Developmental Trajectories of Tobacco/Nicotine and Cannabis Use and Patterns of Product Co-use in Young Adulthood

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ABSTRACT

INTRODUCTION: Concurrent co-use of tobacco/nicotine and cannabis (T/C) products is common among young people and may increase risks for negative health and psychosocial outcomes, but little is known about developmental patterns of T/C co-use. This study aimed to identify distinct trajectory classes of concurrent T/C co-use from ages 16 to 21 and compare groups on T/C co-use behaviors in young adulthood.

METHODS: Participants (n = 2497) reported T/C use on annual online surveys from 2015 to 2019 (ages 16-22). We used parallel process growth mixture models to model simultaneous trajectories of past-month cigarette, e-cigarette, smokeless tobacco, and cannabis use and identify latent classes of T/C trajectories. Classes were then compared on types and number of T/C products used and types of T/C co-use in young adulthood.

RESULTS: Models revealed 4 T/C classes: *Low/No T/C Use, Early Concurrent T/C Co-use, Late Concurrent T/C Co-use*, and *Tobacco Quitters/Cannabis Maintainers*. Compared to other classes, the *Early Concurrent T/C Co-use* group—individuals with rapid progression to concurrent T/C co-use during adolescence—were more likely to report poly-tobacco use, poly-cannabis use, same-occasion sequential T/C co-use and T/C co-administration (ie, mixing T/C) of both combustible and vaping products in young adulthood.

CONCLUSION: Early progression to concurrent T/C co-use in adolescence is prospectively linked to poly-product use and co-use of T/C products in young adulthood. Prevention efforts targeting co-use of T/C products in adolescence may help to reduce riskier patterns of T/C use and co-use in young adulthood.

KEYWORDS: Tobacco, cannabis, marijuana, developmental trajectories, co-use, young adulthood

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Introduction

Concurrent co-use of both tobacco/nicotine and cannabis (T/C) products, defined as using T/C within the same period of time (eg, the past month or year), is highly prevalent among 18 to 24-year-olds. Over 1-in-5 individuals in this age group (21%) report current (past-month) use of both types of substances.[1] In addition, recent data suggest that rates of concurrent T/C co-use may be greater in states where cannabis is legally accessible.[2] The period from middle school through young adulthood represents a critical window of escalation for both drugs,[3,4] and evidence suggests that developmental trajectories of T/C use are interrelated.[5] For example, longitudinal studies show that more frequent cannabis use is associated with subsequent tobacco initiation, greater nicotine dependence,[6,7] and decreased likelihood of cigarette smoking cessation.[8-10] However, little is known about how different trajectories of T/C use during adolescence predict patterns of T/C use once individuals transition into young adulthood and can legally purchase these products (ie, at age 21 and above) in many parts of the United States (U.S.).

Recent changes in the product and regulatory landscapes for T/C in the U.S., such as greater accessibility of electronic nicotine delivery systems (ENDS) and spreading legalization of medical and recreational cannabis, have increased the range of products/devices available to consume these drugs. Data also suggest that use of multiple types of tobacco/nicotine products (ie, poly-tobacco use) has become more common than single-product use among young adults.[11,12] In the nationally representative Population Assessment of Tobacco and Health Study, 22% of 18 to 24 year-olds reported using 2 or more different types of tobacco/nicotine products (compared to approximately 18% for single-product use), with use of combustible cigarettes + ENDS as the dominant pattern of poly-tobacco use. Moreover, poly-tobacco use was more common among those who also engaged in past-month cannabis use.[12] High rates of poly-tobacco use—specifically in the context of combustible

product use—warrants serious concern given the potential for increased exposure to nicotine and other compounds[13] and risks of nicotine dependence.[14,15] Similarly, poly-cannabis use is widespread, with national survey data indicating that over 40% of adults who use cannabis report use of 2 or more products/modes (eg, joint, edible/beverage, vaping device) in the past month.[16] Mirroring findings for tobacco/nicotine products, 2 recent studies of adolescents and young adults in California found that poly-cannabis use was more common than single-product use.[17,18] As with tobacco/nicotine, increases in poly-cannabis use are concerning due to potential for greater exposure to a range of psychoactive and other harmful compounds, which could affect dependence and consequences from use.[19]

