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## Tobacco and cannabis poly-substance and poly-product use trajectories across adolescence and young adulthood

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### Abstract

Tobacco and cannabis poly-substance and poly-product use is common in adolescents and young adults (AYAs), but few studies have examined developmental trajectories of poly-use. This study characterized the prevalence, patterns, and racial/ethnic and sex differences of developmental trajectories of use and poly-use of 8 different widely-marketed tobacco and cannabis products across adolescence and young adulthood. 3322 AYAs from Los Angeles, California completed 5 surveys from fall of 11th grade (2015) to 1–2 years post-high school (2018–2019). Self-reported past 30-day use of three tobacco (nicotine vaping, cigarette, hookah) and five cannabis (combustible, blunt, edible, vaping, dabbing) products were analyzed using parallel growth mixture modeling to identify tobacco and cannabis use and poly-use trajectories; racial/ethnic and sex differences were evaluated as correlates of trajectory membership. Five trajectories were identified: Non-Users (58.6%); Young Adult-Onset Poly-Substance/Poly-Product Users (15.8%); Decreasing Moderate Poly-Substance/Poly-Product Users (9.8%); Increasing Predominant Cannabis Poly-Product Users (8.3%); and Chronic Poly-Substance/Poly-Product Users (7.3%). Within trajectories, developmental patterns of each tobacco and cannabis product were similar. Non-Hispanic White (vs. non-NH White) participants had higher odds of

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#### Credit author statement

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belonging to the Chronic Poly-Substance/Poly-Product Users (vs. Non-Users) trajectory (aOR = 2.24[1.37,3.67]); females (vs. males) had higher odds of belonging to the Young Adult-Onset Poly-Substance/Poly-Product Users (vs. Non-Users) trajectory (aOR = 1.30[1.02–1.66]). Tobacco and cannabis poly-substance use patterns, including use of various products, appear to be a common developmental trajectory during some point in adolescence and young adulthood. The interplay of tobacco and cannabis poly-substance/poly-product use merit attention in prevention and regulatory policies to protect AYA health.

## Keywords

Adolescence; Cannabis; Developmental trajectories; Poly-use; Nicotine/tobacco; Young adulthood

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## 1. Introduction

Recent increases in the diversity and overlap of products in the tobacco and cannabis marketplaces have important implications for the epidemiology of adolescent and young adult (AYA) tobacco and cannabis use. Nicotine vaping in AYAs has increased in recent years, while combustible cigarette and hookah use has decreased but remain unacceptably high (Johnston et al., 2020; Schulenberg et al., 2020). Along with the rapid increase in cannabis vaping in recent years, use of traditional combustible cannabis, edible cannabis, and cannabis dabbing (e.g., use of highly concentrated tetrahydrocannabinol - THC) has become increasingly prevalent (Johnston et al., 2020; Schulenberg et al., 2020; Knapp et al., 2019; Reboussin et al., 2019). The result of the current market raises the possibility for various types of poly-use patterns. Poly-product use patterns within substance classes (e.g., nicotine vaping and combustible cigarette, combustible cannabis and edible cannabis) have been widely reported in AYAs (Cho et al., 2018; Peters et al., 2018). Moreover, significant poly-use of tobacco and cannabis has been shown in adolescence and young adulthood (Dai, 2019; Nguyen et al., 2019; Tucker et al., 2019a). Given the many possible combinations of poly-use involving multiple tobacco and/or cannabis products, identifying homogenous subgroups with distinct longitudinal patterns of tobacco and cannabis use and poly-use is needed to inform the epidemiology of AYA tobacco and cannabis use.

Growth mixture modeling (GMM), a data-driven analytic approach for identifying unobserved subpopulations through distinct longitudinal growth trajectories (Muthén and Muthén, 2000; Wang and Bodner, 2007), has been used extensively to parsimoniously identify substance use trajectories in adolescence and young adulthood (Martineau and Cook, 2017; Park et al., 2020; Passarotti et al., 2015; Tucker et al., 2005). More recently, a parallel process approach to GMM has been utilized to account for heterogeneity in use and poly-use of multiple substances in adolescence, including tobacco (Cho et al., 2018), tobacco and cannabis (Cho et al., 2020; Dunbar et al., 2020), and alcohol, tobacco and cannabis (Richmond-Rakerd et al., 2016) trajectories. To date only one study (Richmond-Rakerd et al., 2016) has assessed poly-use trajectories (multiple tobacco products and combustible cannabis) across the transition from adolescence to young adulthood. Considering poly-use tobacco and cannabis trajectories during this sensitive developmental period, characterized by stressors related to entering college/and or the

workforce as well as increased familial and financial responsibility, is warranted. Shifts from experimental use in adolescence to more problematic, chronic and heavy poly-use in young adulthood is commonly observed (Palmer et al., 2009; Sussman and Arnett, 2014). This study aimed to extend past research by identifying use and poly-use trajectories of the most popular tobacco (nicotine vaping, cigarette, hookah) and cannabis (combustible, blunt, edible, vaping, dabbing) products across the transition from adolescence to young adulthood.

