), an earlier age of onset of e-cigarette use (13.75 [1.88] vs. 14.42 [1.85] years), more frequent e-cigarette use (16.10 [12.05] vs. 10.32 [10.82] days in the past month), and consumption of a greater average number of alcoholic beverages on drinking days (4.03 [2.65] vs. 3.30 [2.57] drinks; See Table 3).

4.0 Discussion

This study is the first of which we are aware to directly compare characteristics of adolescent cannabis vapers and users of other non-vaporized cannabis modalities. The primary aim was to identify differences in demographics and the use of cannabis modalities, tobacco products, and alcohol among adolescents who reported past-month cannabis use but who differed based on whether they reported cannabis vaping or not. Within the total sample, 22.2% of students reported past-month cannabis use. Consistent with prior research, combustible and vaporizable cannabis were the most common modalities of cannabis use, and cannabis vapers were most likely to report vaping cannabis oil (Knapp et al., 2019; MTF, 2020). 23.7% of cannabis vapers reported that they had hacked an e-cigarette to vape cannabis, a unique study finding that has importance for tobacco product regulation.

Students who endorsed past-month cannabis vaping differed in significant and meaningful ways from students who used other cannabis modalities. Our findings replicated previous

research on demographic factors associated with youth cannabis vaping relative to the use of other non-vaporizable modalities of use. Specifically, cannabis vapers were more likely to be male (e.g., Dai et al., 2020; Johnson et al., 2016; Kritikos et al., 2021; Peters et al., 2018; Tormohlen et al., 2019) and white (e.g., Dai et al., 2019; Johnson et al. 2016). Further, as has been observed in prior research (Peters et al., 2018), cannabis vaping was not differentially associated with SES.

In both unadjusted and adjusted models, novel findings showed that cannabis vapers were more likely to begin using cannabis at an earlier age and report past-month use of edible cannabis, other non-combustible cannabis modalities, e-cigarettes, and alcohol. In addition, cannabis vapers were less likely to use combustible cannabis. Unadjusted differences showed that cannabis vapers also were more likely to be past-month users of cannabis dabs, while the adjusted model suggested cannabis vapers may be less likely to use smokeless tobacco products.

While our substance-specific outcomes generally were consistent with extant findings suggesting that cannabis vaping is associated with the use of other substances (e.g., Kritikos et al., 2021; Lee et al., 2021; Tormohlen et al., 2019) and with increased frequency of past-month cannabis use (Tormohlen et al., 2019), the current findings are more nuanced and expand prior research. A unique finding, to the best of our knowledge, is that cannabis vapers were more likely to report using a greater total number of cannabis modalities than were non-vapers (2.54 [1.14] vs. 1.29 [0.54]). Examined a slightly different way, 74.4% of non-vapers reported using only one cannabis modality compared to only 22.5% of cannabis vapers. This raises concerns for young cannabis vapers based on prior research suggesting that using more cannabis modalities confers added risk for negative outcomes in youth (Knapp et al., 2019).

With regard to individual modalities/substances, cannabis vapers were less likely overall to report past-month combustible cannabis use, but when the sample was limited to past-month combustible users, those who also vaped cannabis reported smoking cannabis significantly more frequently than non-vapers. Cannabis vapers also were more likely than non-vapers to dab more frequently, consume more alcoholic beverages per drinking day, use e-cigarettes more frequently, and report an earlier age of e-cigarette use onset when analyses were limited to samples of past-month dabbers, drinkers, and e-cigarette users, respectively. Of note cannabis vaping-associated increases in the use of other substances spanned multiple types of products and routes of administration (e.g., combustible cannabis, dabs, alcohol, e-cigarette use) and were not limited only to shared device features (i.e., cannabis vaping and e-cigarette vaping). However, the observed link between cannabis vaping and e-cigarette use deserves mention. Not only were cannabis vapers more likely to use (nicotine) e-cigarettes and to use them more frequently, but as noted above, 23.7% of cannabis vapers reported modifying e-cigarettes for use with cannabis as opposed to using cannabis-specific vaping devices. Although additional research is needed, the link between cannabis vaping and e-cigarettes may be attributable, in part, to the availability and popularity of e-cigarettes among youth and the proliferation of cannabis devices that resemble nicotine e-cigarettes. In addition, the widespread availability of Internet resources for how to modify e-cigarettes for use with cannabis (e.g., YouTube videos, text-based tutorials) also may be contributing