Increased diversification of products has also led to more ways to co-use T/C products in combination. For example, use of nicotine and cannabis vaping products has become increasingly widespread in recent years. Over 1-in-4 young adults ages 18 to 24 report vaping nicotine in the past month.[20-22] Similarly, data from the nationally representative Monitoring the Future (MTF) study showed a more than 50% increase in cannabis vaping among 12th graders between 2017 and 2018 (4.9% to 7.5%),[22] and other studies suggest increasing rates of cannabis vaping among young people who live in states where cannabis is legal.[23] Most studies have focused on co-use of combustible tobacco cigarettes and combustible cannabis.[24-27] Despite the increasing popularity of vaping products, recent longitudinal studies have not considered their use when characterizing longitudinal patterns of T/C co-use in young people, which may lead to mischaracterizations with respect to longitudinal T/C co-use patterns.[28,29] However, some recent cross-sectional work has begun to assess co-use with respect to vaping and other types of T/C products. For example, Nguyen and colleagues examined cross-sectional associations between past-month use of different types of tobacco/nicotine products and cannabis products in California youth and young adults, and found that concurrent use of ENDS + combustible cannabis and tobacco cigarettes + combustible cannabis were the most frequently reported product combinations.[17] Similarly, another cross-sectional study of young adults reported that, despite widespread availability of non-combustible T/C products, combustible methods were the most commonly-endorsed among individuals reporting past-year T/C use.[29] This is concerning because combustible product use—specifically, cigarette smoking—is associated with serious health consequences. For example, combustible tobacco use accounts for the bulk of tobacco-related death and disease.[30] In contrast, although long-term health effects are yet unknown, available data suggest that nicotine vaping is associated with lower exposure to a range of toxins and is almost certainly less harmful to health compared to combustible tobacco use.[13,31,32] Given known risks associated with combustible products,[30] assessing patterns of combustible versus other types of T/C product co-use has implications for understanding potential health effects from combining T/C products.

Additionally, most research to date has focused on *concurrent* use; [1,24,25,33] however, emerging data indicate that using T/C products *in combination* during the same use episode may be particularly risky. Recent work suggests that young people who use T/C products during the same occasion, via *sequential use* (ie, using 1 drug right after the other) or *co-administration* (ie, mixing T/C together in the same delivery device, such as a joint or blunt), report poorer mental and physical health and higher engagement in delinquent behaviors compared to those who use T/C products concurrently, but on separate use occasions.[29] Thus, in addition to examining different types of T/C product combinations, such as combustible versus non-combustible T/C co-use, assessing different types of co-use of these drugs is also important for understanding risk profiles. To date, no studies have examined how different developmental trajectories of both tobacco/nicotine use *and* cannabis use over the course of adolescence are prospectively associated with different types of T/C product use and riskier T/C co-use patterns, such as same-occasion T/C co-use, in young adulthood. Such data are critical for informing prevention and regulatory efforts in an era of increasing T/C product access and diversity.

This study extends previous research in this area by examining T/C use trajectories from high school (age 16) through young adulthood (age 21) to identify distinct developmental trajectories based on cigarette, ENDS, smokeless tobacco and cannabis use. This approach allows us to discern heterogeneity in developmental trajectories of—or progression toward–concurrent T/C co-use. We then assess group differences across specific types of T/C products used (eg, combustible products; vaping products), number of products used, and same-occasion co-use (both sequential co-use and co-administration) of T/C products in young adulthood (ages 21+). In addition, we examine comparisons across emergent groups on self-reported changes in use of any cannabis, as well as T/C vaping products, following legalization of recreational cannabis in California as of January, 2018. We hypothesized that compared to other use classes, individuals with earlier onset and stable trajectories of concurrent T/C co-use over time would be more likely to: 1) engage in poly-tobacco and poly-cannabis use; 2) report same-occasion co-use of T/C products; and 3) use combustible T/C products in young adulthood.

Methods

Sample and procedures

Participants were from 2 cohorts of students in 6th and 7th grade in 2008 (n = 6509), initially recruited from 16 middle schools in Southern California to evaluate the CHOICE substance use prevention program.[34] Cohorts were followed annually across 11 waves, through 2019. All participants consented to the study, and procedures were approved by the RAND Human Subjects Protections Committee (institutional review board). Procedures are reported in detail elsewhere.[34] Briefly, participants completed waves 1 through 5 during PE classes at 16

middle schools. Adolescents transitioned from middle school to over 200 high schools following wave 5 and were subsequently re-contacted and re-consented to complete annual web-based surveys. At wave 6 (Spring 2013-Spring 2014), 61% of the sample participated in the follow-up survey. At subsequent annual assessments, retention rates ranged from 80% to 92%. At wave 11, fielded in 2018 to 2019, 2497 participants completed the survey. Substance use at wave 10 did not predict attrition at wave 11, similar to what we have found at earlier waves[35]; however, from wave 10, slightly more women (94%) then men (91%) were retained at wave 11, and individuals who were slightly younger at wave 10 were more likely to be retained at wave 11 (mean age 20.6 retained vs mean age 20.9 not retained). There were no differences in retention rates by race/ethnicity. The current study focuses on waves 7 (fielded 2015-2016) through 11 (fielded 2018-2019), corresponding to the period from high school to young adulthood. Because data were set up with naturally occurring cohorts (age), we used an accelerated longitudinal cohort design. This creates a pattern of planned missing data, such that participants only have data for time points they are in the study, which allows us to model developmental trajectories of T/C use across ages 16 to 21 and examine prospective associations of T/C trajectories with distal outcomes in study wave 11, when participants were ages 21 and older.