Beyond identification of poly-substance/poly-product trajectories, we sought to assess racial/ethnic and sex differences across trajectories as a preliminary step to identifying predictors of poly-use tobacco and cannabis trajectories. Available studies suggest that race/ethnicity and sex may differentiate membership in poly-use trajectories. In a recent study using latent growth modeling to identify poly-use of combustible cannabis and tobacco (cigarettes and smokeless) among AYAs, White participants had higher odds of belonging to a poly-use trajectory vs. Hispanic or Asian participants (Tucker et al., 2019b). Using a parallel process GMM to identify trajectories of tobacco (e-cigarette, cigarette, hookah, and cigar) and combustible cannabis across adolescence, Cho et al. (Cho et al., 2020) indicated that Asian (vs. Hispanic) adolescents had lower odds of belonging to an early initiation poly-use trajectory (vs. non-users). Evidence also suggests males (vs. females) are at greater risk of belonging to poly-use trajectories (alcohol, tobacco, cannabis) vs. non-using trajectories, as well as earlier vs. later poly-use (Richmond-Rakerd et al., 2016).

Using a prospective longitudinal design following a cohort of adolescents into young adulthood, we aimed to identify homogenous subgroups with distinct patterns of tobacco and cannabis product use and poly-use and assess racial/ethnic and sex differences of trajectory membership.

## 2. Methods

### 2.1. Participants and procedure

Data were from a prospective cohort study of high school students from the Los Angeles, California metropolitan area. Although assessment began in fall of 9th grade (2013; Wave 1), detailed assessment of cannabis product use was not introduced until fall of 11th grade (2015; Wave 5); thus, data used to model tobacco and cannabis trajectories spanned from Wave 5 (fall of 11th grade; 2015) to Wave 9 (young adulthood; 2018–2019). Students from 10 high schools were surveyed at six-month intervals from 9th grade (fall of 2013; Wave 1) through 12th grade (spring of 2017; Wave 8) using self-administered pencil-and-paper questionnaires in schools. Participants were surveyed again 1–2 years post-high school (2018–2019; Wave 9) through online questionnaires. There were 4100 students eligible to enroll in the study (all 9th graders at participant schools); parental consent and student assent were obtained for 3396 adolescents (82.8%) and participants were re-consented after turning 18 years of age. Just prior to Wave 7 (fall of 12th grade; 2016), California raised the age of tobacco use from 18 to 21 years; California legalized recreational cannabis use prior to Wave 9 (young adulthood; 2018–2019). The University of Southern California Institutional Review Board approved the study.

Of the 3396 participants originally enrolled in the study, the final analytic sample included 3322 respondents (97.8% of cohort enrollees). Missing data across each wave were: 4.0% at fall 11th grade ( $n = 134$ ); 7.7% at spring 11th grade ( $n = 257$ ); 5.4% at fall 12th grade ( $n = 179$ ); 6.4% at spring 12th grade ( $n = 213$ ); and 25.3% in young adulthood (1–2 years post-high school;  $n = 839$ ). Compared to participants with young adulthood data (Wave 9), participants without young adulthood data were less likely to have parents who attended college (64.1% vs. 72.0%;  $\chi^2 = 15.61, p < .001$ ), more likely to be male (60.3% vs. 42.0%;  $\chi^2 = 86.63, p < .001$ ), and less likely to be Asian (12.8% vs. 18.2%;  $\chi^2 = 12.65, p < .01$ ). Substance use at the end of high school (spring of 12th grade-Wave 8) did not significantly differ between those missing young adulthood data vs. non-missing, except on cigarette smoking (7.7% vs. 5.3%;  $\chi^2 = 5.45, p < .05$ ) and cannabis dabbing (10.9% vs. 6.8%;  $\chi^2 = 12.04, p < .01$ ).

## 2.2. Measures

**2.2.1. Tobacco and cannabis product use**—Frequency of tobacco (nicotine vaping, cigarette, hookah) and cannabis (combustible, blunt, edible, vaping, and dabbing) product use was assessed at Waves 5–9, except for dabbing, which was not available until spring 11th grade-Wave 6. At each wave, participants completed separate items assessing the number of days of use in the past 30-days for each of the 8 tobacco/cannabis products (e.g., “In the last 30 days, how many total days have you used cigarettes (Marlboro, Camel, Newport, etc.)?”; “In the last 30 days, how many total days have you used an electronic device to vape THC or hash oil (liquid pot, cannabis oil, weed pen, PAX Era)?”). Between waves, questions were reviewed to ensure product examples reflected language commonly used by AYAs at the time of assessment. This resulted in the addition of examples across waves (e.g., cannabis oil added to descriptors of cannabis vaping, JUUL use added to measure nicotine vaping). Due to low cell counts for high-frequency use patterns, responses for use of each tobacco and cannabis product were recoded into dichotomous variables (any use in the past 30-days; yes [≥ 1 day] vs. no [0 days]).

