Original Investigation | Substance Use and Addiction

Trajectories of Nicotine and Cannabis Vaping and Polyuse From Adolescence to Young Adulthood

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Abstract

IMPORTANCE Little is known about cannabis vaping trajectories across adolescence and young adulthood or the co-occurrence with nicotine vaping.

OBJECTIVE To evaluate nicotine vaping and cannabis vaping trajectories from late adolescence to young adulthood (18 years of age) and the extent of polysubstance vaping.

DESIGN, SETTING, AND PARTICIPANTS In this prospective cohort study, 5 surveys (including information on substance vaped) were completed at 10 high schools in the Los Angeles, California, metro area. Students were surveyed at 6-month intervals from fall of 11th grade (October to December 2015; wave 5) through spring of 12th grade (March to June 2017; wave 8) and again approximately 1 to 2 years after high school (October 2018 to October 2019; wave 9).

EXPOSURES Past 30-day nicotine and cannabis vaping frequency across 5 waves.

MAIN OUTCOMES AND MEASURES Self-reported frequency of nicotine vaping and cannabis vaping within the past 30 days across 5 time points from late adolescence to young adulthood. Trajectories were measured with these past 30-day use frequencies at each wave. Parallel growth mixture modeling estimated conditional probabilities of polysubstance vaping.

RESULTS The analytic sample included 3322 participants with at least 1 time point of data (mean [SD] age, 16.50 [0.42] years at baseline; 1777 [53.5%] female; 1573 [47.4%] Hispanic or Latino). Growth mixture modeling identified the 5-trajectory model as optimal for both nicotine vaping and cannabis vaping. Trajectories for nicotine and cannabis vaping were similar (nonusers: 2246 [67.6%] nicotine, 2157 [64.9%] cannabis; infrequent users: 566 [17.0%] nicotine, 608 [18.3%] cannabis; moderate users: 167 [5.0%] nicotine, 233 [7.0%] cannabis; young adult-onset frequent users: 213 [6.4%] nicotine, 190 [5.7%] cannabis; adolescent-onset escalating frequent users: 131 [3.9%] nicotine, 134 [4.0%] cannabis). Males had greater odds of belonging to the adolescent-onset escalating frequent users nicotine (adjusted odds ratio, 2.88; 95% CI, 1.58-5.23; P < .01) and cannabis (adjusted odds ratio, 1.95; 95% CI,1.03-3.66; P < .05) vaping trajectories compared with nonusers. Polysubstance vaping was common, with those in trajectories reflecting more frequent nicotine vaping (adolescent-onset escalating frequent users and young adult-onset frequent users) having a high probability of membership in a cannabis-use trajectory.

CONCLUSIONS AND RELEVANCE In this cohort study, the prevalence and type of nicotine vaping and cannabis vaping developmental trajectories from late adolescence to young adulthood were similar. Polysubstance vaping was common from late adolescence to young adulthood, particularly among those reporting more frequent vaping use. The findings suggest that public health policy and

(continued)
Introduction

The prevalence of electronic vaporizer use among US adolescents and young adults has substantially increased. Recent past 30-day estimates indicate marked increases for both nicotine vaping (20.9% to 25.4% among 12th graders from 2018 to 2019; 6.5% to 10.6% among young adults from 2017 to 2018) and cannabis vaping (7.5% to 14.0% among 12th graders from 2018 to 2019; 6.6% to 9.3% among young adults from 2017 to 2018). There is a wide distribution in the frequency of past 30-day use among youths, ranging from vaping 1-2 days to daily use; however, the extent to which this wide distribution represents individuals on escalating, deescalating, or stable use trajectories is unclear.

Growth mixture modeling (GMM) is a data-driven analytic approach for identifying unobserved subpopulations and describing distinct longitudinal change. This approach has been applied to identify youth trajectories of combustible cigarette, alcohol, and cannabis use. However, to date, only 2 longitudinal studies have sought to identify trajectories of nicotine vaping. Park et al identified 3 e-cigarette trajectories from 13 to 17 years of age: never (66.6%), low and increasing (20.1%), and high and increasing (13.3%). Westling et al reported 2 trajectories of e-cigarette use from 8th to 9th grade: 94.8% infrequent or no use and 5.1% accelerated use. Both studies indicated that membership in e-cigarette-using trajectories was associated with other substance use.

Although Park et al and Westling et al showed that adolescents can be classified into distinct trajectories of vaping, neither study examined the transition from adolescence to young adulthood. This is a population at high risk because transitions to college and/or the workforce and increased familial and financial responsibility are associated with increased risk of polysubstance use, enduring substance use problems, and substance use disorder. Furthermore, to our knowledge, developmental trajectories of cannabis vaping have not been identified in adolescence or young adulthood; thus, it is unknown how cannabis vaping develops over time. Examining gender and racial/ethnic differences of nicotine and cannabis vaping trajectories is also warranted because there is some evidence that males are more likely to vape than females. Racial/ethnic differences are less clear. In addition, although cross-sectional studies have reported high rates of nicotine and cannabis vaping polyuse among adolescents and young adults, to our knowledge, no longitudinal study has examined co-occurring development of nicotine and cannabis vaping trajectories. Identifying common polysubstance vaping patterns may inform both nicotine and cannabis policy and prevention.