Measures

Socio-demographics and race/ethnicity. Variables included self-reported age, gender, mother's education, and race/ethnicity. Participants were classified into 1 of 6 racial/ethnic groups: Hispanic, non-Hispanic white (reference group), non-Hispanic black, Asian/Pacific Islander, multi-racial (more than 1 race/ethnicity), and other.

Tobacco/nicotine and cannabis use trajectories from ages 16 to 21. Tobacco/nicotine (ie, cigarettes, e-cigarettes, and smokeless tobacco) and cannabis ("marijuana") use were assessed by asking: "During the past month, how many days did you use (cigarettes; e-cigarettes; smokeless tobacco [dip, chew or snuff]); (marijuana [pot, weed, grass, hash, bud, sins])?" Response options were 0 days, 1 day, 2 days, 3 to 5 days, 6 to 9 days, 10 to 19 days, and 20 to 30 days. Due to considerable skew and predominance of low-frequency responses in earlier waves, responses were dichotomized to indicate any (1) versus no (0) use.[35] Participants were classified at each wave as engaging in *tobacco use (or not)* and *cannabis use (or not)* in the past 30 days.

Tobacco/nicotine and cannabis distal outcomes. To characterize patterns of T/C product use in young adulthood, we examined 4 domains for tobacco/nicotine and cannabis: (1) past-month use of any type of product (coded 0 = no, 1 = yes); (2) past-month use of combustible products (coded 0 = no, 1 = yes); (3) past-month use of vaping products (coded 0 = no, 1 = yes); and 4) number of different types of products used in the past-month (summed: range 0-6 for tobacco/nicotine; range 0-8 for cannabis). For tobacco/nicotine products, we had separate items for cigarettes, ENDS (assessed as "e-cigarette" or "personal vaporizer"),[29] smokeless tobacco, hookah, pipe tobacco, and cigars/cigarillos. For cannabis products, we had separate items for joint, blunt (cigar shell), hand pipe (bowl), bong (waterpipe), dabs (wax, shatter, budder, hash oil), edibles, personal vaporizer ("vape pen" or "mod"), and beverages (eg, water, teas, sodas, or other drinks). For tobacco/nicotine products, combustible products included cigarettes, hookah, pipe tobacco, and cigars/cigarillos; vaping products included ENDS. For cannabis, combustible products included joints, blunts, hand pipes, and bongs; vaping products included personal vaporizers and use of ENDS to vape cannabis.

For T/C product co-use at study wave 11, we created variables to indicate past-month *concurrent co-use* (ie, use of both types of products at some point in the past month) of *any* T/C products (coded 0 = no, 1 = yes) and number of different unique T/C co-use product combinations (eg, cigarette + cannabis joint; ENDS + cannabis joint; ENDS + edible cannabis) endorsed in the past month (count variable; possible range 0-66). We then created variables to indicate the following different types of co-use for both *combustible* and *vaping* T/C products: *concurrent co-use* (ie, use of both combustible tobacco and combustible cannabis products in the past month; use of both nicotine vaping and cannabis vaping products in the past month), *sequential T/C co-use* (ie, use of combustible T/C products 1 right after the other; use of vaping T/C products 1 right after the other) and *co-administration* of T/C together in the same delivery device (ie, co-administering combustible T/C products; co-administering vaping T/C products). All past-month co-use indicator variables were coded as 0 = no, 1 = yes.

Finally, we asked participants to indicate how recreational cannabis legalization in California had affected their cannabis product use, and specifically their use of cannabis vaping products. Participants responded to the following 3 items, which were developed by the research team: (1) "As of 1 January 2018, recreational marijuana is sold legally in stores throughout California. How has this affected your marijuana use?"; (2) ". . . how has this affected your use of e-cigarettes or personal vaporizers (eg, "vape pens" or "mods") to vape marijuana alone (that is, not with any e-liquid containing nicotine)?"; and (3) ". . . how has this affected your use of e-cigarettes or personal vaporizers (eg, "vape pens" or "mods") to vape marijuana combined with e-liquid containing nicotine?" Response options for these items were: (1) It has decreased a lot; (2) It has decreased a little; (3) It has stayed the same; (4) It has increased a little; and (5) It has increased a lot. These items were treated as continuous variables on a 1 to 5 scale.