**2.2.2. Correlates**—Age, highest parental education level, race/ethnicity, and sex were self-reported (see Table 1). Highest parental education level was recoded into a binary variable (some college vs. < some college). Race/ethnicity was recoded into three dummy variables (1 = Asian, 0 = non-Asian; 1 = Hispanic/Latino, 0 = non-Hispanic/Latino; 1 = non-Hispanic (NH) White, 0 = non-NH White) for racial/ethnic groups representing 10% of the sample (Asian, Hispanic/Latino, White). Lifetime tobacco use and cannabis use (1 = yes, 0 = no) at baseline (fall of 9th grade-Wave 1) were also included as correlates.

**2.2.3. Analysis plan**—We used parallel process GMM, for which each tobacco and cannabis product was simultaneously modeled as a unique growth process producing 3 growth factors (i.e., intercept, linear and quadratic slopes [rate of change across the five time points]) (Muthén, 2002; Wu et al., 2010). The model estimated trajectory groups based on covariation across the eight distinct sets of growth factors (i.e., one set of growth factors – intercept, linear, quadratic – per product, 24 total factors); unequal time between spring of 12 grade-Wave 8 and young adulthood-Wave 9 was accounted for in the model. GMM uses a data-driven approach to estimate trajectory classes; classes are not identified a

priori but rather derived from the unobserved heterogeneity in the population. An increasing number of trajectory classes were estimated until an optimal model was identified using statistical fit indices, including the Bayesian Information Criterion (BIC) (Schwartz, 1978) and Lo-Mendell Rubin Likelihood Ratio Test (LMR LRT) (Lo et al., 2001), as well as class interpretation and parsimony. Full information maximum likelihood was used to account for missing data. Correlates of identified trajectories were evaluated within the GMM framework using a validated 3-step approach to account for classification error (Asparouhov and Muthén, 2014). After the best fitting class model was chosen, a most likely latent class variable was created using the latent class posterior probabilities. Logits reflecting the classification uncertainty rate were applied to account for measurement error in the most likely class variable. The most likely class variable was then used to assess covariates of trajectory membership. Analyses were conducted with Mplus 8.4 (Muthén, 2017).

### 3. Results

#### 3.1. Descriptive statistics

Table 1 presents demographic information and past 30-day tobacco/cannabis prevalence across waves. Participants were 53.5% female; 47.4% Hispanic/Latino, 16.6% Asian, 16.0% non-Hispanic White; and the mean (SD) age at fall 11th grade was 16.5 (0.4) years. Across all waves, combustible cannabis had the highest past 30-day prevalence (13.0%–28.7%); hookah use had the lowest past 30-day prevalence (2.5%–3.5%).

#### 3.2. Tobacco and cannabis use and poly-use trajectories

**3.2.1. Model selection**—Model fit was evaluated across an increasing number of trajectory classes. Based on statistical indices (Table 2), class interpretability, and parsimony, the five-class model was identified as best-fitting the data. The LMR LRT indicated that the five-class model was ideal; the LMR LRT was not significant past the five-class solution. Although the five-class model did not have the lowest BIC or adjusted-BIC values, the BIC values leveled off between the four- and five-class models. This leveling-off, along with consideration of class interpretation (distinct and homogenous classes) and parsimony, resulted in identifying the five-class model as optimal. Fig. 1 presents the probability of past 30-day use of each tobacco and cannabis product for each identified trajectory.

**3.2.2. Identified trajectories**—Non-Users (58.6%) comprised the largest trajectory class. This trajectory was virtually entirely comprised of no tobacco or cannabis product use across waves (Fig. a). Probability of tobacco and cannabis product use was negligible across waves (<4%).

The Young Adult-Onset Poly-Substance/Poly-Product Users trajectory (15.8%) was characterized by relatively low rates of tobacco and cannabis use in adolescence followed by a significant acceleration in use during young adulthood (Fig. b). The increasing rate of change between spring 12th grade-Wave 8 and young adulthood-Wave 9 probability of use resulted in significant quadratic means for all tobacco and cannabis products. The largest rate of change was observed for combustible cannabis (23.0% to 90.8%;  $p < .001$ ), cannabis vaping (2.6% to 69.3%;  $p < .001$ ), blunt use (9.1% to 72.2%;  $p = .005$ ), edible cannabis

(7.2% to 53.1%;  $p < .001$ ), and nicotine vaping (7.1% to 47.1%;  $p < .001$ ). Smaller increases between late adolescence and young adulthood were observed for cannabis dabbing (0.3%–24.0%;  $p = .02$ ), cigarette smoking (2.8% to 16.4%;  $p = .03$ ), and hookah use (1.4% to 7.6%;  $p = .003$ ).