factors. Importantly, these resources apply to both “open-system” and “closed-system” nicotine e-cigarette devices. Of note, although “closed-system” e-cigarettes like JUUL are designed to have single-use, non-refillable pods, many of these products are easy to open and refill with e-liquids or cannabis concentrates. These issues have important regulatory implications. Namely, closed-system nicotine e-cigarette devices should be manufactured such that they cannot be opened/modified, and additional protections are needed to restrict youth access to videos and other online tutorials for modifying e-cigarettes for use with cannabis (e.g., https://hightimes.com/guides/juul-pods-with-thc-oil/).

The current findings add to a growing literature suggesting that youth cannabis vaping may be associated with increased risks compared to the use of other cannabis modalities. While it remains unknown exactly why cannabis vaping confers unique risk, Jackson and colleagues (2019) postulated that the relationship between cannabis vaping and deviant behavior may be linked to the concealability of cannabis vapes, the reduced odor emitted by them relative to combustible products, and, consequently, a lower risk of being caught. They suggest that this reduced certainty of punishment may embolden youth to engage in other types of deviant behaviors, which may extend to substance use. In addition, one recent study of youth cannabis users (Boisvert et al., 2020) suggested that cannabis vapers experience blunted positive and negative subjective cannabis effects relative to combustible and edible users. While more research is needed, it is possible that cannabis vapers may be using other substances to enhance positive subjective drug effects like happiness, sociability, and relaxation. Our results are consistent with either line of reasoning given that cannabis vaping was associated with greater rates of past-month use of a variety of cannabis modalities and other substances as well as heavier substance use. However, future research must determine the directionality of the relationship between cannabis vaping and other substance use behaviors. For example, it is possible that an underlying predisposition to risk-taking drives both cannabis vaping and the use of other substances, that cannabis vapers are more likely to try/use other substances for a variety of reasons, or that heavier substance users are drawn to cannabis vaping, perhaps given its increased potency relative to other cannabis. modalities (Orens et al., 2018).

The study findings should be considered alongside its limitations. The study was conducted in six Connecticut high schools and contained only a limited number of demographic and substance-related covariates in the model, which may limit generalizability. However, the rates of past-month cannabis use (20.8%) and cannabis vaping (10.7%) observed in the current study were similar to those observed in the 2020 national MTF survey (21.1%; 12.2%). That said, additional, targeted, and more comprehensive research is needed on this topic. Regarding cannabis vaping, we only assessed lifetime use of cannabis vaping products (e.g., concentrates vs. flower) and did not differentiate past-month cannabis vaping forms. Thus, it is possible that not all past-month cannabis vapers were using concentrates. As such, future research should differentiate past-month use of different cannabis vaping modalities. In addition, we did not differentiate dabbing through the use of a blowtorch/nail, portable dab-pen, or newer electronic dab rigs that have an electronically heated bowl into which a dab is placed either prior to heating or with tweezers or a metal or glass “nail” once the maximum temperature has been reached (e.g., Dr. Dabber Switch). Of note, the use of a dab-pen involves putting wax into an electronically-controlled vaping device, which is

similar to our description of “an e-cigarette or vape-pen filled with wax,” and may have resulted in overlap between the categories. Future research needs to distinguish between traditional and more recent dabbing devices to capture unique variance associated with each. Further, we did not assess age of initiation for each of the assessed cannabis modalities, so it is not clear whether vaping cannabis, specifically, preceded or followed the use of other cannabis modalities and/or other substances. Finally, all data were cross-sectional, so the causality and directionality of the relationship between cannabis vaping and the use of other substances could not be determined.