Analytic plan

We used a parallel process growth mixture model (PP-GMM)[36,37] to model simultaneous heterogeneity in T/C use from ages 16 to 21-22. We ran a series of models for the

PP-GMM to simultaneously model heterogeneity and patterns of T/C use during adolescence. The latent class variable was defined by tobacco as well as cannabis use growth factors (eg, intercept and slope; with the intercept centered at 18 years old). Given low prevalence rate of T/C use in early adolescent waves, we used dichotomous (yes or no) indicators at each wave. That is, each wave is modeled as a binary indicator of whether participants endorsed tobacco use and a binary indicator for cannabis use. This model allows for change, itself, to serve as both an outcome and a predictor. That is, each individual is grouped with participants that have similar trajectories in both tobacco and cannabis use. Thus, individuals can be grouped based on their use of both products or a single product over the course of the study. We used the robust maximum likelihood estimator, which can accommodate categorical and ordinal data, missing data, and provide unbiased and consistent estimates.[38] Further, because our data modeled growth of categorical data, we used a Monte Carlo Integration algorithm with 500 random starts. Growth mixture models allow for variation in growth trajectories, resulting in separate growth models for each emergent latent class, which have unique parameter estimates (eg, means, variance, and co-variance, and residual variance). We used log likelihood ratio tests to assess need for random linear and quadratic slopes. A series of models was estimated with 1 to 5 classes, and fit was assessed using the above-mentioned criteria.

To address questions surrounding *distal tobacco/nicotine and cannabis outcomes*, we used the manual three-step auxiliary Bolck, Croon, and Hagenaars (BCH) approach[39] which uses a pseudo-class Wald chi-square test to assess mean differences between classes. The same process was used with categorical distal outcomes however, the manual three-step auxiliary approach using the categorical function (DCAT) was used. Both procedures fix parameters of latent classes to ensure that measurement of classes is not influenced by covariates.

As with all mixture models, several indicators were used to assess model fit: lower values of negative 2 log likelihood (-2LL), Akaike Information Criteria (AIC), Bayesian Information Criteria (BIC), the sample size adjusted Bayesian Information Criteria (aBIC), and a non-significant Vuong-Lo-Mendell-Rubin Likelihood Ratio test (VLRT), Lo-Mendell-Rubin adjusted likelihood ratio test (LRT), and bootstrapped likelihood ratio test (BLRT) indicate better model fit.

Results

Participants

Mean age at wave 7 was 17.2 years old (see Table 1). The sample was 54.8% female, 45.3% Hispanic (n = 1130), 20.6% white (n = 515), 20.4% Asian/Pacific Islander (n = 509), 10.0% multiethnic (n = 250), 2.3% black (n = 58), and 1.3% other (n = 33).

Table 1. Descriptive characteristics of the sample.

	M(SD) OR N(%)
Demographics	
Age (wave 7)	17.2 (0.7)
Female gender n(%)	1366 (54.8%)
Race/ethnicity n(%)	
White	515 (20.6%)
Hispanic	1130 (45.3%)
Asian/Pacific Islander	509 (20.4%)
Black	58 (2.3%)
Multi-ethnic	250 (10.0%)
Other	33 (1.3%)
Mother's education n(%)	
Did not finish high school	360 (14.4%)
Finished high school or some college	751 (30.1%)
Finished college or higher	1301 (52.1%)
Sexual orientation n(%)	
Straight/heterosexual	2123 (85.1%)
Gay	54 (2.2%)
Lesbian	37 (1.5%
Bisexual	209 (8.4%)
Questioning	49 (2.0%)
Asexual	23 (0.9%)
Past-month tobacco and cannabis use	
Any past-month tobacco use (wave 11)	641 (25.8%)
Any past-month cannabis use (wave 11)	828 (33.2%)

83 participants did not know mother's education (3.3%).

Tobacco and cannabis PP-GMM

PP-GMM models were fit starting with a one-class model. Fit indices (see Table 2) determined the best fitting model. Non-significant LRT and BLRT values for the five-class solution indicates that a four-class solution fit the data best.

Figure 1 displays item probability plots for T/C use by class. The *Early Concurrent T/C Co-use* class (n = 139, 6.1%) represents participants who demonstrated increases in T/C use from mid-to-late adolescence (17 years old), and a relatively sharp acceleration of T/C use into young adulthood (~20-21 years old), suggesting progression toward persistent T/C concurrent co-use. The *Late Concurrent T/C Co-use* class (n = 663, 28.9%) represents participants with low probability of T/C use during mid-adolescence (16 years old), and a gradual and persistent increase in the probability of T/C use beginning in early young adulthood (~18-19 years

Table 2. Model fit statistics for parallel process growth mixture for tobacco/nicotine and cannabis use.

CLASS NO.	-2 LOG-LIKELIHOOD	AIC	BIC	ABIC	ENTROPY	VLRT	*P*	LMRT	P	BLRT	*P*
1 Class	13476.9	13492.9	13538.8	13513.4							
2 Class	12839.5	12865.5	12865.5	12898.8	0.77	637.4	<.00	621.3	<0.00	636.4	<.00
3 Class	12742.3	12778.3	12881.6	12824.4	0.68	96.5	.02	94.0	0.02	96.5	<.00
4 Class	12680.9	12726.9	12858.9	12785.8	0.62	61.4	.01	59.8	0.02	61.4	<.00
5 Class	12646.9	12702.8	12863.5	12774.6	0.62	22.4	.10	31.0	0.11	31.7	.01

Abbreviations: aBIC, Sample size-adjusted BIC; AIC, Akaike Information Criterion; BIC, Bayesian Information Criterion; BLRT, Parametric Bootstrapped Likelihood Ratio Test; LMRT, Lo-Mendell-Rubin Likelihood Ratio Test.