The Decreasing Moderate Poly-Substance/Poly-Product Users trajectory (9.8%) reflected lower probability of tobacco and cannabis use that gradually decreased across waves (Fig. c). Probability of tobacco and cannabis use was under 25% in fall of 11th grade-Wave 5 for every product except combustible cannabis (37.8%). By young adulthood-Wave 9, probability of all product use had decreased to 10% except for nicotine vaping (29.5%). Combustible cannabis ( $p = .001$ ), blunt use ( $p = .002$ ), and edible cannabis ( $p < .001$ ) followed similar decelerating trajectories. A significant decrease was also observed for hookah use ( $p = .01$ ). Cigarette smoking, cannabis vaping, and cannabis dabbing use remained low (< 10%) and stable across waves. For nicotine vaping, decreased use was initially observed, but was followed with an increase resulting in similar probabilities of use between fall of 11th grade-Wave 5 (17.9%) and young adulthood-Wave 9 (19.5%;  $p < .001$ ).

The Increasing Predominately Cannabis Poly-Product Users trajectory (8.3%) exhibited a steady increase in probability of use of most cannabis products across waves with more subtle increases in use of certain tobacco products, except for a significant increase in nicotine vaping from late adolescence to young adulthood (Fig. d). Significant increases in probability of use between fall of 11th grade-Wave 5 and young adulthood-Wave 9 were observed for blunt use (12.0% to 92.0%;  $p < .001$ ), cannabis vaping (0.8% to 78.8%;  $p = .004$ ), combustible cannabis (28.3% to 98.9%;  $p = .004$ ), and edible cannabis (9.8% to 60.9%;  $p < .001$ ). A significant increase was observed for cannabis dabbing from spring 11th grade-Wave 6 to young adulthood-Wave 9; 1.4% to 44.9%;  $p < .001$ ). Nicotine vaping remained stable early on (9.2%–11.3%, fall 11th grade-Wave 5 to fall 12th grade-Wave 7) but significantly increased during late adolescence (18.5% spring 12th grade-Wave 8) into young adulthood (58.6%;  $p < .001$ ). Although not significant, increases in cigarette smoking (5.2% to 38.7%) and hookah use (2.6% to 13.1%) were also observed across waves.

The smallest trajectory group, Chronic Poly-Substance/Poly-Product Users (7.3% of the sample), was comprised of persistently high probability of use for various tobacco and cannabis products throughout most of the study period (Fig. e). Probability of use was highest for combustible cannabis, which ranged from 79.1%–92.4% across waves. Blunt use was also high across waves (above 70%) and followed a similar pattern to combustible cannabis. Edible cannabis and cannabis dabbing remained at about 55–65% across the study period. A significant increase (40.9% fall of 11th grade-Wave 5 to 67.6% young adulthood-Wave 9) was observed for cannabis vaping ( $p = .001$ ). Nicotine vaping was stable across adolescence (32.9–41.2%) but significantly increased in young adulthood to 67.6% ( $p < .001$ ). Cigarette smoking (31.4%–45.4%) and hookah use (15.8%–22.8%) remained stable across waves; hookah use had the lowest probability of use of any tobacco and cannabis product.



### 3.3. Correlates of tobacco and cannabis use and poly-use trajectories

Covariates were added to the parallel process GMM to determine the odds of trajectory membership in each of the four substance-using trajectories vs. the Non-Users trajectory (Table 3). Females (aOR = 1.30 [1.02,1.66]), as well as participants with parents that attended at least some college (aOR = 1.39[1.03,1.88]) had higher odds of belonging to the Young Adult-Onset Poly-Substance/Poly-Product Users vs. Non-Users trajectory. Asian (aOR = 0.67[0.46,0.97]) and Latino (aOR = 0.68[0.49,0.95]) participants had lower odds of belonging to the Young Adult-Onset Poly-Substance/Poly-Product Users vs. Non-Users trajectory. Non-Hispanic White participants had higher odds of membership in the Chronic Poly-Substance/Poly-Product Users (aOR = 2.24 [1.37,3.67]) vs. Non-Users trajectory. Baseline lifetime tobacco use (Young Adult-Onset: aOR = 2.57[1.88,3.53]; Decreasing Moderate: aOR = 3.41[2.33,4.99]; Increasing Predominately Cannabis: aOR = 4.70[3.19,6.92]; Chronic: aOR = 8.91[5.80,13.69]) and cannabis use (Decreasing Moderate: aOR = 3.46[2.22,5.40]; Increasing Predominately Cannabis aOR = 2.51[1.59,3.95]; Chronic: aOR = 4.27 [1.72,6.71]) predicted membership across all substance-using trajectories vs. Non-Users, with the exception that lifetime cannabis use did not predict to the Young Adult-Onset Poly-Substance/Poly-Product Users trajectory.