Using a prospective longitudinal design following a cohort of adolescents through young adulthood (≥18 years of age), the current study evaluated nicotine and cannabis vaping trajectories, demographic covariates of trajectories, and co-occurrence of nicotine and cannabis vaping trajectories.

Methods

Participants and Procedure

Data were drawn from a prospective cohort study of high school students from the Los Angeles, California, metro area. Students from 10 high schools were surveyed at 6-month intervals from 9th grade (October to December 2013; wave 1) through 12th grade (March to June 2017; wave 8) using self-administered pencil-and-paper questionnaires in schools. Participants were surveyed again 1 to 2
years after high school (October 2018 to October 2019) through online questionnaires. Questions pertaining to specific substance vaped were first asked at wave 5; thus, the current study assessed survey data from waves 5 to 9. All 9th graders at wave 1 were eligible to participate. This study was approved by the University of Southern California institutional review board. For waves 1 to 8, written or verbal parental consent and student assent were obtained. For wave 9, participants were contacted after turning 18 years of age and provided written informed consent. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) and American Association for Public Opinion Research (AAPOR) reporting guidelines.

Measures

Nicotine and Cannabis Vaping

Frequency of nicotine vaping and cannabis vaping was assessed across waves 5 to 9. Participants indicated the number of days of nicotine and cannabis vaping in the past 30 days by answering the following 2 questions, respectively: “In the last 30 days, how many total days have you used an electronic cigarette with nicotine (e-cigs, personal vaporizer, PV [personal vaporizer])?” “In the last 30 days, how many total days have you used an electronic device to vape THC [tetrahydrocannabinol] or hash oil (liquid pot, cannabis oil, weed pen, PAX Era [PAX Labs, Inc])?” JUUL (JUUL Labs, Inc) use was also added to the wave 9 survey. Response categories (0, 1-2, 3-5, 6-9, 10-19, 20-29, or 30 days) were recoded into quantitative count variables by taking the median integer (rounded up when necessary) within each response range (0, 2, 4, 8, 15, 25, or 30 days), as done in previous work with this sample.25,26

Covariates

Age, highest parental educational level, gender, and race/ethnicity were self-reported. Highest parental educational level was recoded into a binary variable (college degree or higher vs some college or less). Race/ethnicity was recoded into 3 dummy variables (1, Asian; 0, non-Asian; 1, Hispanic or /Latino; 0, not Hispanic or Latino; 1, White; 0, non-White) for racial/ethnic groups representing 10% or more of the sample (Asian, Hispanic or Latino, and White).

Statistical Analysis

Growth mixture modeling (GMM) was used to identify latent trajectories of nicotine and cannabis vaping. This approach captures heterogeneity within the population by identifying different growth trajectories of a latent variable based on unique intercepts and slopes.27 An increasing number of classes are estimated until an optimal model is identified. Similar to structural equation modeling in which statistical indexes (eg, confirmatory fit index, root mean square error of approximation) are used to identify the best-fitting model, the bayesian information criterion28 and Lo-Mendell-Rubin likelihood ratio test29 are commonly used indexes for GMM. Owing to the large number of 0s resulting in skewed distributions for past 30-day nicotine and cannabis vaping, vaping variables were treated as count outcomes; a zero-inflated Poisson model was used to account for both processes generating 0 days scores (vape users who did not use in the past 30 days and never users). Full information maximum likelihood was used to account for missing data, which allowed participants with at least 1 time point of data to be included in trajectory analyses (3322 of 3396 in the original cohort). Simulation studies report samples near 1200 as adequate for complex GMM.30 Covariates of each trajectory model were evaluated within the GMM framework using a validated 3-step approach to account for classification error.31 Parallel growth mixture modeling (PGMM) assessed co-occurrence of nicotine and cannabis vaping trajectories. PGMM estimates the unique developmental growth parameters of 2 distinct processes and how each process relates to the other across time.32 PGMM was used to calculate the probability of cross-classification between a specific nicotine vaping trajectory and cannabis vaping trajectory. A 2-sided P < .05 was considered to be statistically significant. Analyses were conducted with Mplus, version 8.4.33
## Table 1. Descriptive Characteristics