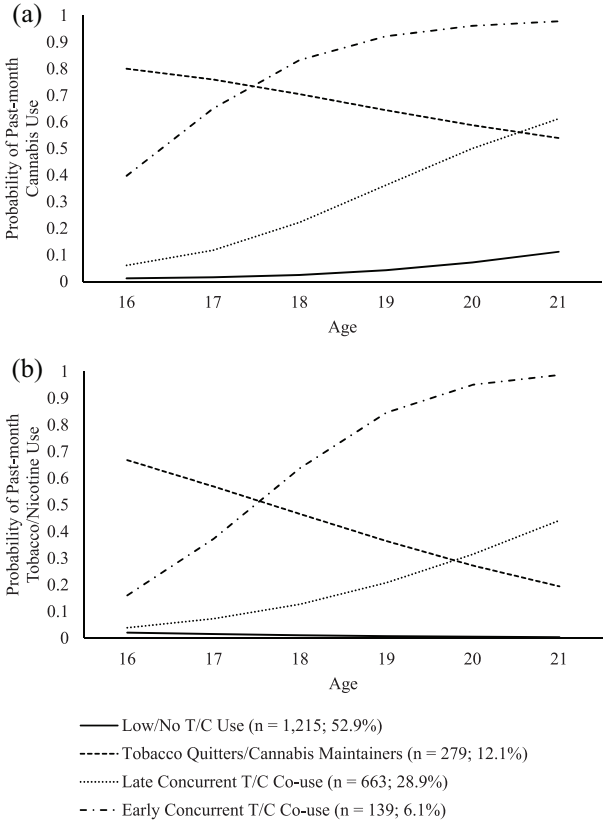

Figure 1. Tobacco/nicotine and cannabis use from ages 16 to 21 by class. This figure shows probability plots for past-month cannabis use (panel a) and past-month tobacco/nicotine use (panel b) from ages 16 to 21 for each tobacco/nicotine and cannabis class based upon parallel process growth mixture models.

old). The *Tobacco Quitters/Cannabis Maintainers* class (n = 279, 12.1%; hereafter, *Quitters/Maintainers*) represents participants with the highest endorsement of both past-month cannabis and tobacco use in mid-adolescence (16 years old). This group significant decreases in tobacco use over time, with some decrease in cannabis use, although their cannabis use still remained relatively high (0.54 probability of use at age 21). Finally, the *Low/No T/C Use* class (n = 1215; 52.9%) represents participants with consistently very low probability of T/C use over time.

Tobacco and cannabis outcomes in young adulthood

Table 3 shows comparisons in distal outcomes across T/C trajectory classes. Classes differed with respect to likelihood of current use of tobacco/nicotine products at wave 11, such that individuals in the *Early Concurrent T/C Co-use* class were significantly more likely to report current use of any tobacco products, use of combustible tobacco and nicotine vaping/ENDS products, and use of more different types of tobacco/nicotine products in young adulthood compared to all classes (Table 3). In addition, individuals in the *Late Concurrent T/C Co-use* and *Quitters/Maintainers* classes were more likely to endorse any tobacco use, combustible and vaping/ENDS use, and to use more types of tobacco products compared to the *Low/No Use* class.

Largely similar patterns were observed for cannabis product use, such that the *Early Concurrent T/C Co-use* class was more likely to endorse any cannabis product use, combustible and vaping product use, and report more different types of products used in the past month than the *Low/No Use* and *Quitters/Maintainers* classes. However, the *Early Concurrent T/C Co-use* class did not differ from the *Late Concurrent T/C Co-use* class with respect to any cannabis product use, cannabis vaping, or the number of different types of products used. Individuals in the *Early Concurrent T/C Co-use* class and those in the *Quitters/Maintainers* class were also more likely than individuals in the *Late Concurrent T/C Co-use* class to report use of combustible cannabis products in the past month. The 4 classes did not differ with respect to self-reported effects of recreational cannabis legalization on their subsequent cannabis use, which suggests that legalization did not differentially affect perceived cannabis use across groups. The *Early Concurrent T/C Co-use* class differed from the *Low/No Use* class on self-reported impact of cannabis legalization on cannabis vaping, such that the *Low/No Use* class had lower mean ratings (ie, legalization had less of an effect on use).

For T/C co-use outcomes, the *Early Concurrent T/C Co-use* class was significantly more likely to report concurrent

Table 3. Distal outcomes at wave 11 and comparisons across tobacco/nicotine and cannabis trajectory classes.