## 4. Discussion

The current study advanced understanding of the epidemiology of tobacco and cannabis poly-use in AYAs by identifying developmental trajectories of use and poly-use of 8 different tobacco and cannabis products across adolescence and young adulthood. There are thousands of possible configurations of use and poly-use of the various tobacco and cannabis products available on the marketplace and how these use patterns emerge across development. Using a parallel approach to GMM, this study reduced this variation into a parsimonious model that identified 5 distinct underlying subpopulations of use and poly-use: 1) Non-Users (58.6%); 2) Young Adult-Onset Poly-Substance/Poly-Product Users (15.8%); 3) Decreasing Moderate Poly-Substance/Poly-Product Users (9.8%); 4) Increasing Predominately Cannabis Poly-Product Users (8.3%); and 5) Chronic Poly-Substance/Poly-Product Users (7.3%). These developmental patterns indicate a significant proportion of youth who are at risk for poly-substance and poly-product use across adolescence and young adulthood. A more comprehensive, integrative approach to both tobacco and cannabis prevention and regulation in adolescence and young adulthood is warranted.

A take home message from the study is that a substantial proportion of AYAs may be at risk for poly-use of various tobacco and cannabis products, which varied distinctly by developmental timing (e.g., young adult-onset) and prevalence (chronically high, increasing across time). Though tobacco-only or cannabis-only use is possible, single-substance use in this study was too rare to emerge as a standalone trajectory, indicating that poly-substance use may be the normative pattern of tobacco or cannabis use in AYAs. Given the proportion of AYAs engaging in tobacco and cannabis poly-use observed in this study and two previous developmental trajectory studies reporting substantial proportions of tobacco and cannabis poly-use in AYAs<sup>16,17</sup>, it is critical for public health efforts to address the widespread tobacco and cannabis poly-use occurring in adolescence and young adulthood. This is

particularly important as tobacco and cannabis poly-users are at greater risk of deleterious health outcomes compared to single-substance users, including cognitive deficits, mental health impairments, and greater substance dependence (Schulte and Hser, 2013; Ream et al., 2008; Schauer et al., 2017).

Although timing of use differed across the Young Adult-Onset Poly-Substance/Poly-Product Users, Increasing Predominately Cannabis Poly-Product Users, and Chronic Poly-Substance/Poly-Product Users trajectories, AYAs in all three subgroups reported concerning poly-substance/poly-product use as they transitioned from adolescence into young adulthood. For example, during a period characterized by significant changes to higher-order neuro-cognitive processes (Galván and Tottenham, 2016), combustible cannabis, linked to deficits in decision-making, sustained attention, and planning (Lisdahl et al., 2014), had the highest probability of use of any substance/product across all three subgroups. Acknowledging that policies and interventions focused on changing context can be effective at decreasing health-risk behaviors (Steinberg, 2015), increased tobacco/cannabis regulatory efforts aimed at restricting youth consumption may prevent escalating poly-substance/poly-product use for those in the Increasing Predominately Cannabis trajectory, adolescent substance use treatment services may best serve adolescents in the Chronic Poly-Substance/Poly-Product Users trajectory, and prevention programs aimed at increasing resources to cope with the transition to young adulthood may offset poly-substance-poly-product use in the Young Adult-Onset trajectory. Furthermore, though there were only a handful of demographic differences across trajectories, findings suggest that prevention/interventions efforts may benefit by targeting certain groups during specific developmental periods (e.g., White AYAs in early adolescence to buffer chronic poly-substance/poly-product use, females during the transition to young adulthood when they may be vulnerable to poly-substance/poly-product use onset). Given that prior literature on White youth suggest contextual variables like deviant peer affiliation and poor parental monitoring may underlie chronic poly-use (Kennedy et al., 2016; Osman et al., 2018) and later onset poly-use in women may be a response to trauma or negative affect (McHugh et al., 2018), future work should seek to identify the underlying processes that distinguish poly-substance/poly-product use trajectories.