In sum, our findings suggest that cannabis vaping may be associated with heightened risk of other substance use, including the use of other cannabis modalities, tobacco products, and alcohol. Future prospective studies are needed to better understand the directionality of the relationships between cannabis vaping and other substance use, and additional research is needed to understand why cannabis vaping is associated with more negative substance-related outcomes than are other cannabis use modalities. In addition, further research is needed to better understand the link between cannabis vaping and e-cigarette use, and additional regulations are needed to prevent the ability to modify nicotine e-cigarettes for use with cannabis.

Acknowledgments

We wish to thank all participants who contributed to this work.

Role of Funding Source

Research reported in this publication was supported by grant number U54DA036151 from the National Institute on Drug Abuse (NIDA) and FDA Center for Tobacco Products (CTP). The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH or the Food and Drug Administration.

References

Barrus DG, Capogrossi KL, Cates SC, Gourdet CK, Peiper NC, Novak SP, Lefever TW and Wiley JL, 2016. Tasty THC: promises and challenges of cannabis edibles. Methods Report (RTI Press).

Bidwell LC, YorkWilliams SL, Mueller RL, Bryan AD, Hutchison KE, 2018. Exploring cannabis concentrates on the legal market: User profiles, product strength, and health-related outcomes. Addict Behav Rep. 8, 102–106. [PubMed: 30167450]

Boisvert EE, Bae D, Pang RD, Davis JP, Kelley-Quon LI, Barrington-Trimis JL, Leventhal AM, 2020. Subjective effects of combustible, vaporized, and edible cannabis: Results from a survey of adolescent cannabis users. Drug Alcohol Depend. 206, 107716. [PubMed: 31718923]

Boyce W, Torsheim T, Currie C and Zambon A, 2006. The family affluence scale as a measure of national wealth: validation of an adolescent self-report measure. Soc. Indic. Res 78(3),.473–487.

Centers for Disease Control and Prevention. 2019. Outbreak of lung injury associated with the use of e-cigarette, or vaping, products. https://www.cdc.gov/lunginjury. Accessed: July 27, 2021.

Dai H, Siahpush M., 2020. Use of e-cigarettes for nicotine, marijuana, and just flavoring among U.S. youth. Am J Prev Med. 58(2), 244–249. [PubMed: 31859171]

Delnevo CD, Bover-Manderski MT, Hrywna M, 2011. Cigar, marijuana, and blunt use among US adolescents: Are we accurately estimating the prevalence of cigar smoking among youth? Prev. Med 52(6), 475. [PubMed: 21443900]

Dharmapuri S, Miller K and Klein JD, 2020. Marijuana and the pediatric population. Pediatrics, 146(2).

Di Forti M, Quattrone D, Freeman TP, et al. The contribution of cannabis use to variation in the incidence of psychotic disorder across Europe (EU-GEI): A multicentre case-control study. The Lancet. Psychiatry 2019;6(5):427–436 [PubMed: 30902669]

Eggers ME, Lee YO, Jackson K, Wiley JL, Porter L and Nonnemaker JM, 2017. Youth use of electronic vapor products and blunts for administering cannabis. Addict. Behav 70, 79–82. [PubMed: 28214740]

Fataar F, Hammond D, 2019. The prevalence of vaping and smoking as modes of delivery for nicotine and cannabis among youth in Canada, England and the United States. Int. J. Environ. Res. Public Health 16(21), 4111.

Giroud C, de Cesare M, Berthet A, Varlet V, Concha-Lozano N, Favrat B, 2015. E-cigarettes: A review of new trends in cannabis use. Int. J. Environ. Res. Public Health 12(8), 9988–10008. [PubMed: 26308021]

Hädener M, Vieten S, Weinmann W, Mahler H, 2019. A preliminary investigation of lung availability of cannabinoids by smoking marijuana or dabbing BHO and decarboxylation rate of THC-and CBD-acids. Forensic Sci. Int 295, 207–212. [PubMed: 30638755]

Ibara AB, 2018. Pot vaping: Savvy teens hacking devices to inhale cannabis. https://www.dispatch.com/news/20180912/pot-vaping-savvy-teens-hacking-devices-to-inhale-cannabis. Accessed: July 27, 2021.

