


A Longitudinal Study of E-Cigarette, Cigarette, and Marijuana Use Sequence in Youth

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ABSTRACT

OBJECTIVE: There is evidence linking youth use of electronic (e-) cigarettes to subsequent cigarette and marijuana use, raising public health concerns. We examined the sequence of use of e-cigarettes, conventional cigarettes, and marijuana in a longitudinal sample of adolescents, to determine if use of e-cigarettes often preceded use of other substances.

METHODS: We collected self-reports from 1123 Oregon adolescents (52% female; 37% Hispanic) longitudinally from 8th to 11th grade (8 total surveys) regarding their lifetime (ever use) and current use (last 30 days) of e-cigarettes, cigarettes, and marijuana. If applicable, students also reported the delivery method of their current marijuana use.

RESULTS: Almost 10% of adolescents reported using e-cigarettes prior to use of cigarettes or marijuana, and the majority of these youth initiated use of marijuana, cigarettes, or both by 11th grade. More youth transitioned from e-cigarette use to marijuana use then from e-cigarettes to use of conventional cigarettes. Participants who were co-using e-cigarettes and marijuana in 11th grade had an increased likelihood of consuming marijuana via vaping, dabbing, and edibles, compared to those who were only using marijuana.

DISCUSSION: E-cigarettes were often the first substance used in this longitudinal sample, and more of these youth subsequently used marijuana compared to cigarettes. While research has focused on the progression from e-cigarettes to cigarettes in youth, these findings indicate that more attention should be focused on the subsequent initiation of marijuana.

KEYWORDS: Electronic Nicotine Delivery Systems, Vaping, Marijuana Use, Cigarette Smoking, Adolescent, Tobacco, Cannabis

TYPE: Original Research

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Introduction

Adolescent use of electronic (e-) cigarettes has increased rapidly in recent years¹, although it did decline during the COVID-19 pandemic.² By 2014, youth use of e-cigarettes was more prevalent than any other tobacco product.³ E-cigarettes are ever-evolving, with new technology, marketing strategies, and flavors constantly emerging as tobacco companies develop and promote non-combustible products. Nicotine delivery devices can look like conventional cigarettes (cig-a-likes), pens or sticks (e-cigarettes, vape pens, e-pens, vape sticks, e-hookahs), flash drives, or modifiable tank systems. They typically deliver nicotine and other substances via heating liquid into inhalable aerosol. While not all e-liquids contain nicotine, 99% of e-cigarette products sold in convenience stores and other public outlets in 2015 contained nicotine.⁴

Although there are no studies on the health effects of long-term e-cigarette use, nicotine in any form is known to be addictive and harmful to adolescent brain development.⁵ As the brain is not yet fully developed in adolescence, exposure to nicotine during this time can disrupt the growth of brain circuits that control attention and learning, and can have lasting effects

such as impulse control issues and mood disorders.⁶ In addition, e-liquid contents and the fine/ultrafine particulates in the aerosol likely pose health risks at any age⁷, and evidence indicates that e-cigarette use may cause unique changes in the lungs and lung secretions⁸ and respiratory symptoms in adolescents.⁹ Although e-cigarettes are likely less hazardous than combustible tobacco, adolescent e-cigarette users also have carcinogenic volatile organic compounds present in their bodies indicating that they are not truly “safe” to use.^{10,11}

Beyond the health risks they face, youth who use e-cigarettes are likely to: (1) initiate use of combustible tobacco products in the future^{12–15}, (2) co-use e-cigarettes with other substances, including marijuana¹⁶, and (3) be more willing to use conventional cigarettes compared to those who had never used any nicotine/tobacco product.¹⁷ It remains unclear if vaping nicotine is a “gateway” to combustible products, or if there is a “common liability” underlying use of multiple substances.¹² There is also evidence of diversion of potential cigarette smokers to use of e-cigarettes, as the use of combustible products has continued to decline in youth and young adults at the same time vaping has rapidly increased.¹⁸ E-cigarettes may



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be especially enticing to youth as they can be used surreptitiously, have minimal odor, look high-tech and modern, are available in many appealing flavors, and are perceived as safer than other tobacco products.^{19,20} Although a great deal of research has focused on whether e-cigarette use in youth has replaced or led to subsequent use of combustible tobacco products, much less research has examined associations between e-cigarette and marijuana use.