Another overarching result was that the timing of use of various tobacco and cannabis products generally followed very similar developmental patterns within trajectory subgroups. Nowhere was this observed as clearly as in the Young Adult-Onset Poly-Substance/Poly-Product Users trajectory. Although the probability of use in young adulthood varied somewhat by product, the growth trajectory for every tobacco and cannabis product showed a significant increase in use from late adolescence into young adulthood. Like the current study, Dunbar et al. (Dunbar et al., 2020) identified a trajectory profile characterized by low tobacco and cannabis co-use in adolescence followed by an increase in young adulthood; this trajectory subgroup also comprised a significant proportion of their sample (28.9%). Although it is possible that a cohort effect may have resulted in increased use of tobacco and cannabis use during the young adulthood wave, which spanned 2018–2019 when “pod” vaporizers like JUUL and disposable vaporizers surged in popularity and marijuana use in California was legalized (Barrington-Trimis and Leventhal, 2018; Delnevo et al., 2020; Smart and Pacula, 2019), the corroboration of a young adult-onset trajectory



in Dunbar et al. (Dunbar et al., 2020) suggests a potentially significant number of young adults initiating tobacco and cannabis use are being overlooked by public health efforts focused on adolescent poly-use. Research is needed to elucidate why some individuals may be more vulnerable to tobacco and cannabis poly-use in young adulthood but not adolescence, as they may not follow previously established adolescent pathways to poly-use such as lack of school connectedness, poor academic achievement, and unstable family support (Tomczyk et al., 2016; Zuckermann et al., 2020). For example, though baseline cannabis use predicted to the Chronic, Increasing Predominately Cannabis, and Decreasing Moderate trajectories vs. Non-Users trajectory, it did not predict membership in the Young Adult-Onset trajectory, highlighting the need to better understand the epidemiological distinctions between adolescent and young adult substance use. Additional longitudinal studies following adolescents into young adulthood are essential to understanding the epidemiology of poly-substance/poly-product use.

Limitations of this study should be considered. The use of a sample specific to Southern California limits generalizability of findings to other regions; however, a regionally-specific sample increases the likelihood that participants were exposed to similar tobacco and cannabis regulatory policies and trends during assessment. The study relied on self-report of past 30-day tobacco and cannabis use, though self-report is the most common method of measuring substance use behaviors. There was greater missing data in the young adulthood wave than adolescent waves; however, full information maximum likelihood enabled participants with at least one wave of data to be analyzed. Although the sample was racially/ethnically diverse in terms of Latino/Hispanic, Asian-American, and Non-Hispanic White, evaluating racial/ethnic differences among African-American/Black or multiracial vs. other ethnicities was not feasible due to low cell counts for these groups resulting in problematic standard errors. Though this prospective cohort study has comprehensive information on substance use, it lacks data on school and family variables that likely differentiate membership between poly-product/poly-use trajectories; in-depth measures of multiple contexts and health behaviors should be a priority for epidemiological studies capturing the transition from adolescence to young adulthood.

## 5. Conclusions

In this study of tobacco and cannabis use and poly-use trajectories, over 40% of AYAs were classified into one of four poly-using trajectories involving use of multiple tobacco and cannabis products, including a sizeable subgroup characterized by substantial increases in poly-use after adolescence. White AYAs were disproportionately represented in a chronic poly-substance/poly-product use trajectory while females were more likely to belong to a poly-substance/poly-product trajectory characterized by young adult-onset, suggesting regulatory and prevention efforts should consider when to target specific demographic groups. Prevention/intervention efforts and regulatory policies may need to consider tobacco and cannabis poly-use as a normative substance-using trajectory (vs. single-substance use) in adolescence and young adulthood. Further research on the determinants and health consequences of tobacco and cannabis poly-use trajectories is needed to understand targets for intervention, policy priorities for reducing poly-use, and important distinctions between

adolescent and young adult poly-use, especially as the tobacco and cannabis marketplace continues to evolve.