Jackson DB, Boccio CM, Leal WE, Vaughn MG, 2019. It's all the rage! Exploring the nuances in the link between vaping and adolescent delinquency. J Crim Justice. 63, 58–69.

Johnson RM, Brooks-Russell A, Ma M, Fairman BJ, Tolliver RL Jr, Levinson AH, 2016. Usual modes of marijuana consumption among high school students in Colorado. J Stud Alcohol Drugs. 77(4), 580–588. [PubMed: 27340962]

King BA, Jones CM, Baldwin GT, Briss PA, 2020. The EVALI and youth vaping epidemics—implications for public health. N Engl J Med. 382(8), 689–691. [PubMed: 31951683]

Knapp AA, Lee DC, Borodovsky JT, Auty SG, Gabrielli J, Budney AJ, 2018. Emerging trends in cannabis administration among adolescent cannabis users. J. Adolesc. Health 64, 487–493. [PubMed: 30205931]

Kritikos AF, Johnson JK, Hodgkin D, 2021. Past 30-day marijuana vaping: Prevalence and predictors of use in a nationally representative study of US youth. Am. J. Prev. Med 60(2), 258–266. [PubMed: 33309447]

Lee J, Kong G, Kassas B and Salloum RG, 2021. Predictors of vaping marijuana initiation among US adolescents: Results from the Population Assessment of Tobacco and Health (PATH) study Wave 3 (2015–2016) and Wave 4 (2016–2018). Drug. Alcohol. Depend 226, 108905. [PubMed: 34304122]

Loflin M & Earleywine M A new method of cannabis ingestion: the dangers of dabs? 2014. Addict Behav. 39(10), 1430–1433 [PubMed: 24930049]

Lozier MJ, Wallace B, Anderson K, Ellington S, Jones CM, Rose D, Baldwin G, King BA, Briss P, Mikosz CA, Austin C, Brown S, Chandra G, Coulliette-Salmond A, Coy K, Currie D, Cyrus A, Danielson M, Fajardo G, Gately A, Goyal S, Graves S, Hamilton J, Hayes D, Hughes D, Israel M, Landen M, Lynfield R, Newton S, Njai R, Pollack L, Ratto J, Ritchey M, Roguski K, Salvatore P, Soroka S, Swedo E, Thomas K, Thomas S, 2019. Update: Demographic, product, and substance-use characteristics of hospitalized patients in a nationwide outbreak of e-cigarette, or vaping, product use–associated lung injuries — United States, December 2019. MMWR. Morb. Mortal. Wkly. Rep 10.15585/mmwr.mm6849e1

Maloney-Hall B, Wallingford SC, Konefal S and Young MM, 2020. Original quantitative research-Psychotic disorder and cannabis use 2006–2015. Health Promot. Chronic Dis 40(5–6), 176–183.

Miech R, Leventhal A, Johnston L, O'Malley PM, Patrick ME, Barrington-Trimis J, 2021. Trends in use and perceptions of nicotine vaping among US youth from 2017 to 2020. JAMA Pediatr. 175(2), 185–190. [PubMed: 33320241]

Monitoring the Future Study: Trends in prevalence of various drugs (2020). https://www.drugabuse.gov/drug-topics/trends-statistics/monitoring-future/monitoring-future-study-trends-in-prevalence-various-drugs

Monte AA, Shelton SK, Mills E, Saben J, Hopkinson A, Sonn B, Devivo M, Chang T, Fox J, Brevik C and Williamson K, 2019. Acute illness associated with cannabis use, by route of exposure: an observational study. Annals of internal medicine, 170(8), pp.531–537. [PubMed: 30909297]

Morean ME, Kong G, Camenga DR, Cavallo DA, Krishnan-Sarin S, 2015. High school students' use of electronic cigarettes to vaporize cannabis. Pediatrics. 136(4), 611–616. [PubMed: 26347431]

Morean ME, Lipshie N, Josephson M, Foster D, 2017. Predictors of adult e-cigarette users vaporizing cannabis using e-cigarettes and vape-pens. Subst Use Misuse. 52(8), 974–981. [PubMed: 28323498]

National Academies of Sciences, Engineering, and Medicine. 2017. The health effects of cannabis and cannabinoids: The current state of evidence and recommendations for research. Washington, DC: The National Academies Press. 10.17226/24625.