	LOW/NO USE (CLASS 1)	TOBACCO QUITTERS/ CANNABIS MAINTAINERS (CLASS 2)	LATE CONCURRENT T/C CO-USE (CLASS 3)	EARLY CONCURRENT T/C CO-USE (CLASS 4)	DIRECTIONS OF SIGNIFICANT CLASS DIFFERENCES ($P < .05$)
Tobacco/Nicotine					
Past-month use of any tobacco/nicotine product (*P*(*SE*))	0.02 (0.02)	0.43 (0.05)	0.48 (0.03)	1.00 (0.05)	4 > 1,2,3 2,3 > 1
Number of products used in past month[a] (*mean (SE)*)	0.02 (0.03)	0.77 (0.12)	0.89 (0.08)	2.46 (0.18)	4 > 1,2,3 2,3 > 1
Past-month use of combustible products (*P*(*SE*))	0.18 (0.02)	0.77 (0.11)	1.89 (0.12)	0.79 (0.05)	4 > 1,2,3 2,3 > 1
Past-month use of vaping/ENDS (*P*(*SE*))	0.01 (0.01)	0.25 (0.04)	0.34 (0.03)	0.92 (0.06)	4 > 1,2,3 2,3 > 1
Cannabis					
Past-month use of any product (*P*(*SE*))	0.07 (0.01)	0.70 (0.04)	0.59 (0.03)	0.83 (0.05)	4 > 1,3 2,3 > 1
Number of products used in past month[b] (*mean (SE)*)	0.09 (0.05)	2.55 (0.22)	1.97 (0.15)	3.31 (0.29)	4 > 1,3 3 > 1
Past-month use of combustible products (*P*(*SE*))	0.05 (0.01)	0.61 (0.05)	0.50 (0.03)	0.84 (0.05)	4 > 1,2,3 2,3 > 1
Past-month use of vaping products (*P*(*SE*))	0.02 (0.01)	0.49 (0.05)	0.34 (0.03)	0.57 (0.06)	4 > 1,3 2,3 > 1
How has legalization affected your marijuana use? (1-5 scale) (*mean (SE)*)	3.01 (0.06)	2.95 (0.09)	3.00 (0.06)	3.00 (0.11)	–
How has legalization affected your use of e-cigarettes or personal vaporizers (eg, “vape pens” or “mods”) to vape marijuana alone (that is, not with any e-liquid containing nicotine)? (1-5 scale) (*mean (SE)*)	2.73 (0.10)	2.78 (0.09)	2.80 (0.07)	3.00 (0.10)	4 > 1
Past-month Co-use of T/C Products					
Concurrent co-use of any T/C products (*p*(*SE*))	0.00	0.35 (0.05)	0.27 (0.02)	0.84 (0.06)	4 > 1,2,3 2,3 > 1
Number of T/C product/method combinations[c] (*mean (SE)*)	0.18 (0.16)	2.94 (0.80)	1.65 (0.48)	6.58 (1.39)	4 > 1,2,3 2,3 > 1

(Continued)

Table 3. (Continued)

	LOW/NO USE (CLASS 1)	TOBACCO QUITTERS/ CANNABIS MAINTAINERS (CLASS 2)	LATE CONCURRENT T/C CO-USE (CLASS 3)	EARLY CONCURRENT T/C CO-USE (CLASS 4)	DIRECTIONS OF SIGNIFICANT CLASS DIFFERENCES ($P < .05$)
Combustible T/C product co-use					
Combustible product concurrent co-use (*P*(*SE*))	0.01 (0.01)	0.22 (0.04)	0.14 (0.02)	0.64 (0.06)	4 > 1,2,3 2,3 > 1
Combustible product sequential use (*P*(*SE*))	0.01 (0.01)	0.13 (0.03)	0.12 (0.02)	0.39 (0.06)	4 > 1,2,3 2,3 > 1
Combustible product co-administration (*P*(*SE*))	0.00	0.18 (0.04)	0.06 (0.02)	0.53 (0.06)	4 > 1,2,3 3 > 1 2 > 1
Vaping T/C product co-use					
Vaping product concurrent co-use (*p*(*SE*))	0.00	0.31 (0.06)	0.28 (0.04)	0.95 (0.07)	4 > 1,2,3 2,3 > 1
Vaping product sequential use (*P*(*SE*))	0.00	0.12 (0.03)	0.07 (0.02)	0.32 (0.06)	4 > 1,2,3 2,3 > 1
Vaping product co-administration (*P*(*SE*))	0.01 (0.00)	0.06 (0.02)	0.02 (0.01)	0.11 (0.03)	2,4 > 1 4 > 3
How has cannabis legalization affected your use of e-cigarettes or personal vaporizers (eg, “vape pens” or “mods”) to vape marijuana combined with e-liquid containing nicotine? (1-5 scale) (*mean (SE)*)	2.68 (0.10)	2.56 (0.09)	2.68 (0.06)	2.89 (0.10)	4 > 2