There is a high prevalence of lifetime and current use of marijuana among youth, even during the COVID-19 pandemic, when marijuana availability declined.² Nationwide, 23% of youth reported using marijuana in the past 30 days pre-pandemic, which declined to 20% during the pandemic.² Using the same sample of Oregon youth as the present study, legalization of recreational marijuana resulted in increased marijuana use among youth who had initiated use prior to legalization, but those who had never used marijuana did not start using post-legalization.²¹ We also found that co-use of marijuana with e-cigarettes was high; youth who were regular users of e-cigarettes in 8th grade were almost 19 times more likely to be current users of marijuana a year later compared to infrequent or non-e-cigarette users.²²

Regular marijuana use during adolescence can alter brain development, increase the likelihood of school dropout, and can result in cognitive impairment²³, resulting in persistent functional deficits in adulthood.²⁴ There is also a high risk of subsequent dependence when marijuana use begins in adolescence.²⁵ Co-using marijuana and nicotine may lead to higher levels of dependence and addiction of both substances, especially for adolescents.²⁶

Although the most common method of marijuana consumption is inhalation of smoke from combustible plant material, other methods are becoming increasingly popular.²⁷ For youth in particular, the use of vaporizers for marijuana consumption is increasing; Morean and colleagues²⁸ found that almost 30% of high school e-cigarette users had also vaped marijuana. Electronic Nicotine Delivery Systems (ENDS; e-cigarettes) can be easily modified to efficiently vaporize liquid hash oil, which contains higher concentrations of THC compared to dried marijuana.²⁸ Vaporization can also be done inconspicuously, as there is little odor when marijuana is vaporized; this could lead to greater use at home or school and increased overall consumption. Marijuana vaporizers often look indistinguishable from ENDS, or even from medical devices, such as asthma inhalers. Similar to marketing of ENDS/e-cigarettes, the health benefits of vaping marijuana are touted in online advertisements and discussions, with claims of harm reduction compared to inhaling carcinogenic smoke.²⁹ However, also similar to e-cigarettes, there are negative neurocognitive effects of exposing adolescent brains to THC, similar to the negative impact of nicotine exposure on adolescent brain development.³⁰ Other increasingly popular methods of marijuana/THC delivery include dabbing, which often involves heating and inhaling a concentrated form of marijuana on metal

(such as a nail head), eating marijuana (the edibles are often in sweets such as cookies, brownies, chocolates, or candies), and applying topical marijuana-infused lotions, balms, salves, oils, or sprays (transdermal delivery methods do not typically enter the bloodstream and typically are used for localized pain relief, not for getting “high”).

Legalization of marijuana appears to impact the marijuana delivery method used by youth as well. A large study using a convenience sample of youth ages 14-18 found that, in states with legal recreational or medical marijuana, youth were more than twice as likely to have tried vaping marijuana compared to youth in states without legal marijuana.³¹ Youth from states with higher densities of marijuana dispensaries, such as Oregon, began vaping 2.2 months earlier compared to youth with no or low density dispensaries, and over half of youth reported having vaped marijuana if it was legal in their state, compared to 36% having vaped marijuana in states with non-legal marijuana.³¹ With the rising popularity of vaporizers, for both nicotine and marijuana, it is imperative to examine if youth who use e-cigarettes are also more likely to use vaporizers to consume marijuana – specifically, if using the same type of delivery device makes a transition from e-cigarettes to vaping marijuana easier for youth.

In this study, we examine the rates and sequence of e-cigarette, conventional cigarette, and marijuana use in a longitudinal sample of youth followed from 8th grade to 11th grade, and explored the current methods of marijuana use. First, we provide rates of lifetime use over time for students who participated in the student survey in the spring of 8th grade (N = 1123). Second, we examine the ordered sequence of substance use for the 3 substances under examination from 8th to 11th grade. We expected that e-cigarettes would be the most commonly initiated substance, often preceding use of other substances. Third, we explore the timing of transitions from e-cigarette-only use to use of cigarettes and marijuana, by examining youth with early onset of e-cigarettes-only (at the baseline 8th grade survey, n = 85), and subsequent transitions to use of conventional cigarettes and/or marijuana. Finally, we test whether 11th grade youth who were current co-users of e-cigarettes and marijuana (n = 53) had any significant differences in the methods they were using to consume marijuana (e.g., smoking, vaping, dabbing, edibles), compared to youth who were currently marijuana-only users (n = 66). We expected that youth who co-used e-cigarettes and marijuana would report a higher frequency of vaping marijuana, compared to marijuana-only users.