Orens A, Light M, Lewandowski B, Rowberry J, Saloga C, 2018. Marijuana policy group. Market size and demand for marijuana in Colorado: 2017 market update. Available at: https://spl.cde.state.co.us/artemis/revmonos/rev132si92018internet/Market%20Size%20and%20Demand%20for%20Marijuana%20in%20Colorado%202017%20Market%20Update.pdf. Accessed July 27, 2021.

Patrick ME, Miech RA, Kloska DD, Wagner AC, Johnston LD, 2020. Trends in marijuana vaping and edible consumption from 2015 to 2018 among adolescents in the US. JAMA Pediatr. 174(9), 900–902. [PubMed: 32250422]

Peters EN, Bae D, Barrington-Trimis JL, Jarvis BP, Leventhal AM, 2018. Prevalence and sociodemographic correlates of adolescent use and polyuse of combustible, vaporized, and edible cannabis products. JAMA Netw. 1(5), e182765–e182765.

Peters EN, Bae D, Barrington-Trimis JL, Jarvis BP and Leventhal AM, 2018. Prevalence and sociodemographic correlates of adolescent use and polyuse of combustible, vaporized, and edible cannabis products. JAMA Netw. Open 1(5), e182765–e182765. [PubMed: 30646180]

School and State Finance Project. 2016. 10 years later: An updated look at CT's District Reference Groups (DRGs). Available from: http://ctschoolfinance.org/resources/2016drgs. Accessed March 9, 2021.

Simon P, Camenga DR, Morean ME, Kong G, Bold KW, Cavallo DA, & Krishnan-Sarin S, 2018. Socioeconomic status and adolescent e-cigarette use: the mediating role of e-cigarette advertisement exposure. Prev. Med 112, 193–198. [PubMed: 29673887]

Spindle TR, Cone EJ, Schlienz NJ, Mitchell JM, Bigelow GE, Flegel R, Vandrey R, 2018. Acute effects of smoked and vaporized cannabis in healthy adults who infrequently use cannabis: a crossover trial. JAMA Netw. 1(7), e184841–e184841.

Struble CA, Ellis JD, & Lundahl LH, 2019. Beyond the bud: Emerging methods of cannabis consumption for youth. Pediatric Clinics, 66(6), 1087–1097. [PubMed: 31679599]

Troutt WD, Didonato MD, 2017. Carbonyl compounds produced by vaporizing cannabis oil thinning agents. J. Altern. Complement. Med 10.1089/acm.2016.0337

Tormohlen KN, Brooks-Russell A, Ma M, Schneider KE, Levinson AH, Johnson RM, 2019. Modes of marijuana consumption among Colorado high school students before and after the initiation of retail marijuana sales for adults. J. Stud. Alcohol Drugs (1), 46–55. [PubMed: 30807274]

Highlights

- 56.3% of adolescent past-month cannabis users reported vaping cannabis.
- Cannabis-specific vapes (92%) and hacked/modified e-cigarettes (24%) were used.
- Cannabis vapers were more often male, non-Hispanic White, and initiated use earlier.
- Cannabis vapers reported using more cannabis modalities (e.g., edibles, combustible).
- Cannabis vapers were more likely to report past-month alcohol and nicotine e-cigarette use.