Abbreviations: ENDS, electronic nicotine delivery system; *mean (SE)*, model-based class mean (standard error); *P(SE)*, model-based probability(standard error); T/C, tobacco/nicotine and cannabis.
Group mean differences for continuous outcomes were assessed using the manual three-step auxiliary BCH approach, which uses a pseudo-class Wald chi-square test to assess mean differences between classes. Group differences for categorical outcomes were assessed using the manual three-step auxiliary DCAT approach. Directions of significant group differences at $P < .05$ are shown.
[a]Total of 6 possible product types; participant responses ranged from 0 to 6.
[b]Total of 8 possible product types; participant responses ranged from 0 to 8.
[c]Total of 66 possible unique product combinations; participant responses ranged from 0 to 20.

past-month T/C co-use compared to all classes. Similarly, the *Late Concurrent T/C Co-use* and the *Quitters/Maintainers* classes were more likely to report concurrent T/C co-use compared to the *Low/No Use* class. Similar patterns of class differences were observed for concurrent and sequential co-use of combustible and vaping T/C products, as well as number of different types of concurrent T/C product/method combinations endorsed. Individuals in the *Early Concurrent T/C Co-use* class had an extremely high probability (*Probability* = .95, SE = .07) of endorsing past-month *concurrent co-use* of T/C vaping products (see Table 3). Slightly different patterns emerged for combustible and vaping T/C co-administration. The *Early Concurrent T/C Co-use* class was significantly more likely to report past-month combustible T/C co-administration compared to all other classes; the *Late Concurrent T/C Co-use* class was more likely to report combustible T/C co-administration compared to the *Low/No Use* and the *Quitters/Maintainers* classes; and the *Quitters/Maintainers* class was more likely to do so than the *Low/No Use* class. Both the *Early Concurrent T/C Co-use* and *Late Concurrent T/C Co-use* classes were more likely to report co-administration of T/C vaping products compared to the *Low/No Use* class, and the *Early Concurrent T/C Co-use* class was more likely to endorse past-month vaping co-administration compared to the *Quitters/Maintainers* class. Finally, the *Early Concurrent T/C Co-use* class differed from the *Late Concurrent T/C Co-use* class with respect to self-report changes in T/C vaping co-administration following recreational cannabis legalization in California.

Discussion

Given widespread co-use of T/C among young adults, and recent changes in T/C product and regulatory landscapes, it is important to understand how T/C use during adolescence predicts future product use and types of T/C co-use in young adulthood. This is one of the first longitudinal studies to examine classes of adolescent and young adult T/C use based upon longitudinal patterns of use of both types of drugs, modeled simultaneously in a parallel process growth mixture model. We identified 4 distinct T/C trajectory classes, characterized by: (1) consistently low or no engagement in T/C use over time; (2) sharply decreasing probability of tobacco use and moderate decreasing probability of cannabis use; (3) progression to moderate-high probability of concurrent T/C co-use; and (4) rapid progression to stable, high probability of persistent concurrent T/C co-use. The current study adds to the existing literature on T/C co-use by examining prospective associations between these T/C co-use trajectory classes and the number and types of products (vaping; combustible) used as well as providing information on more nuanced patterns of T/C co-use (eg, same-occasion sequential co-use and co-administration) in young adulthood.

Consistent with hypotheses, those in the *Early Concurrent T/C Co-use* class were more likely to use combustible products, engage in poly-product use for tobacco and cannabis, and report concurrent and same-occasion co-use (ie, sequential use; co-administration) of T/C in young adulthood compared to individuals in other classes. Numerous studies suggest that young people who initiate tobacco use *or* cannabis use at earlier ages may be at greater risk for developing dependence on these drugs and progressing to heavier use,[40-44] and recent work by our team suggests that more rapid escalation of past-year T/C co-use is associated with a range of poorer outcomes in young adulthood.[45] The current study expands upon prior work by showing that young people who report co-use of T/C products earlier in life and who rapidly progress toward persistent past-month co-use of both drugs in adolescence are more likely to go on to use more different types of tobacco/nicotine *and* cannabis products, and more likely to show riskier patterns of T/C co-use (eg, co-administering T/C in the same use episode) in young adulthood compared to their peers who show different T/C use profiles in adolescence. One possibility is that persistent engagement in concurrent T/C co-use during adolescence may increase exposure to opportunities to use T/C in combination, reinforcing this pattern of use over time.[45] In addition, concurrent T/C co-use may increase awareness and exposure to more types of products, which may in turn increase likelihood of poly-product use. These findings suggest that, rather than targeting a single substance or type of product (eg, cigarettes), adolescent tobacco (and cannabis) prevention programs should include content on co-use of T/C and its potential consequences, as well as the full breadth of product types now available that may be used to support same occasion co-use, especially given that some products (eg, combustible products) may carry different health risks compared to others.