Methods

Participants and Recruitment

Seven school districts in Oregon agreed to participate in this study, and families of all 8th graders in each district were invited to participate. Criteria for school district recruitment included being in a rural or suburban community, having an above

Oregon state average number of students eligible to receive free or reduced lunch, and willingness for both middle and high schools to participate in the longitudinal study. Parents of all 1409 8th grade students in participating districts were mailed a description of the study along with an opt-out card to return if they did not want their child to participate in the study; 107 (7.6%) opted out. An additional 40 students (2.8%) were ineligible for participation due to being a ward of the state, not being fluent in English or Spanish, or seldom attending school, and 74 students (5.3%) had left participating school districts by the time of the first study assessment. If a participating student left a participating school or school district, they were no longer followed for the study, but if they returned to the participating school they re-joined the study. See ²² for additional details on participant recruitment and study methodology.

Student data were collected via web-based computer surveys under the supervision of project staff, and were administered 3 times each school year starting in the spring of 8th grade and ending in the fall of 11th grade, for a total of 8 waves of surveys. The study took place between 2014 and 2017. At baseline, 1123 8th grade participants completed at least 1 item on the survey. A majority of participants completed 7 (n = 219; 20%) or all 8 (n = 451; 40%) assessment waves. Approximately 10% completed only 1 wave (n = 110), 3% completed 2 waves (n = 35), 5% completed 3 waves (n = 52), 8% completed 4 waves (n = 90), 6% completed 5 waves (n = 71), and 9% completed 6 waves (n = 95). Of the 1123 participants in this data set, 52.3% were female, 36.6% were Hispanic, 59.2% were Non-Hispanic (mostly White), and 4.2% were unknown. The mean age at the time of the baseline survey was 14.4 years old (SD = .5). For the current study, we utilized all available data for participants who completed at least 1 item on the baseline assessment. Participants with reported substance use in 8th grade were less likely to continue participation in 9th grade compared to those with no reported substance use (p < .05).

The research design and procedures were reviewed and approved by the Oregon Research Institute Institutional Review Board. All participating students completed an assent form prior to any data collection.

Measures

Lifetime and current substance use. At each assessment wave, students reported whether they had ever used e-cigarettes, cigarettes, or marijuana (e.g., “In your whole life, how many different times have you ever smoked an e-cigarette [“vape pen”] or an e-hookah, even a puff?”). If participants had never tried a substance, they were coded as “never used”. If they reported any use ever, they were coded “ever users”. Lifetime use was a non-decreasing lifetime prevalence variable (i.e., lifetime use was not allowed to revert back to “never used” in subsequent assessments after a participant reported use). If any prior lifetime use was reported, students were then asked how many days out of the last 30 they had used each substance to assess current use (e.g.,

“In the last 30 days, on how many days would you say you have smoked an e-cigarette [“vape pen”] or an e-hookah, even a puff?”. Those with past-30 day use were classified as “current users” of that substance.

Method of current marijuana use. In the 11th grade survey, participants who reported using marijuana at least once in the past 30 days were then asked “In the past 30 days, how often did you use marijuana in any of the following ways? (a) Smoking marijuana (cigarette, joint, pipe, water pipe), (b) Eating marijuana (edibles, food, sweets, drinks, capsules), (c) Vaping marijuana, (d) Dabbing marijuana, and (e) Using marijuana on skin (patches, lotions).” Response options for each method of marijuana consumption were: Never, 1 time, 2-5 times, 6-10 times, and More than 10 times.

Demographics. Students reported their age, gender, and race/ethnicity.

Statistical Analysis

We created a descriptive report of lifetime substance use by substance and survey wave, which made use of all available data at each survey wave. For students who reported lifetime use of e-cigarettes only by the spring of 8th grade, a matrix was created to identify the sequence of substance use initiation from 8th through 11th grades, while taking into account the timing of the transitions across the 8 waves of surveys. For students who reported current marijuana use in the spring of 11th grade, a set of contingency analyses were performed to evaluate differential rates in method of marijuana consumption between students with and without current use of e-cigarettes. All analyses were performed in SPSS version 23.

Results

By the baseline survey, 14.9% of participants (n = 167) had already used all of the substances being examined: e-cigarettes, cigarettes, and marijuana, so we do not have any information about the sequence of substance initiation for these students. Across all survey waves, there were low rates of solo substance users; about 5% of the sample reported solo use of e-cigarettes (n = 56), 4.4% reported solo use of marijuana (n = 49), and about 3% were solo cigarette users (n = 36). Thus, most substance-using participants had tried more than 1 of the substances being examined by the fall of 11th grade.