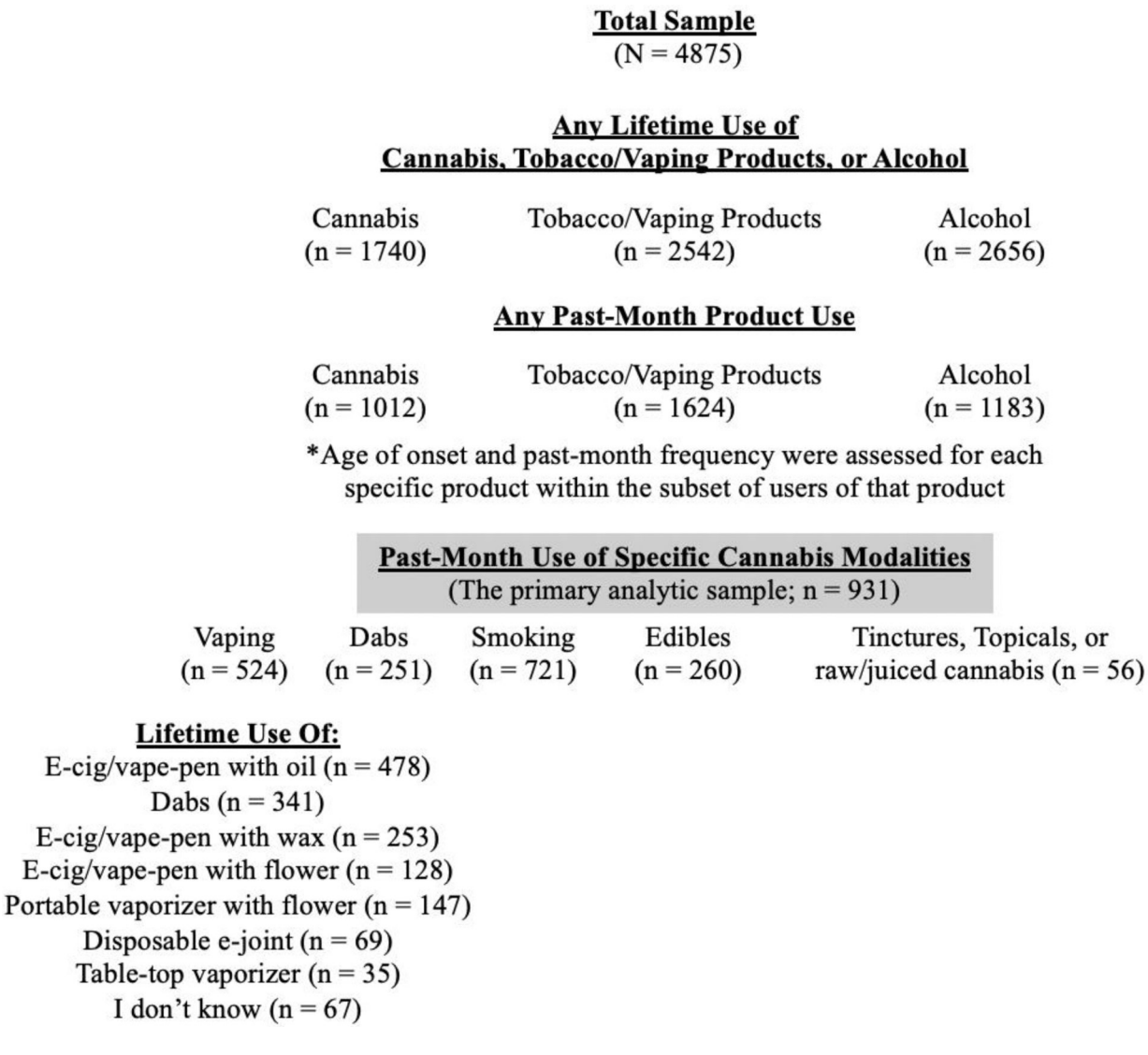

Figure 1.
Study flow

Figure Note. A simplified category for all tobacco/vaping products is included in the flow chart for ease of presentation. Tobacco/vaping products included e-cigarettes, cigarettes, hookah, smokeless tobacco, blunts, cigarillos/little cigars, and large cigars. In addition, the average number of drinks per drinking day was calculated for past-month alcohol users.