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## Fig a-e

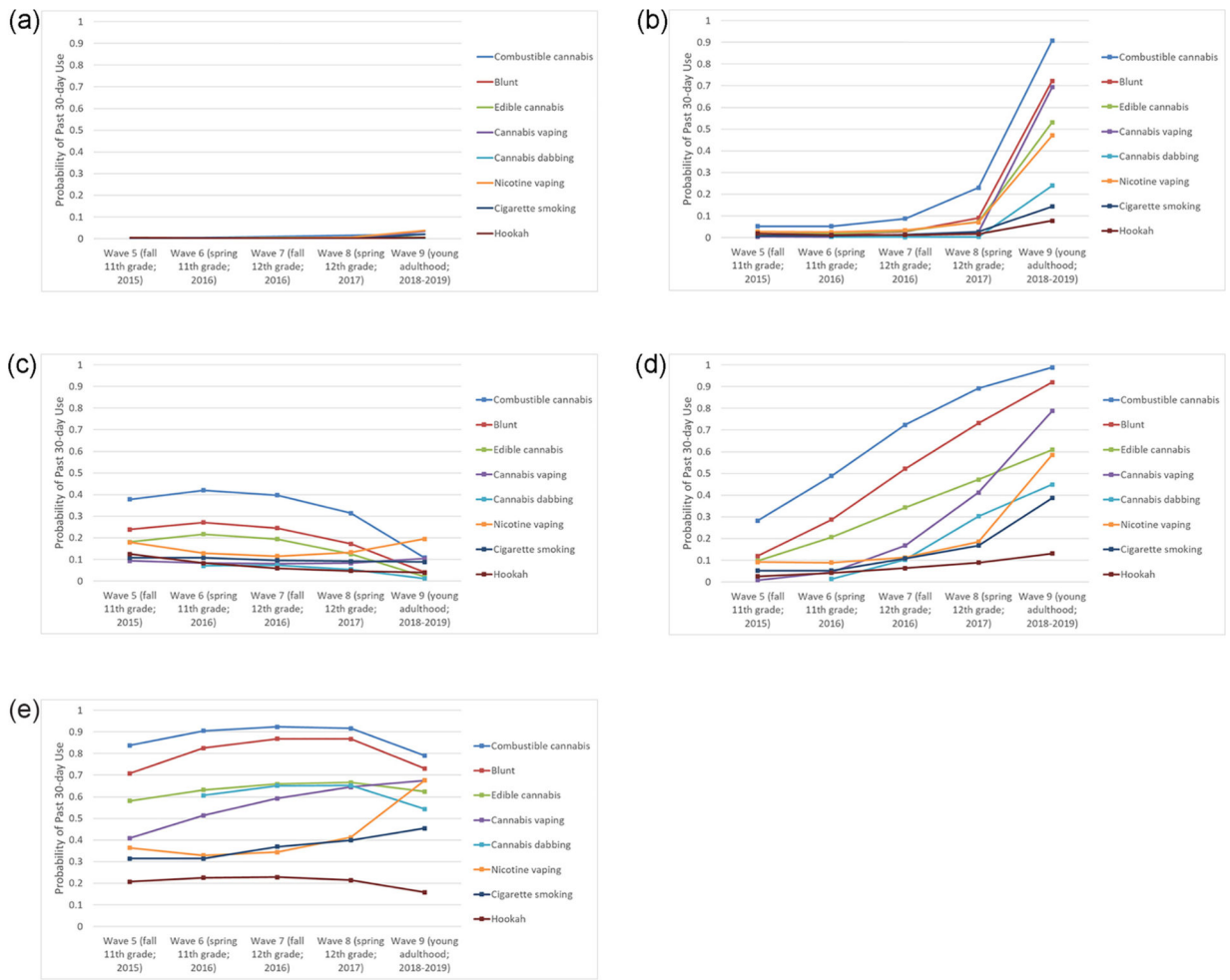
- a. Non-Users (N = 1948; 58.6%).
- b. Young Adult-Onset Poly-Substance/Poly-Product Users (N = 526; 15.8%).
- c. Decreasing Moderate Poly-Substance/Poly-Product Users (N = 327; 9.8%).
- d. Increasing Predominately Cannabis Poly-Product Users (N = 277; 8.3%).
- e. Chronic Poly-Substance/Poly-Product Users (N = 244; 7.3%).

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**Fig. 1.**  
Tobacco and Cannabis Use and Poly-use Trajectories.

**Table 1**Descriptive characteristics ( $N = 3322$ ).

<b>Demographics</b>	<b>N(%) or Mean <math>\pm</math> SD</b>				
Age at baseline (fall of 11th grade)	16.50 $\pm$ 0.42				
Parent highest education level					
Some college	2014 (60.6%)				
Some college	856 (25.8%)				
Unknown	452 (13.6%)				
Gender					
Female	1777 (53.5%)				
Male	1544 (46.5%)				
Ethnicity					
American Indian/Alaska	34 (1.0%)				
Native	551 (16.6%)				
Asian	161 (4.8%)				
Black/African American	1573 (47.4%)				
Hispanic/Latino	138 (4.2%)				
Hawaiian/Pacific	533 (16.0%)				
Islander					
Non-Hispanic White	49 (1.5%)				
Multiracial	67 (2.0%)				
Other					
Unknown					
<b>Past 30-day tobacco and Cannabis use</b>	<b>Fall 11th grade<sup>a</sup></b>	<b>Spring 11th grade<sup>b</sup></b>	<b>Fall 12th grade<sup>c</sup></b>	<b>Spring 12th grade<sup>d</sup></b>	<b>Young adulthood<sup>e</sup></b>
Nicotine Vaping	183 (5.7%)	167 (5.4%)	139 (4.4%)	232 (7.5%)	547 (22.0%)
Cigarette smoking	130 (4.0%)	119 (3.9%)	132 (4.2%)	181 (5.8%)	219 (8.8%)
Hookah	113 (3.5%)	92 (3.0%)	80 (2.5%)	103 (3.3%)	85 (3.4%)
Combustible Cannabis	413 (13.0%)	493 (16.1%)	528 (16.8%)	688 (22.1%)	712 (28.7%)
Blunt	259 (8.1%)	339 (11.1%)	385 (12.2%)	498 (16.0%)	541 (21.8%)
Edible Cannabis	223 (7.0%)	280 (9.1%)	274 (8.7%)	365 (11.7%)	374 (15.1%)
Cannabis Vaping	134 (4.2%)	137 (4.7%)	176 (5.6%)	306 (9.8%)	599 (24.1%)
Cannabis dabbing	-	153 (5.0%)	178 (5.7%)	239 (7.7%)	245 (9.9%)