We also observed other important class distinctions and similarities on outcomes. The *Early Concurrent T/C Co-use* group evidenced the highest likelihood of combustible cannabis product use and combustible T/C co-use in young adulthood compared to other groups. For example, individuals in the *Early Concurrent T/C Co-use* group had a 53% probability of endorsing past-month *co-administration* (ie, mixing both tobacco and cannabis together) of combustible T/C. This is consistent with prior work suggesting that combustible T/C remains the dominant form of T/C co-administration among young people.[29,46] This is particularly concerning given the well-established, serious health consequences associated with combustible product use.[30] Moreover, combustible product use may be associated with greater dependence, which could make cessation more difficult for individuals who use these types of products.[47] As the tobacco and cannabis markets become increasingly diverse, this indicates a need to emphasize the established risks of combustible products (ie, at the far end of the risk continuum[32]) compared to other types of available products in prevention and intervention efforts to reduce harms to public health.

We also observed notable group differences with respect to T/C vaping product use. For example, although individuals in the *Early Concurrent T/C Co-use* and *Late Concurrent T/C Co-use* groups showed similar rates of cannabis vaping in

young adulthood, the *Early Concurrent T/C Co-use* group had remarkably high rates of concurrent T/C vaping co-use and sequential vaping co-use compared to all other classes. Specifically, individuals in this group had a 95% probability of using both T/C vaping products in the past month, approximately 30% probability of reporting sequential co-use of T/C vaping products (ie, 1 product right after the other), and over 10% probability of reporting co-administration of T/C vaping products. High rates of T/C vaping co-use among some young adults are concerning due to limited data on long-term consequences of use and co-use of these relatively novel products. Although extant evidence suggests that nicotine vaping (ie, ENDS use) exposes individuals to fewer known toxicants compared to combustible tobacco products,[31] and is likely to be considerably less harmful to health relative to combustible product use,[32] findings from studies of ENDS cannot be generalized to cannabis vaping products, for which the research base is quite limited. Moreover, in the context of other findings showing high probability of combustible T/C co-use, poly-tobacco use, and poly-cannabis use in the *Early Concurrent T/C Co-use* group, these individuals may risk particularly high exposure to nicotine, THC, and various other compounds that could increase risk of dependence and other negative health consequences.[13-15,19] Cannabis vaping products may deliver particularly high concentrations of THC, which could place individuals who use these products at risk for negative consequences including cannabis use disorder.[23,48] Moreover, recent reports indicate that some cannabis vaping products may lead to serious health problems: as of 25 February 2020, the Centers for Disease Control and Prevention documented 2807 cases of serious lung injury associated with use of vaping products. Approximately 3-quarters of cases involved individuals under age 35, and recent use of cannabis vaping products was reported by a majority (82%) of hospitalized patients.[49] As cannabis vaping products become increasingly accessible, efforts to protect public health may benefit from clearly communicating differences between nicotine and cannabis vaping products, particularly "black market" cannabis vaping products[50] that are not subject to stringent regulatory oversight and may carry differential health risks compared to ENDS. Such efforts may be particularly important given data suggesting that perceived risk of cannabis use among young people may be decreasing in line with changes in cannabis legalization.[51]

Findings should be considered in context of limitations. First, data were self-reported. Although we have no indication that individuals misrepresented their T/C use, data were not biochemically validated. In addition, although a strength of the study was its inclusion of ENDS and smokeless tobacco products (ie, in addition to cigarette smoking) in characterizing trajectories of tobacco/nicotine use, data on past-month tobacco/nicotine use were dichotomized, which precluded assessment of trajectory groups in relation to frequency of past-month tobacco use. Similarly, although our use of longitudinal data to characterize progression toward stable, concurrent T/C co-use is a considerable strength, our use of dichotomous indicators for any past-month T/C use may have captured those who were simply experimenting with products at a given time point. Future work is needed to examine potential differences in young adult outcomes in relation to frequency of tobacco/nicotine and cannabis use during adolescence (eg, progression to daily T/C use). Although the sample is racially/ethnically diverse and models adjusted for race/ethnicity (and other demographic characteristics), a limitation of our data is that the proportion of black participants in the sample is low relative to the general population. Finally, the sample was based predominantly in California, and findings may not generalize to other samples in different tobacco/nicotine and cannabis regulatory environments. However, as more states consider adopting policy measures similar to those in California (eg, legalizing recreational cannabis), these findings may represent an important example of young adult T/C use patterns under these regulatory conditions.

Conclusion

Results highlight that early progression to persistent concurrent T/C co-use during adolescence increases risk for poly-tobacco and poly-cannabis use, sequential T/C co-use, and co-administration of T/C in young adulthood. Prevention efforts must address co-use of T/C products and provide up-to-date information on emerging products so teens can better understand harms associated with different products, particularly given that perceived risk of cannabis use has decreased in recent years.[51] In the context of rapidly shifting T/C regulatory environments, and expanded access to different products, ongoing surveillance of types of T/C product use and co-use is essential for ensuring prevention efforts are up-to-date and align with contemporary use trends.

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Data Availability Statement

Data for this study are not available because data collection for the parent study is still in progress.

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