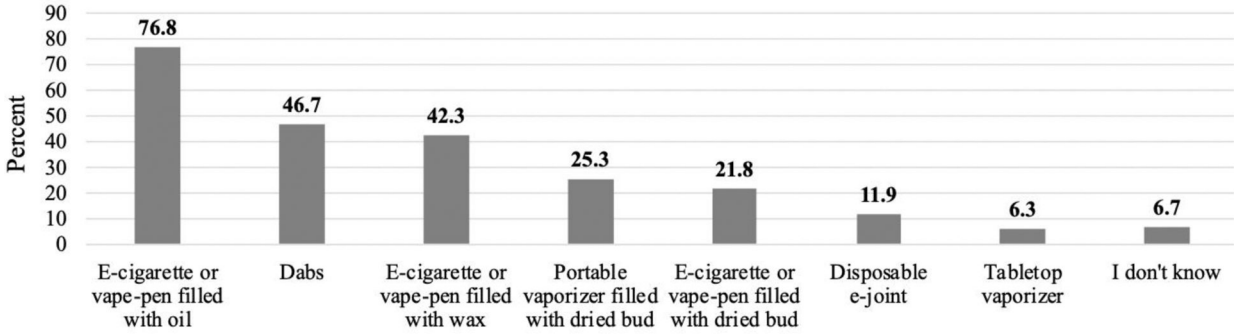

Figure 2.

Endorsement of lifetime modalities of vaporizing cannabis among past-month cannabis vapers (n=524)

Table 1.

Descriptive statistics and unadjusted differences observed by past-month cannabis vaping status

		Cannabis Vaping Status	
	Total Sample N = 931	**No n = 407**	**Yes n = 524**
Age	16.36 (1.27)	16.33 (1.29)	16.38 (1.26)
Male Sex	47.2	42.5	**50.9** **
Hispanic/Latio/a/x	34.4	36.4	32.8
Race			
White	56.0	43.7	**65.5** ***
Black	15.5	**24.8**	8.2 ***
Multiracial	12.6	14.5	11.1
Other	16.0	17.0	15.3
Socioeconomic Status	6.95 (1.87)	6.87 (1.88)	7.00 (1.87)
Cannabis Use			
Age of cannabis onset	14.15 (1.88)	**14.39 (1.90)**	13.97 (1.85) ***
Total cannabis modalities used	1.95 (1.09)	1.29 (0.54)	**2.54 (1.14)** ***
Vaporized cannabis	56.3	0.0	100.0
Dabs	27.0	19.7	**32.6** ***
Combustible cannabis	77.4	**83.3**	72.9 ***
Edible cannabis	27.9	23.8	**31.1** **
Tinctures, topicals, or raw/juiced cannabis	6.0	2.7	**8.6** ***
Alcohol Use	54.2	43.6	**56.4** ***
Tobacco Use			
Any tobacco product use	94.2	92.4	95.6
Total tobacco products used	1.79 (1.07)	1.64 (11.04)	**1.90 (1.08)** ***
Any e-cigarette use	80.1	68.6	**89.1** ***
Total e-cigarette devices used	1.85 (1.40)	1.42 (1.32)	**2.19 (1.37)** ***
Disposable or cig-a-like	19.8	15.0	**23.5** ***
Vape-pen	47.4	34.6	**57.3** ***
JUUL	65.0	55.5	**73.2** ***
Pod other than JUUL	33.7	19.9	**44.4** ***
Mod	19.2	16.5	**21.3** *
Heated tobacco	0.8	0.7	0.8
Any traditional tobacco product use	72.4	75.2	70.2
Total traditional tobacco products used	0.98 (0.93)	0.95 (0.86)	1.00 (0.97)
Cigarette	8.3	6.9	9.4
Hookah	9.8	9.1	10.3
Cigarillo	5.7	3.7	7.3

		Cannabis Vaping Status	
	Total Sample N = 931	**No n = 407**	**Yes n = 524**
Cigar	4.0	2.7	5.0
Blunt	68.6	70.4	67.1
Smokeless	1.9	2.2	1.7

Note.

* $p < .05$

** $p < .01$

*** $p < .001$

Total tobacco products (sum of any past-month e-cigarette, heated tobacco, cigarette, hookah, cigarillo, cigar, blunt, and smokeless tobacco use); Total e-cigarette devices used (sum of any past-month disposable/cig-a-like, vape-pen, JUUL, non-JUUL pod, and mod use); Total traditional tobacco products (sum of any past-month cigarette, hookah, cigarillo, cigar, blunt, and smokeless tobacco use)

Table 2.