<sup>a</sup>Percentage based on 3188 responses at fall 11th grade.<sup>b</sup>Percentage based on 3065 responses at spring 11th grade.<sup>c</sup>Percentage based on 3143 responses at fall 12th grade.<sup>d</sup>Percentage based on 3109 responses at spring 12th grade.<sup>e</sup>Percentage based on 2483 responses at young adulthood (1–2 years post-high school).



**Table 2**

Model fit indices for tobacco and cannabis use and poly-use trajectories.

Trajectory#	AIC <sup>a</sup>	BIC <sup>b</sup>	Adjusted BIC <sup>c</sup>	LMR LRT <i>p</i> -value for <i>k</i> -1 <sup>d</sup>	Entropy
1	67,464.59	67,611.20	67,534.94	N/A	N/A
2	50,078.71	50,378.02	50,222.32	< 0.0001	0.95
3	46,133.33	46,595.34	46,360.21	< 0.0001	0.91
4	44,966.07	45,570.80	45,256.23	< 0.0001	0.90
5	43,972.26	44,729.70	44,335.69	< 0.0001	0.89
6	43,468.93	44,379.07	43,905.63	0.7621	0.89
7	43,137.80	44,200.65	43,647.78	0.7544	0.89

<sup>a</sup>AIC = Akaike information criterion.

<sup>b</sup>BIC = Bayesian information criterion.

<sup>c</sup>Sample-size adjusted Bayesian information criterion.

<sup>d</sup>LMR LRT = Lo-Mendell-Rubin likelihood ratio test, *p*-value for *k*-1 refers to significant improvement in model fit between the class (*k*) and the class preceding it (*k*-1).

**Table 3**

Estimated adjusted Odds Ratios (OR) of tobacco and cannabis use and poly-use trajectory membership.

	Young adult-onset Poly-substance/poly-product Vs non-users	Decreasing moderate Poly-substance/poly-product users Vs non-users	Increasing predominately Cannabis Poly-product users Vs non-users	Chronic Poly-substance/poly-product users Vs non-users
	OR(95%CI)	OR(95%CI)	OR(95%CI)	OR(95%CI)
Age (years) at baseline	0.80(0.59–1.09)	1.33(0.89–1.98)	0.76(0.49–1.18)	1.13(0.74–1.71)
Highest parental education level <sup>a</sup>	1.39(1.03–1.88)	1.02(0.72–1.43)	0.15(0.81–1.62)	1.31(0.85–2.01)
Female vs. male	1.30(1.02–1.66)	1.00(0.73–1.37)	0.93(0.69–1.27)	0.73(0.52–1.02)
Race/Ethnicity <sup>b</sup>				
Asian vs. non-Asian	0.67(0.46–0.97)	0.38(0.20–0.71)	0.73(0.40–1.32)	0.55(0.28–0.1.10)
Latino vs. non-Latino	0.68(0.49–0.95)	0.88(0.59–1.32)	1.20(0.76–1.90)	0.83(0.51–1.36)
NH <sup>c</sup> White vs. non-NH White	0.70(0.48–1.04)	0.61(0.36–1.05)	1.34(0.79–2.27)	2.24(1.37–3.67)
Lifetime tobacco use at baseline (wave 1)	2.57(1.88–3.53)	3.41(2.33–4.99)	4.70(3.19–6.92)	8.91(5.80–13.69)
Lifetime Cannabis use at baseline (wave 1)	1.19(0.73–1.93)	3.46(2.22–5.40)	2.51(1.59–3.95)	4.27(1.72–6.71)

<sup>a</sup>Highest parental education level was college degree or higher vs. some college or less.

<sup>b</sup>Race/ethnicity modeled as dummy-coded variables.

<sup>c</sup>Non-Hispanic.