Overall, lifetime substance prevalence by the fall of 11th grade in this Oregon sample were high: 47.8% (n = 537) for e-cigarettes, 39.4% (n = 443) for cigarettes, and 45.5% (n = 511) for marijuana. Of those reporting e-cigarette use onset, 27.0% began by the spring of 8th grade (i.e., had already initiated use by the time of the baseline survey). The largest uptick in e-cigarette initiation, 7.0% of youth, occurred between the spring of 8th grade and the fall of 9th grade (this time period covered the transition from middle school to high school and spanned a

summer). Similar large increases in use were seen for the other substances during this time period as well, with 4.9% of participants initiating cigarettes and 7.9% initiating marijuana between waves 1 and 2. (See [Supplementary Table 1](#) for details on participant lifetime use of e-cigarettes, cigarettes, and marijuana.)

We then examined the sequence of onset to substances (see [Table 1](#)). Use of e-cigarettes preceded use of cigarettes or marijuana for 107 participants (9.5% of the sample), while use of cigarettes preceded use of e-cigarettes or marijuana for 37 participants (3.3%) and use of marijuana preceded use of

e-cigarettes or cigarettes for 40 participants (3.6%). More youth transitioned from e-cigarette use to marijuana use ($n = 93$; 8.3%) then from e-cigarette to conventional cigarettes ($n = 67$; 6.0%). A large number of participants ($n = 325$) reported co-use of e-cigarettes and either cigarettes or marijuana at the same time point, so we cannot determine the sequence of initiation of e-cigarettes and the other substances for these students.

Next, we examined the sequence of substance use for participants with early onset of e-cigarette use. Of the 303 participants who used e-cigarettes before the end of 8th grade, 85

Table 1. Sequence of Initiation of E-cigarettes (E), Cigarettes (C), and Marijuana (M) from 8th grade through 11th grade (N = 1123).

NUMBER OF TRANSITIONS	SEQUENCE	FREQUENCY	PERCENT	
Not Applicable	No substance use	478	42.6	
No Transitions	E	56	5.0	
	C	36	3.2	
	M	49	4.4	
	EC	22	2.0	
	EM	38	3.4	
	CM	12	1.1	
	ECM	167	14.9	
	One Transition	E→C	14	1.2
E→M		40	3.6	
EC→M		25	2.2	
EM→C		47	4.2	
E→CM		26	2.3	
C→E		6	0.5	
C→M		8	0.7	
C→EM		14	1.2	
CM→E		9	0.8	
M→E		19	1.7	
M→C		3	0.3	
M→EC		12	1.1	
Two Transitions		E→C→M	8	0.7
		E→M→C	19	1.7
		C→E→M	6	0.5
	C→M→E	3	0.3	
	M→C→E	2	0.2	
	M→E→C	4	0.4	

Note. Substances grouped together indicate the participant reported use of each substance in the same assessment wave. An arrow indicates a transition to lifetime use in a subsequent wave.

had not yet initiated conventional cigarettes or marijuana. Figure 1 depicts those participants with e-cigarette-only use at baseline, and illustrates if and when they initiated cigarettes and/or marijuana over the next 7 waves of data collection. By the fall of 9th grade, the second survey wave, of those early-onset e-cigarette users, 57 remained e-cigarette only users, 2 had initiated conventional cigarettes, 19 had initiated marijuana, and 9 had initiated both cigarettes and marijuana. By the last survey, in the fall of 11th grade, 20 remained e-cigarette-only lifetime users, 4 had tried cigarettes, 24 had tried marijuana, and 39 had used all 3 substances at least once. Of the 85 participants who initiated use of e-cigarettes but not marijuana or cigarettes in 8th grade, 38 (44.7%) used marijuana as their second substance and 20 (23.5%) used cigarettes as their second substance.

Finally, we examined the association between e-cigarette use and method of marijuana consumption. During the fall of 11th grade 7.9% ($n = 53$) of youth reported current e-cigarette and marijuana use and 10.3% ($n = 66$) of youth reported current marijuana use and no current e-cigarette use. A greater proportion of youth who reported current marijuana use and current e-cigarette use consumed marijuana via vaping (20% vs. 50%, $p < .001$), dabbing (30% vs. 54%, $p < .01$), and edibles (35% vs. 57%, $p < .05$; see Table 2) compared to those reporting current marijuana use and no current e-cigarette use. There were no significant differences found between rates of smoking marijuana or applying it topically between these 2 groups.