Binary logistic regression model showing correlates of past-month cannabis vaping

	B	S.E.	Wald	df	Odds Ratio	95% CI	
School	--	--	18.23**	5	--	--	--
Age	0.10	0.07	2.44	1	1.11	0.97	1.26
Male Sex	0.57	0.16	12.78	1	1.77***	1.29	2.42
Socioeconomic Status	−0.04	0.04	0.67	1	0.97	0.89	1.05
Hispanic Ethnicity	0.01	0.20	0.00	1	1.01	0.69	1.48
Race			19.56***	3			
White (ref)							
Black	−1.12	0.26	19.00	1	0.33***	0.19	0.61
Multiracial	−0.46	0.24	3.59	1	0.63	0.80	8.12
Other	−0.33	0.25	1.80	1	0.72	0.77	2.20
Cannabis Use							
Age of cannabis use onset	−0.13	0.05	7.69	1	0.88**	0.80	0.96
Dab use	0.24	0.18	1.66	1	1.27	0.89	1.81
Combustible cannabis use	−0.77	0.22	12.01	1	0.46***	0.30	0.72
Edible cannabis use	0.39	0.19	4.29	1	1.48*	1.02	2.14
Tinctures, topicals or, raw/juiced cannabis use	0.94	0.41	5.25	1	2.56*	1.15	5.70
Alcohol Use	0.47	0.17	7.92	1	1.59**	1.15	2.20
Tobacco Use							
E-cigarette use	1.04	0.20	26.15	1	2.83***	1.90	4.21
Cigarette use	0.02	0.30	0.00	1	1.02	0.56	1.84
Hookah use	−0.02	0.28	0.01	1	0.98	0.57	1.68
Cigarillo use	0.31	0.43	0.52	1	1.36	0.59	3.14
Cigar use	−0.27	0.49	0.31	1	0.76	0.29	2.00
Blunt use	0.37	0.21	3.18	1	1.45	0.96	2.18
Smokeless tobacco use	−1.98	0.65	9.29	1	0.14**	0.04	0.49

Note, χ^2 (25) = 204.76, $p < .001$, $R^2 = 0.27$; Past-month use of heated tobacco products was not included in the model due to an insufficient sample size; -- School was included in the model to account for the fact that participants came from six schools. However, individual effects by school are not included in the table given that between-school differences are not interpretable.

* $p<.05$

** $p<.01$

*** $p<.001$

Table 3.

Unadjusted differences by cannabis vaping status among students who reported past-month use of different cannabis modalities and substances

			Cannabis Vaping Status			
	Total within Subsamples		No Past-Month Vaping		Past-Month Vaping	
	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
Cannabis Vaping Frequency	--	--	--	--	524	10.29 (10.24)
Cannabis Dabbing Frequency	251	7.93 (9.24)	80	6.24 (8.67)	171	**8.73 (9.41)** *
Combustible Cannabis Frequency	721	11.21 (10.75)	339	8.13 (9.30)	382	**13.95 (11.22)** ***
Edible Cannabis Frequency	260	5.93 (7.88)	97	5.40 (7.66)	163	6.25 (8.01)
Other Cannabis (tinctures, topicals, raw/juiced cannabis) Frequency	56	7.75 (9.81)	11	9.09 (10.77)	45	7.42 (9.66)
E-cigarette Age of Onset	745	14.00 (1.90)	279	**14.42 (1.85)**	466	13.75 (1.88) ***
E-cigarette Use Frequency	745	13.93 (11.93)	279	10.32 (10.82)	466	**16.10 (12.05)** ***
Alcohol Age of Onset	502	12.98 (2.62)	176	13.08 (2.70)	326	12.93 (2.58)
Alcohol Frequency	502	6.51 (7.34)	176	6.69 (8.38)	326	6.41 (6.73)
Alcohol (Drinks per Drinking Day)	499	3.78 (2.64)	174	3.30 (2.57)	325	**4.03 (2.65)** ***

Note. Frequency refers to number of days in the past 30 days. -- indicates a variable that is not relevant to a given group.Age of onset reflects age of initiation in years.

* $p < .05$

** $p < .01$

*** $p < .001$