| Variable                                      | Participants (N = 3322) |
|-----------------------------------------------|-------------------------|
| **Age at baseline, mean (SD), y**             | 16.50 (0.42)            |
| **Highest parental educational level**        |                         |
| College degree or higher                      | 2014 (60.6)             |
| Some college or less                          | 856 (25.8)              |
| **Gender**                                    |                         |
| Female                                        | 1777 (53.5)             |
| Male                                          | 1544 (46.5)             |
| **Race/ethnicity**                            |                         |
| American Indian or Alaska Native              | 34 (1.0)                |
| Asian                                         | 551 (16.6)              |
| Black                                         | 161 (4.8)               |
| Hispanic or Latino                            | 1573 (47.4)             |
| Native Hawaiian or Pacific Islander           | 138 (4.2)               |
| White                                         | 533 (16.0)              |
| Multiracial                                   | 216 (6.5)               |
| Other                                         | 49 (1.5)                |
| Unknown                                       | 67 (2.0)                |
| **Nicotine vaping, any past 30-d use**         |                         |
| Wave 5                                        |                         |
| No/total No. (%)                              | 183/3188 (5.7)          |
| Mean (SD), d                                  | 8.50 (9.72)             |
| Wave 6                                        |                         |
| No/total No. (%)                              | 167/3065 (5.4)          |
| Mean (SD), d                                  | 8.53 (9.20)             |
| Wave 7                                        |                         |
| No/total No. (%)                              | 139/3143 (4.4)          |
| Mean (SD), d                                  | 8.65 (10.04)            |
| Wave 8                                        |                         |
| No/total No. (%)                              | 232/3109 (7.5)          |
| Mean (SD), d                                  | 9.38 (10.01)            |
| Wave 9                                        |                         |
| No/total No. (%)                              | 547/2483 (22.0)         |
| Mean (SD), d                                  | 11.34 (11.18)           |
| **Cannabis vaping, any past 30-d use**         |                         |
| Wave 5                                        |                         |
| No/total No. (%)                              | 134/3188 (4.2)          |
| Mean (SD), d                                  | 8.87 (9.37)             |
| Wave 6                                        |                         |
| No/total No. (%)                              | 137/3065 (4.7)          |
| Mean (SD), d                                  | 8.96 (9.18)             |
| Wave 7                                        |                         |
| No/total No. (%)                              | 176/3143 (5.6)          |
| Mean (SD), d                                  | 8.93 (9.68)             |
| Wave 8                                        |                         |
| No/total No. (%)                              | 306/3109 (9.8)          |
| Mean (SD), d                                  | 8.61 (9.05)             |
| Wave 9                                        |                         |
| No/total No. (%)                              | 599/2483 (24.1)         |
| Mean (SD), d                                  | 9.78 (9.58)             |

* Data are presented as number (percentage) of participants unless otherwise indicated. Baseline was wave 5, fall of 11th grade; wave 6, spring of 11th grade; wave 7, fall of 12th grade; wave 8, spring of 12th grade; and wave 9, young adulthood.
Results

Descriptive Statistics
A total of 4100 students were eligible to enroll in the study; parental consent and student assent were obtained for 3396 adolescents (82.8%). Of the 3396 participants originally enrolled in the study, those with at least 1 time point of past 30-day vaping data from waves 5 to 9 were included in the analysis (n = 3322). Data distinguishing between nicotine vaping and cannabis vaping were available from waves 5 (fall of 11th grade) to wave 9 (young adulthood). Data were missing for 134 (4.0%) students in wave 5, 257 (7.7%) in wave 6, 179 (5.4%) in wave 7, 213 (6.4%) in wave 8, and 839 (25.3%) in wave 9.

Of the 3322 participants 1777 (53.5%) were female, and 1573 (47.4%) were Hispanic or Latino; the mean (SD) age at baseline was 16.50 (0.42) years (Table 1). From waves 5 to 8, the number of adolescents who reported any nicotine vaping in the past 30 days ranged from 139 (4.4%; in wave 7) to 232 (7.5%; in wave 8); the number then increased to 547 (22.0%) in wave 9 (young adulthood). For cannabis vaping, any use in the past 30 days steadily increased from 134 (4.2%) participants in wave 5 to 306 (9.8%) in wave 8 and then to 599 (24.1%) in wave 9. eTable 1 in the Supplement presents bootstrapped-derived correlations between nicotine and cannabis vaping and within-substance correlations. Across waves, nicotine vaping was significantly associated with cannabis vaping (r, 0.06-0.44; all P < .001 except for P = .002 for nicotine wave 9 and cannabis wave 5 and P = .01 for nicotine wave 5 and cannabis wave 9). Within substance correlations ranged from 0.22 to 0.55 for nicotine vaping and from 0.11 to 0.33 for cannabis vaping (P < .001 for all except P = .08 for cannabis in waves 5 and 9).

Nicotine Vaping Trajectories
Model fit was evaluated across an increasing number of trajectory classes. The bayesian information criterion and Lo-Mendell-Rubin likelihood ratio test indicated that the 5-class model was the best fit (eTable 2 in the Supplement); the bayesian information criterion value was lowest for the 5-class model, and the Lo-Mendell-Rubin likelihood ratio test was not significant past the 5-class solution. Figure 1 presents mean days of past 30-day nicotine vaping at each wave for each identified trajectory. The largest trajectory class (non-users; 2246 [67.6%] of the sample) was composed of nonnicotine vapers across waves. The other 4 trajectories were characterized by varying nicotine vaping frequency and developmental timing. Infrequent users (566 [17.0%]) reported a mean of 0.45 days (95% CI, 0-1.22 days) of nicotine vaping in adolescence and a mean of 1.89 days (95% CI, 1.12-2.66 days) in young adulthood. Moderate users (167 [5.0%]) reported nicotine vaping for a mean of 2.33 days (95% CI, 1.67-2.99 days) in adolescence and a mean of 6.54 days (95% CI, 5.88-7.20 days) in young adulthood. Young adult–onset frequent users (213 [6.4%]) reported a mean of 0.76 days...
(95% CI, 0.29-1.23 days) of nicotine vaping in adolescence, with an increase to a mean of 19.75 days (95% CI, 19.28-20.22 days) in young adulthood. Adolescent-onset escalating frequent users (131 [3.9%]) were characterized by escalating frequent nicotine vaping use from late adolescence (mean, 7.38 days; 95% CI, 7.02-7.74 days) to young adulthood (mean, 21.49 days; 95% CI, 21.13-21.84 days).