Discussion

E-cigarette use was initiated prior to cigarettes or marijuana for about 10% of youth in this sample, and more of these youth subsequently initiated marijuana use compared to combustible cigarettes. This extends the current literature, as prospective studies indicate that youth who initiate e-cigarettes are more likely to subsequently initiate conventional cigarettes^{13,14}, it appears they may be even more likely to subsequently initiate marijuana use. In this sample, youth were more likely to transition from e-cigarettes to cigarettes or marijuana than the reverse; fewer youth reported onset of cigarette or marijuana use prior to use of the other substances.

Some research has indicated that today's youth may be replacing cigarettes with e-cigarettes, as rates of conventional smoking by teens have declined, while rates of vaping have increased.¹⁸ Historically, use of conventional cigarettes has long been associated with smoking marijuana.^{32,33} Our findings indicate that youth who use e-cigarettes, many of whom have not initiated use of combustible cigarettes, may now be susceptible to marijuana initiation and use via non-combustible delivery methods, especially vaping.²⁸

In fact, we found that youth who used both e-cigarettes and marijuana in 11th grade were significantly more likely to vape, dab, and eat marijuana compared to marijuana users who were not concurrently using e-cigarettes. Methods of nicotine and marijuana administration are changing as vaporizers are

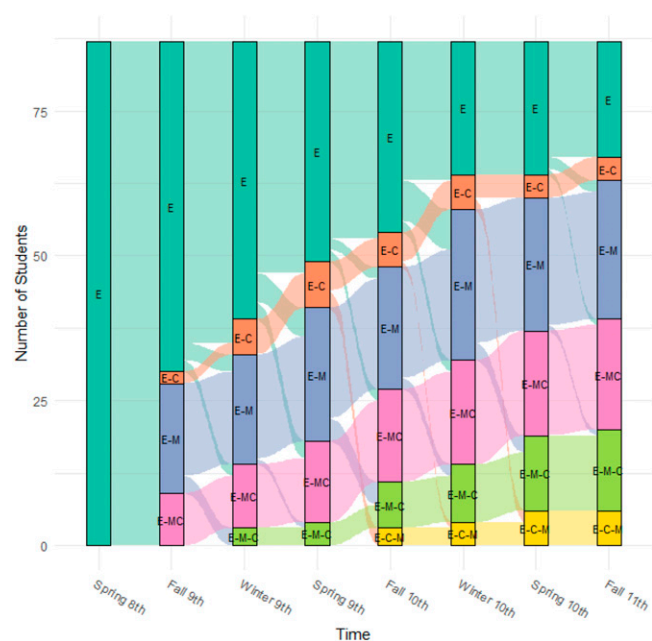


Figure 1. 8th Grade E-cigarette-only Users and the Sequence and Timing of Subsequent Transitions to Conventional Cigarettes and/or Marijuana ($n = 85$). Note. E-cigarette use = E; Cigarette use = C; Marijuana use = M. The order of use groups (e.g., E, C, M) corresponds to both the sequence and timing of use, such that E-C indicates e-cigarette users transitioning to cigarettes at a time point, E-MC indicates e-cigarette users transitioning to marijuana and cigarettes at the same time point, E-C-M indicates e-cigarette users transitioning first to cigarettes, and subsequently to marijuana, etc.

increasingly popular²⁸, and as recreational marijuana is legalized, thus increasing access to, and knowledge of, marijuana edibles.^{27,31} These data were collected in Oregon from 2014 to 2017, where recreational marijuana was legalized in 2015. With a variety of routes of administration becoming increasingly popular for marijuana consumption, it is perhaps not surprising that the prevalence of marijuana use among youth has remained steady, even as cigarette use, which is closely linked to marijuana use, has sharply declined.³⁴ E-cigarette use may be related to marijuana use, similar to the historical association between use of conventional cigarettes and marijuana. Polysubstance use was common in this sample, with few youth remaining solo users of any of these substances by the time they were in 11th grade (age 17).

