Prevention Science (2020) 21:530–544
https://doi.org/10.1007/s11121-020-01086-7

Early and Late Adolescent Factors that Predict Co-use of Cannabis with Alcohol and Tobacco in Young Adulthood

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Published online: 20 January 2020

Abstract
The changing legal landscape of cannabis in the USA has coincided with changes in how cannabis is used, including its co-use with other substances. This study analyzed 10 years of data from a diverse cohort of youth ($N = 2429$; 54% Hispanic, 16% Asian, 16% white, 3% black, 10% multiracial) to examine predictors in early and late adolescence of co-use of alcohol with cannabis (AC) and tobacco with cannabis (TC) at age 21. Two forms of co-use were examined: concurrent (use of both substances in past month) and sequential (use of one substance right after the other). Analyses focused on four predictor domains: individual (e.g., resistance self-efficacy), peer (e.g., time spent around peers who use), family (e.g., sibling use), and neighborhood (i.e., perceived alcohol and drug problems in neighborhood). For each co-use combination (AC or TC), we estimated parallel process piecewise latent growth models in a structural equation modeling framework using Mplus v8. The final AC and TC co-use models included all predictor variables from the four domains. Increases in positive expectancies and time spent around peers who use AC, as well as steeper decreases in resistance self-efficacy, were all related to a greater likelihood of AC co-use in young adulthood. Increases in sibling TC use and time spent around peers who use TC, as well as steeper decreases in resistance self-efficacy, were all related to a greater likelihood of TC co-use in young adulthood. Overall, findings highlight the importance of addressing peer influence in prevention programming during both early and late adolescence.

Keywords Adolescents · Young adults · Marijuana · Cannabis · Alcohol · Co-use · Functioning

Introduction

The changing legal landscape of medical and recreational cannabis across the USA has led to changes in how cannabis is used (Knapp et al. 2019; Borodovsky et al. 2016), and how it is combined with other substances, such as alcohol (Yurasek et al. 2017; Subbaraman 2016) and tobacco (Lipperman-Kreda and Grube 2018; Tucker et al. 2019). Historically, young adults report the highest rates of cannabis use and cannabis use disorder, and recent data suggest that cannabis use and associated negative consequences are increasing among young adults (Azofeifa et al. 2016; Hasin et al. 2015; Hasin et al. 2016; Ahrnsbrak et al. 2017), many of whom now have legal access to cannabis if they are 21 or older in states where cannabis is legalized. These changes are concerning given that concurrent co-use of cannabis with alcohol or tobacco is on the rise (Schlienz and Lee 2018), and there is potential for increased health and psychosocial harms associated with cannabis and polysubstance use (Cohn et al. 2016; Ramo et al. 2012; Yurasek et al. 2017). Moreover, the rate of cannabis legislative reform continues to outpace regulatory efforts to reduce potential harm (Schlienz and Lee 2018). As of early 2019, 10 states and the District of Columbia have laws for legalized recreational cannabis, and 33 states have laws for legalized medical cannabis; however, the effects of such changes on cannabis use and co-use with other substances are yet unknown (D'Amico et al. 2017). In the context of a rapidly changing cannabis policy climate, there is an urgent need to understand patterns, predictors, and outcomes of co-

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use of cannabis and other substances to prevent negative consequences associated with cannabis use and co-use with other substances.

Prevalence of Co-use among Adolescents and Young Adults

In response to the changing cannabis legalization landscape, research in the area of cannabis co-use with tobacco or alcohol has ramped up to better understand patterns of co-use among adolescents and young adults. It is important to note that the definition of co-use can vary from study to study (Meier and Hatsukami 2016), and most studies to date have defined "co-use" as reports of use of both substances within a certain time frame, such as the past 30 days (Agrawal et al. 2011; Cohn et al. 2016; Schauer and Peters 2018). This is now typically referred to in the literature as "concurrent co-use." However, it is not known from this concurrent co-use data whether these substances were actually used together during the same use episode (e.g., one product right after another or by mixing products together). Thus, recent studies have begun to address this by examining sequential use (using both products on the same occasion, one right after the other, but not mixing them together) and co-administration (using both products on the same occasion by mixing them in the same delivery device).

Tobacco and Cannabis (TC)

Schauer and colleagues (2015) analyzed cross-sectional data from the National Survey on Drug Use and Health for people 18 and older and found that rates of concurrent cannabis and tobacco co-use increased by 18.2% from 2003 to 2012, with youth aged 18 to 25 reporting the highest rates of co-use over the 10-year period. Furthermore, Wang et al. (2016) found that greater numbers of people reported concurrent co-use of cannabis and tobacco in states where medical cannabis was legalized, and recent studies have indicated that co-use of cannabis and tobacco is common. For example, our work from this same sample found that over one third (37.2%) of 2429 mainly California young adults between 20 and 21 reported concurrent co-use (Tucker et al. 2019).