**Cannabis Vaping Trajectories**

Similar to the nicotine vaping trajectories, the bayesian information criterion and Lo-Mendell-Rubin likelihood ratio test indicated that the 5-class model was optimal (eTable 2 in the Supplement). The identified trajectories for cannabis vaping were similar to those identified for nicotine vaping (Figure 2). The largest trajectory class (nonusers; 2157 [64.9%] of the sample) was composed of non–cannabis vapers across waves. The other 4 trajectories were characterized by varying frequency and developmental timing of use. Infrequent users (608 [18.3%]) reported a mean of 0.57 days (95% CI, 0-1.55 days) of cannabis vaping in adolescence and a mean of 2.19 days (95% CI, 1.21-3.17 days) in young adulthood. Moderate users (233 [7.0%]) reported cannabis vaping for a mean of 4.60 days (95% CI, 3.98-5.22 days) in adolescence and a mean of 6.75 days (95% CI, 6.13-7.37 days) in young adulthood. Young adult-onset frequent users (190 [5.7%]) reported little cannabis vaping in adolescence (mean, 0.74 days; 95% CI, 0-1.66 days) but an increase was observed in young adulthood (mean, 17.57 days; 95% CI, 16.65-18.49 days). Adolescent-onset escalating frequent users (134 [4.0%]) reported escalating frequent cannabis vaping use from late adolescence (mean, 7.31 days; 95% CI, 7.02-7.60 days) to young adulthood (mean, 19.94 days; 95% CI, 19.65-20.23 days).

**Covariates of Nicotine and Cannabis Vaping Trajectories**

Covariates were added to each vaping trajectory model to assess the odds of trajectory membership based on age, highest parental educational level, gender, and race/ethnicity (Table 2). For nicotine vaping trajectories, males (vs females) had higher odds of membership in the adolescent-onset escalating frequent users (adjusted odds ratio [aOR], 2.88; 95% CI, 1.58-5.23; \( P = .001 \)) and moderate users (aOR, 1.98; 95% CI, 1.26-3.14; \( P = .003 \)) trajectories compared with nonusers. Latino and Hispanic individuals (vs non-Latino and non-Hispanic individuals) had lower odds of membership in the adolescent-onset escalating frequent users trajectory compared with the nonusers trajectory (aOR, 0.38; 95% CI, 0.17-0.82; \( P = .01 \)). For cannabis vaping trajectories, males (vs females) had higher odds of membership in the adolescent-onset escalating frequent users compared with the nonusers trajectory (aOR, 1.95; 95% CI, 1.03-3.66; \( P = .04 \)).

![Figure 2. Growth Mixture Model of 5 Cannabis Vaping Trajectories Representing Past 30-Day Use of Cannabis Vaping During Adolescence and Young Adulthood](https://jamanetwork.com/)

Error bars indicate 95% CIs.
Co-occurring Nicotine and Cannabis Vaping Trajectories
PGMM was used to assess co-occurring trajectories of nicotine and cannabis vaping. Before examining conditional probabilities of membership in the cannabis vaping trajectories given membership in the nicotine vaping trajectories (Table 3), an overview of classification across both sets of trajectories indicated that 57.6% belonged to nonusers nicotine and cannabis vaping trajectories, 7.5% were classified into a nicotine-use but not a cannabis-use vaping trajectory, 9.8% were classified into a cannabis-use but not a nicotine-use vaping trajectory, and 25.1% belonged to both nicotine-use and cannabis-use vaping trajectories. As shown in Table 3, conditional probabilities indicated that participants in the nonusers nicotine vaping trajectory had the highest probability of membership in the nonusers cannabis vaping trajectory (85.5%). Of the nonusers nicotine vaping trajectory members who were members in one of the cannabis-use vaping trajectories (ie, single-substance cannabis vaping), most were in the infrequent users cannabis vaping trajectory (8.8%). For each of the 4 nicotine-use vaping trajectories, comembership in the nonusers cannabis vaping trajectory (ie, single-substance nicotine vaping) was uncommon (range, 6.7%-32.0%).

Participants in the infrequent users nicotine vaping trajectory had the highest probability of being classified in the infrequent users (38.7%) and nonusers (32.0%) cannabis vaping trajectories. Individuals in the moderate users nicotine vaping trajectory had higher probabilities of belonging to the infrequent users (34.5%) and moderate users (27.5%) cannabis vaping trajectories. Participants in the young adult-onset frequent users nicotine vaping trajectory had the highest probability of belonging to the infrequent users (39.6%) and moderate users (25.3%) cannabis vaping trajectories.