Interestingly, a significant proportion (close to 15%) of the sample had already initiated use of all 3 substances under examination by the end of 8th grade; this is rather high at the average age of 14, while still in middle school. This indicates a potential common liability for these substances within this sample.³⁵ One possible explanation for this high prevalence is the geographic and socioeconomic composition of the sample; about 40% of participating youth lived in rural areas that typically have higher substance use compared to suburban or urban areas, and all participating districts served lower income communities.³⁶ Access to these substances may be associated with youth use as well. E-cigarettes and e-liquid were available to minors in Oregon until the end of May, 2015, when vaping

Table 2. Comparison of Method of Marijuana Consumption by Participants Reporting Current Marijuana Use (n = 66) and those Reporting Current Use of both Marijuana and E-cigarettes (n = 53) in 11th grade.

METHOD OF MARIJUANA CONSUMPTION	CURRENT MARIJUANA USE	CURRENT USE OF MARIJUANA/ E-CIGARETTES	F/CHISQ	P
Smoking	57 (87.7%)	40 (78.4%)	1.79	.180
Edibles	23 (34.8%)	29 (56.9%)	5.65	.017
Vaping	13 (20.3%)	26 (50.0%)	11.33	<.001
Dabbing	20 (30.3%)	28 (53.8%)	6.68	.009
Topically	5 (7.8%)	9 (17.6%)	2.57	.109

Note. Participants could select more than 1 method of marijuana consumption.

products were included in existing tobacco sales to minors laws; thus, some of these data were collected prior to the expansion of the tobacco sales laws to include “inhalant delivery systems”. Our results indicate that prevention efforts for these substances should target late childhood and young adolescents, prior to initiation.

High rates of e-cigarette and marijuana use among youth may also be due in part to more favorable attitudes towards use of e-cigarettes and marijuana compared to cigarettes.³⁷⁻⁴⁰ Studies of attitudes and perceptions around e-cigarettes and marijuana show that adolescents hold more favorable attitudes towards and attribute fewer health and social risks to e-cigarettes and marijuana compared to other tobacco products^{41,42}, particularly combustible cigarettes, and that those who have used e-cigarettes or marijuana hold more positive attitudes towards them.⁴³ Prevention campaigns similar to those done for conventional cigarettes, focusing on the risks of adolescent use of marijuana and e-cigarettes and reducing their perceived appeal, may be effective to combat these differences in attitudes and perceptions towards these substances.

While this study has many strengths, including the longitudinal, frequent youth assessments of substance use, there were also some limitations. First, we used self-report measures of substance use, however, participant reports were largely consistent over time and we reminded participants at the time of each survey that their answers were confidential. Second, the survey items assessing use of “e-cigarettes” did not specify use of e-cigarettes with nicotine liquid only, so some participants may have reported on their use of e-cigarettes without nicotine (with non-nicotine flavored e-liquids, liquid marijuana, or other contents). However, when these data were collected, between 2014 and 2017, most e-cigarettes sold did contain nicotine.⁴ Third, the participant sample was primarily composed of White and Hispanic students living in rural and suburban areas in 1 state. Thus, these findings may not be generalizable to more diverse populations or urban areas, but do provide insight into substance use in a state with recently legalized marijuana. Fourth, a number of participants had already initiated substance use by our baseline assessment done in the spring of participants’ 8th grade year, indicating that future studies examining the sequence of substance use in youth should begin before age 14 to

better capture use as it occurs. In addition, participants who reported substance use in 8th grade were less likely to complete assessments in 9th grade, so potentially the most at-risk participants were lost to later follow-ups. Fifth, even though we conducted assessments 3 times each year, many youth reported onset of 2 or more substances at the same assessment time point. This pattern of use underscores the need for more frequent assessments or the utilization of a different survey methodology to accurately capture the sequence of substance use onset for youth.

The current study examined the sequence of e-cigarette, cigarette, and marijuana use in a longitudinal sample of 8th through 11th graders, across 8 waves of data collection. E-cigarettes were the most commonly used substance of the 3, and adolescents tended to initiate use of e-cigarettes earlier than cigarettes or marijuana. More youth transitioned from e-cigarettes to marijuana than to cigarettes, and those who were co-using e-cigarettes and marijuana in 11th grade were more likely to be vaping, dabbing, or eating marijuana. The appeal of e-cigarettes to youth appears to be quite strong, and, similar to findings regarding strong links between use of cigarettes and marijuana, there may be similarly strong links between e-cigarettes and marijuana use. More research is needed to further evaluate these associations and to contribute to the development of efficacious prevention and intervention strategies.

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