Alcohol and Cannabis (AC)

A recent review paper reported that over 75% of people who report using cannabis also report concurrent drinking (Yurasek et al. 2017). In addition, this review indicated that higher levels of use of one substance were related to higher levels or an increase in use of the other substance. A paper that assessed substitution versus complementarity of alcohol and cannabis found that these substances act as both substitutes and complements, with many youth reporting co-use across studies, and in some cases, youth reported using less alcohol when more liberal cannabis policies were in place (Subbaraman 2016). Event level studies, where youth report their daily use of alcohol and their daily use of cannabis and other substances, have also shown that the most common pattern of concurrent co-use among college students is alcohol and cannabis (39%) (Mallett et al. 2017).

Different Types of Co-use and Correlates of Co-use

In this section, we briefly review the large literature on types and correlates of co-use. It is important to note that although many studies have been conducted in the area of co-use of TC and AC, some studies are more rigorous than others in terms of study design, products examined, representativeness of sample, and control variables. In addition to describing recent studies, we also include information from systematic reviews by Ramo et al. (2012) for TC, and Yurasek et al. (2017) for AC, which summarize co-use findings across hundreds of studies. These studies were conducted across two decades, and include data across states with different legalization policies, which could affect overall findings. Both reviews note that greater rigor is needed in this area, including utilization of longitudinal data to assess associations, and defining co-use consistently across studies.

Tobacco and Cannabis

In a 2012 review of correlates and consequences of concurrent tobacco and cannabis co-use among 13–25 year-olds, Ramo and colleagues found 114 studies that examined TC co-use, and 59 of these studies focused on correlates of co-use. They defined factors consistently associated with an increased likelihood of co-use based on significant associations in at least four studies. Based on this definition, their review indicated that African American ethnicity and mental and physical health characteristics (e.g., anxiety symptoms, perceived general health) were typically associated with greater concurrent co-use, whereas getting good grades was associated with lower concurrent co-use (Ramo et al. 2012).

More recent research has begun to examine effects of different types of co-use, including sequential co-use (e.g., one substance right after the other) and co-administration (e.g., using both products on the same occasion by mixing them in the same delivery device) (Tucker et al. 2019; Hernández-Serrano et al. 2015; Meier and Hatsukami 2016). Our group recently examined types of cannabis and tobacco/nicotine co-use and associated outcomes in young adulthood among a predominantly California-based sample of 2429 youth (Tucker et al. 2019) (note: the same cohort examined in the current study). We defined five mutually exclusive groups at age 21 for (a) those who used cannabis in the past year and (b) those who used tobacco/nicotine in the past year: (1) single-

product use (28% cannabis and 18% tobacco/nicotine); (2) concurrent use only (using both products, but only on separate occasions; 31% of those who used cannabis, 36% of those who used tobacco/nicotine); (3) sequential use only (using both products on the same occasion, one right after the other, but not mixing them together; 14 and 17%, respectively); (4) co-administration only (using both products on the same occasion by mixing them in the same delivery device;10% in each subsample); and (5) both sequential use and co-administration (17 and 20%, respectively). Youth who used both substances on the same occasion (i.e., sequential and/or co-administration) reported heavier use and greater problematic behaviors than those who did not use on the same occasion (i.e., single drug use and concurrent use). Another study outside the USA on concurrent and sequential use of cannabis and tobacco and cannabis, tobacco, and alcohol assessed 477 Spanish University students at one point in time. Approximately one third of students reported concurrent co-use of cannabis and tobacco, about 3% reported sequential use of cannabis and tobacco, and about 8% reported sequential use of cannabis, tobacco, and alcohol. They examined correlates of co-use versus single product use, specifically, demographics and GPA. They found no differences by demographics, but GPA was higher for those who did not report any co-use; they did not find differences on demographics or GPA among co-use groups (Hernández-Serrano et al. 2015).

Alcohol and Cannabis

A 2017 review of co-use of alcohol and cannabis among many different populations and age groups, including adolescents, young adults, and adults, found that concurrent co-use is associated with heavier substance use consumption patterns compared to single product use, as well as greater risk for substance use disorders, behavioral and social consequences, and mental health disorders. This review also found that in alcohol and cannabis administration studies, participants experienced more impairment when they received both alcohol and cannabis versus cannabis or alcohol alone (Yurasek et al. 2017).