Table 2. Estimated Adjusted Odds Ratios of Nicotine Vaping and Cannabis Vaping Trajectory Membership

| Characteristic                        | Infrequent users | Moderate users | Young adult-onset frequent users | Adolescent-onset escalating frequent users |
|---------------------------------------|------------------|----------------|----------------------------------|--------------------------------------------|
|                                       | Nicotine         | Cannabis       | Nicotine                         | Cannabis                                   |
| Age                                   | 0.83             | 1.00           | 0.87                             | 1.47                                       |
|                                       | (0.60-1.13)      | (0.74-1.36)    | (0.46-1.63)                      | (0.84-2.60)                                |
| Highest parental educational levelb   | 1.17             | 1.15           | 1.26                             | 1.59                                       |
|                                       | (0.86-1.61)      | (0.85-1.56)    | (0.72-2.21)                      | (0.74-3.41)                                |
| Male vs female                        | 0.97             | 0.82           | 1.98                             | 1.16                                       |
|                                       | (0.75-1.26)      | (0.63-1.05)    | (1.26-3.14)                      | (0.72-1.87)                                |
| Asian vs non-Asian                    | 0.66             | 0.87           | 0.79                             | 1.72                                       |
|                                       | (.41-1.05)       | (0.58-1.31)    | (0.40-1.56)                      | (0.81-3.68)                                |
| Latino or Hispanic vs non-Latino or non-Hispanic | 0.81 | 0.86 | 0.55 | 0.57 |
|                                       | (0.56-1.16)      | (0.61-1.22)    | (0.30-1.00)                      | (0.28-1.19)                                |
| White vs non-White                    | 1.23             | 1.05           | 0.85                             | 2.01                                       |
|                                       | (0.82-1.86)      | (0.70-1.57)    | (0.41-1.73)                      | (0.98-4.11)                                |

* The reference was the nonusers trajectory.

b Highest parental educational level was college degree or higher vs some college or less.

c \( P = .003. \)

d \( P = .001. \)

e \( P = .004. \)

Table 3. Probability of Cannabis Vaping Trajectory Membership Based on Nicotine Vaping Trajectory Membership

| Nicotine vaping | Nonusers | Infrequent | Moderate | Young adult-onset frequent | Adolescent-onset escalating frequent |
|-----------------|----------|------------|----------|----------------------------|--------------------------------------|
| Nonusers        | 85.5     | 8.8        | 1.4      | 3.8                        | 0.4                                 |
| Users           |          |            |          |                            |                                      |
| Infrequent      | 32.0     | 38.7       | 15.3     | 9.1                        | 4.8                                 |
| Moderate        | 20.0     | 34.5       | 27.5     | 12.1                       | 5.8                                 |
| Young adult-onset frequent | 6.7 | 39.6 | 25.3 | 18.8 | 9.7 |
| Adolescent-onset escalating frequent | 15.0 | 26.5 | 2.9 | 10.0 | 45.5 |
Those in the adolescent-onset escalating frequent users nicotine vaping trajectory had the highest probability of membership in the adolescent-onset escalating frequent users cannabis vaping trajectory (45.5%).

**Discussion**

The current study corroborates prior research showing associations between nicotine and cannabis vaping in adolescence.21-24 Our findings go beyond this literature by identifying developmental trajectories of cannabis vaping and examining co-occurring nicotine and cannabis vaping trajectories from late adolescence into young adulthood. Results indicate that trajectories of nicotine and cannabis vaping were similar; nonusers, infrequent users, moderate users, young adult-onset frequent users, and adolescent-onset escalating frequent users characterized vaping trajectories. Our co-occurring trajectory assessment allowed for the identification of distinct polysubstance vaping use and found that those in nicotine-use trajectories had a high likelihood of belonging to cannabis-use trajectories. Polysubstance vaping was common (25.1% of sample). For each nicotine-use vaping trajectory, the probability of being classified in a cannabis-use vaping trajectory ranged from 68% to 93% depending on the frequency of nicotine vaping. These findings suggest that addressing polysubstance vaping in public health policy and showing the potential benefits of prevention efforts in young adulthood in addition to adolescence are important.

For both nicotine and cannabis vaping, 5 trajectories distinguished between frequency and developmental timing of use, which is consistent with previous studies that identified adolescent e-cigarette trajectories characterized by frequency and increasing use.11,12 Of note, the proportion of the sample in each trajectory and type of trajectory were similar between nicotine and cannabis vaping. These similarities suggest that developmental trajectories of nicotine and cannabis vaping may share underlying risk processes, which has been observed in polyuse of combustible tobacco and cannabis use.34,35 In this study, males (vs females) had close to double (cannabis) and triple (nicotine) the odds of belonging to the adolescent-onset escalating frequent users trajectory compared with the nonusers trajectory. These results align with previous findings indicating that male adolescents have a higher likelihood of vaping than female adolescents17,18 and suggest that males who begin vaping in adolescence may be more likely than females to escalate their intake substantially. Race/ethnicity was not associated with membership in similar nicotine and cannabis vaping trajectories, but Latino individuals (vs non-Latino individuals) had lower odds of belonging to the adolescent-onset escalating frequent users nicotine trajectory than to the nonusers trajectory. As public health initiatives expand from their focus on nicotine vaping to other vaped substances, such as cannabis, understanding shared processes and pathways to polysubstance vaping is critical to appropriately tailor public health and clinical interventions to those most at risk.

The methods used to examine development of nicotine and cannabis vaping from late adolescence into young adulthood allowed for the identification of a trajectory (young adult-onset frequent users) that was characterized by frequent vaping in young adulthood but not in adolescence. The increase in both past 30-day nicotine and cannabis vaping observed among young adult-onset frequent users between the spring of 12th grade (mean, 1-2 days) and young adulthood (mean, 18-20 days) is noteworthy. Although a cohort effect may have been associated with increased use of nicotine and cannabis vaping during the young adulthood wave, which spanned from 2018 to 2019 when pod vaporizers, such as JUUL, and disposable vaporizers increased in popularity and marijuana use in California was legalized,36-38 research is needed to elucidate why some individuals may have a greater risk of nicotine and/or cannabis vaping in young adulthood but not adolescence; these individuals may not be following the previously established adolescent pathways to vaping.39-41 A substantial number of young adults initiating nicotine or cannabis vaping may be overlooked by public health efforts focused on adolescent vaping. Although prevention strategies focused on adolescent vaping should remain prominent, efforts specifically addressing young adult vaping use may be warranted to substantially reduce nicotine and cannabis vaping.
By examining co-occurring nicotine and cannabis vaping trajectories, this study was able to show that most individuals classified into a nicotine-use vaping trajectory were also classified into a cannabis-use vaping trajectory. Those in trajectories reflecting more frequent nicotine vaping use (adolescent-onset escalating frequent users and young adult-onset frequent users) had a high probability of membership (85% and 93%, respectively) in a cannabis-use vaping trajectory. Although 46% of adolescent-onset escalating frequent users of nicotine vaping were classified into the corresponding cannabis vaping trajectory, young adult-onset frequent users had higher probabilities of belonging to the infrequent (40%) or moderate (25%) users cannabis vaping trajectories, which suggests the possibility of distinct risk processes and pathways to polysubstance vaping in adolescence vs young adulthood. Furthermore, policies targeting nicotine vaping through restrictions on flavors and cartridge-based devices may need to expand to other vaped substances, such as cannabis, to better address co-occurring health risk behaviors among younger populations. Addressing polysubstance vaping is critical because polysubstance vaping users are likely to be at high risk of deleterious health outcomes common among combustible tobacco and cannabis polyusers, such as cognitive deficits, mental health impairments, and greater substance dependence.

Limitations
This study has limitations. The use of a sample specific to Southern California limits generalizability to other regions; however, a regionally specific sample increases the likelihood that participants were experiencing similar regulatory policies and trends in vaping use. The study also relied on self-report of vaping use, but self-report is the most common method of measuring substance use. Although the sample was racially/ethnically diverse, evaluating racial/ethnic differences between Black individuals and other ethnicity/race participants was not feasible owing to low representation. There were more missing data in wave 9 (young adulthood) compared with waves 5 to 8 (adolescence); however, full information maximum likelihood enabled participants with at least 1 wave of data to be included in the analysis. Although the study examined the transition from adolescence to young adulthood, additional waves in young adulthood would better inform young adult vaping use.

Conclusions
In this study, nicotine and cannabis vaping trajectory models were similar; this, additional work appears to be needed to evaluate shared risk processes. A significant proportion of individuals initiated and participated in both nicotine and cannabis vaping during young adulthood, suggesting that research is warranted to identify developmentally appropriate interventions. Further study of the substantial polysubstance vaping observed between nicotine and cannabis vaping trajectories appears to be needed to develop more effective regulatory practices and interventions.
Author Contributions: Dr Lanza had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Concept and design: Lanza, Barrington-Trimis, McConnell, Braymiller, Leventhal.

Acquisition, analysis, or interpretation of data: Lanza, Barrington-Trimis, Cho, Braymiller, Krueger, Leventhal.

Drafting of the manuscript: Lanza, Cho, Leventhal.

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Statistical analysis: Lanza, Cho, Krueger.

Obtained funding: Barrington-Trimis, Leventhal.

Administrative, technical, or material support: Barrington-Trimis, Cho, Leventhal.

Supervision: Barrington-Trimis, Leventhal.

Conflict of Interest Disclosures: Dr McConnell reported receiving grants from the National Institutes of Health during the conduct of the study. Dr Krueger reported receiving grants from the University of Southern California during the conduct of the study. No other disclosures were reported.

Funding/Support: This project was supported in part by Tobacco Centers of Regulatory Science award U54CA180905 from the National Cancer Institute and the US Food and Drug Administration, award RO1CA229617 (Leventhal) from the National Cancer Institute, award 27-IR-0034 (Barrington-Trimis) from the California Tobacco-Related Disease Research Program, and awards KO1DA042950 (Barrington-Trimis) and K24DA048160 (Leventhal) from the National Institute on Drug Abuse.

Role of the Funder/Sponsor: The funders had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

REFERENCES

1. Schulenberg J, Johnston L, O’Malley P, et al. Monitoring the future national survey results on drug use, 1975-2018: Volume II, college students and adults ages 19-60: 2019. Accessed March 30, 2020. http://monitoringthefuture.org/pubs.html#monographs

2. Miech R, Johnston L, O’Malley PM, Bachman JG, Patrick ME. Trends in adolescent vaping, 2017-2019. N Engl J Med. 2019;381(15):1490-1491. doi:10.1056/NEJMjoc1910739

3. Miech RA, Patrick ME, O’Malley PM, Johnston LD, Bachman JG. Trends in reported marijuana vaping among US adolescents, 2017-2019. JAMA. 2019;323(5):475-476. doi:10.1001/jama.2019.20185

4. Barrington-Trimis JL, Kong G, Leventhal AM, et al. e-Cigarette use and subsequent smoking frequency among adolescents. Pediatrics. 2018;142(6):e20180486. doi:10.1542/peds.2018-0486

5. Vogel EA, Cho J, McConnell RS, Barrington-Trimis JL, Leventhal AM. Prevalence of electronic cigarette dependence among youth and its association with future use. JAMA Netw Open. 2020;3(2):e1921513-e1921513. doi:10.1001/jamanetworkopen.2019.21513

6. Muthén B, Muthén LK. Integrating person-centered and variable-centered analyses: growth mixture modeling with latent trajectory classes. Alcohol Clin Exp Res. 2000;24(6):882-891. doi:10.1111/j.1530-0277.2000.tb02070.x

7. Wang M, Bodner TE. Growth mixture modeling: Identifying and predicting unobserved subpopulations with longitudinal data. Organ Res Methods. 2007;10(4):635-656. doi:10.1177/1094428106289397

8. Cho J, Goldenson NI, Stone MD, et al. Characterizing polytobacco use trajectories and their associations with substance use and mental health across mid-adolescence. Nicotine Tob Res. 2018;20(suppl_1):S31-S38. doi:10.1093/ntr/ntx270

9. Martineau KM, Cook EC. Trajectories of adolescent alcohol use: the effect of individual and social risk factors by race. J Child Adolesc Subst Abuse. 2017;26(5):387-400. doi:10.1080/1067828X.2017.1307796

10. Passaretti AM, Crane NA, Hedeker D, Mermelstein RJ. Longitudinal trajectories of marijuana use from adolescence to young adulthood. Addict Behav. 2015;45:301-308. doi:10.1016/j.addbeh.2015.02.008

11. Park E, Livingston JA, Wang W, Kwon M, Eiden RD, Chang YP. Adolescent e-cigarette use trajectories and subsequent alcohol and marijuana use. Addict Behav. 2020;103:106213. doi:10.1016/j.addbeh.2019.106213

12. Westling E, Rusby JC, Crowley R, Light JM. Electronic cigarette use by youth: prevalence, correlates, and use trajectories from middle to high school. J Adolesc Health. 2017;60(6):660-666. doi:10.1016/j.jadohealth.2016.12.019

13. Haardörfer R, Berg CJ, Lewis M, et al. Polytobacco, marijuana, and alcohol use patterns in college students: a latent class analysis. Addict Behav. 2016;59:58-64. doi:10.1016/j.addbeh.2016.03.034
14. Berg CJ, Payne J, Henriksen L, et al. Reasons for marijuana and tobacco co-use among young adults: a mixed methods scale development study. *Subst Use Misuse.* 2018;53(3):357-369. doi:10.1080/10826084.2017.1327978

15. Palmer RHC, Young SE, Hopfer CJ, et al. Developmental epidemiology of drug use and abuse in adolescence and young adulthood: evidence of generalized risk. *Drug Alcohol Depend.* 2009;102(1-3):78-87. doi:10.1016/j.drugalcdep.2009.01.012

16. Sussman S, Arnett JJ. Emerging adulthood: developmental period facilitative of the addictions. *Evaluat Health Prof.* 2014;37(2):147-155. doi:10.1177/0163278714521812

17. Kong G, Kuguru KE, Krishnan-Sarin S. Gender differences in US adolescent e-cigarette use. *Curr Addict Rep.* 2017;4(4):422-430. doi:10.1007/s40429-017-0176-5

18. Meich 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. doi:10.1136/tobaccocontrol-2016-053014

19. Barrington-Trimis JL, Bello MS, Liu F, et al. Ethnic differences in patterns of cigarette and e-cigarette use over time among adolescents. *J Adolesc Health.* 2019;65(3):359-365. doi:10.1016/j.jadohealth.2019.04.002

20. Wong DW, Fan W. Ethnic and sex differences in e-cigarette use and relation to alcohol use in California adolescents: the California Health Interview Survey. *Public Health.* 2018;157:147-152. doi:10.1016/j.puhe.2018.01.019

21. Kowitt SD, Osman A, Meernik C, et al. Vaping among adolescents: prevalence and associations with tobacco use from a cross-sectional study in the USA. *BMU Open.* 2019;9(6):e028535. doi:10.1136/bmjopen-2018-028535

22. Morean ME, Kong G, Camenga DR, Cavallo DA, Krishnan-Sarin S. High school students' use of electronic cigarettes to vaporize cannabis. *Pediatrics.* 2015;136(4):611-616. doi:10.1542/peds.2015-1727

23. Trivers KF, Phillips E, Gentzke AS, Tynan MA, Neff LJ. Prevalence of cannabis use in electronic cigarettes among US youth. *JAMA Pediatr.* 2018;172(11):1097-1099. doi:10.1001/jamapediatrics.2018.1920

24. Nguyen N, Barrington-Trimis JL, Urman R, et al. Past 30-day co-use of tobacco and marijuana products among adolescents and young adults in California. *Addict Behav.* 2019;98:106053. doi:10.1016/j.addbeh.2019.106053

25. Goldenson NI, Leventhal AM, Stone MD, McConnell RS, Barrington-Trimis JL. Associations of electronic cigarette nicotine concentration with subsequent cigarette smoking and vaping levels in adolescents. *JAMA Pediatr.* 2017;171(12):1192-1199. doi:10.1001/jamapediatrics.2017.3209

26. Leventhal AM, Goldenson NI, Cho J, et al. Flavored e-cigarette use and progression of vaping in adolescents. *Pediatrics.* 2019;144(5):e20190789. doi:10.1542/peds.2019-0789

27. Muthén B. Beyond SEM: general latent variable modeling. *Behaviormetrika.* 2002;29:81-117. doi:10.2333/bhmk.29.81

28. Schwartz G. Estimating the dimension of the model. *Ann Stat.* 1978;6:461-464. doi:10.1214/aos/1176344136

29. Lo Y, Mendell NR, Rubin DB. Testing the number of components in a normal mixture. *Biometrika.* 2001;88:767-778. doi:10.1093/biomet/88.3.767

30. Kim SY. Sample size requirements in single- and multiphase growth mixture models: a Monte Carlo simulation study. *Struct Equ Modeling.* 2012;19:457-476. doi:10.1080/10705511.2012.687672

31. Asparouhov T, Muthén B. Auxiliary variables in mixture modeling: three-step approaches using Mplus. *Struct Equ Modeling.* 2014;21:329-341. doi:10.1080/10705511.2014.915181

32. Wu J, Witkiewitz K, McMahon RJ, Dodge KA; Conduct Problems Prevention Research Group. A parallel process growth mixture model of conduct problems and substance use with risky sexual behavior. *Drug Alcohol Depend.* 2010;111(3):207-214. doi:10.1016/j.drugalcdep.2010.04.013

33. Muthén LK, Muthén BO. *Mplus User’s Guide.* 8th ed. Los Angeles, CA: Muthén & Muthén, 2017.

34. Tucker JS, Rodriguez A, Dunbar MS, et al. Cannabis and tobacco use and co-use: trajectories and correlates from early adolescence to emerging adulthood. *Drug Alcohol Depend.* 2019;204:107499. doi:10.1016/j.drugalcdep.2019.06.004

35. Meier E, Hatsukami DK. A review of the additive health risk of cannabis and tobacco co-use. *Drug Alcohol Depend.* 2016;166:6-12. doi:10.1016/j.drugalcdep.2016.07.013

36. Barrington-Trimis JL, Leventhal AM. Adolescents’ use of “pod mod” e-cigarettes—urgent concerns. *N Engl J Med.* 2018;379(12):1099-1102. doi:10.1056/NEJMbh1805758

37. Delneo C, Giovenco DP, Hrywna M. Rapid proliferation of illegal pod-mod disposable e-cigarettes. *Tob Control.* 2020;30:505485. doi:10.1136/tobaccocontrol-2019-055485
38. Smart R, Pacula RL. Early evidence of the impact of cannabis legalization on cannabis use, cannabis use disorder, and the use of other substances: findings from state policy evaluations. *Am J Drug Alcohol Abuse.* 2019; 45(6):644-663. doi:10.1080/00952990.2019.1669626

39. Kwon E, Seo DC, Lin HC, Chen Z. Predictors of youth e-cigarette use susceptibility in a U.S. nationally representative sample. *Addict Behav.* 2018;82:79-85. doi:10.1016/j.addbeh.2018.02.026

40. Leventhal AM, Strong DR, Sussman S, et al. Psychiatric comorbidity in adolescent electronic and conventional cigarette use. *J Psychiatr Res.* 2016;73:71-78. doi:10.1016/j.jpsychires.2015.11.008

41. Wills TA, Knight R, Williams RJ, Pagano I, Sargent JD. Risk factors for exclusive e-cigarette use and dual e-cigarette use and tobacco use in adolescents. *Pediatrics.* 2015;135(1):e43-e51. doi:10.1542/peds.2014-0760

42. US Food and Drug Administration Center for Tobacco Products. *Enforcement priorities for electronic nicotine delivery system (ENDS) and other deemed products on the market without premarket authorization.* Vol. FDA-2019-D-06612020. US Food and Drug Administration; 2020.

43. Connor JP, Gullo MJ, White A, Kelly AB. Polysubstance use: diagnostic challenges, patterns of use and health. *Curr Opin Psychiatry.* 2014;27(4):269-275. doi:10.1097/YCO.0000000000000069

44. Schulte MT, Hser YI. Substance use and associated health conditions throughout the lifespan. *Public Health Rev.* 2014;35(2):3. doi:10.1007/BF03391702

45. Ream GL, Benoit E, Johnson BD, Dunlap E. Smoking tobacco along with marijuana increases symptoms of cannabis dependence. *Drug Alcohol Depend.* 2008;95(3):199-208. doi:10.1016/j.drugalcdep.2008.01.011

46. Schauer GL, King BA, McAfee TA. Prevalence, correlates, and trends in tobacco use and cessation among current, former, and never adult marijuana users with a history of tobacco use, 2005-2014. *Addict Behav.* 2017;73:165-171. doi:10.1016/j.addbeh.2017.04.023

**SUPPLEMENT.**

eTable 1. Correlations between nicotine vaping and nicotine cannabis across waves

eTable 2. Model fit indices for nicotine vaping trajectories