Three recent studies assessed both concurrent and sequential use patterns and correlates among mainly white (62–71%) 12th grade students using data from Monitoring the Future (MTF). One cross-sectional study using MTF data from 1976 to 2011 found that sequential use (called "simultaneous use" in the study) of alcohol and cannabis was more likely among adolescents who were truant and reported greater alcohol use (Terry-McElrath et al. 2013). A second cross-sectional study using MTF data from 1976 to 2016 identified four patterns of use: sequential (called "simultaneous use" in the study) alcohol and cannabis use with heavy drinking (11.2%), sequential use without heavy drinking (21.6%), concurrent use of alcohol and cannabis with no sequential use (10.7%), and alcohol use only (56.4%). Youth who engaged in sequential use reported greater rates of binge drinking and past month cannabis use compared to youth who only reported concurrent use (Patrick et al. 2018). Adolescents in either of the sequential use groups were more likely to report being out three or more evenings a week, truancy in the past month, and other illicit drug use compared to teens in the concurrent use group and the alcohol only use group. The third study used longitudinal data from MTF with 1719 youth followed from 12th grade to age 19–20 (Patrick et al. 2019). They examined predictors of co-use, and found that males, whites, and those attending a 2-year college were more likely to report sequential use (called "simultaneous use" in the study). Finally, a longitudinal study among students in Canada showed that alcohol intoxication, cannabis use, and perception of best friend use in grades 7 and 8 were all associated with a greater likelihood of concurrent cannabis and alcohol co-use in the past 12 months in 10th grade (Brière et al. 2011).

Event-level studies among college students show similar results whereby concurrent cannabis and alcohol co-use is associated with more problems. For example, daily cannabis use was related to a greater number of daily drinks, and weekly cannabis use was associated with greater positive and negative alcohol consequences (Gunn et al. 2018; Metrik et al. 2018). In addition, for students who reported concurrent co-use of other substances with alcohol, as the number of substances increased per occasion, so did the number of consequences (Mallett et al. 2017).

The Current Study

The literature on co-use of cannabis and tobacco and co-use of cannabis and alcohol has emphasized the need for prevention and intervention programs to address use of multiple substances as youth who report co-use also tend to report poorer mental health, greater likelihood of cannabis use disorder, and poorer psychosocial outcomes (Yurasek et al. 2017; Ramo et al. 2012; Lipperman-Kreda et al. 2017) than youth who report use of only one substance. Because this is a newer area, and because of the availability of new products that may facilitate co-use, such as personal vaporizers for cannabis and nicotine, there are many questions that still must be answered. To date, there is a lack of longitudinal and methodologically rigorous studies that address correlates of co-use (Yurasek et al. 2017; Ramo et al. 2012). Studies have also tended to focus on co-use of cannabis with one substance (e.g., tobacco or alcohol), mainly describe patterns of use and associated outcomes at one point in time, and are limited in terms of domains examined that may be associated with co-use. Overall, there is little longitudinal information on factors that may predict future cannabis co-use with alcohol or tobacco in young people. Such data have critical implications for efforts to prevent and reduce co-use and associated negative

consequences. The current study adds to this burgeoning literature by conducting a methodologically rigorous longitudinal analysis using 10 years of data collected in a racially/ethnically diverse cohort of youth ($N = 2429$) to examine adolescent predictors of co-use during emerging adulthood. To our knowledge, this is the first longitudinal study to examine antecedents of co-use utilizing data from two important developmental periods: early and late adolescence.

We examined four predictor domains: individual, peer, family, and neighborhood. These domains were based on the prevention and intervention literature, which is grounded in theory. For example, Social Learning Theory suggests that people make assumptions about their environment based on perceptions of the behavior and attitudes of others (Bandura 1977; Maisto et al. 1999; Bandura 1986)—which may or may not be accurate—and these assumptions can affect subsequent engagement in risk behaviors, like substance use. For example, most teens overestimate the percentage of peers who drink, smoke cigarettes, and use cannabis, and this overestimation can increase their use of these drugs (Salvy et al. 2014; Eisenberg et al. 2014; Wambeam et al. 2014). We examined these same domains across both early and late adolescence (waves 1–9) to determine whether certain domains were more strongly associated with concurrent or sequential co-use of cannabis and alcohol/tobacco over time at age 21 (Wave 10) to help inform interventions during early and late adolescence. We looked at both periods separately to examine whether certain factors, such as peer or family characteristics, might be more influential during these different developmental periods.

From the individual domain, we assessed effects of resistance self-efficacy (RSE) and positive expectancies, as increased RSE and decreased positive expectancies are associated with reduced substance use (Shih et al. 2017; Montes et al. 2017), and both are often addressed in adolescent and young adult interventions (e.g., Robbins et al. 2016; Schwinn et al. 2017; Velasco et al. 2017; Metrik et al. 2009; Magill et al. 2017). For the peer domain, we examined effects of perceptions of peer use or norms and time spent around peers who use substances. Both norms and time spent around peers who use are related to increased substance use (Schuler et al. 2018; Neighbors et al. 2007; Davis et al. 2019), and peer influence is typically targeted in intervention work with adolescents and young adults (D'Amico et al. 2015, 2018a; Buckner et al. 2019). We also examined family substance use, specifically sibling use and use of the most important adult in the youth's life, as family use is a strong predictor of individual use (Abar and Turrisi 2008; Alati et al. 2014; Yurasek et al. 2019), and is a context that is often addressed as part of making changes in substance use (Byrnes et al. 2019; Spirito et al. 2018). Finally, we examined subjective neighborhood characteristics, such as perceptions of alcohol and drug problems in the neighborhood, as research has shown the importance of this setting as both a protective and risk factor for substance use (Shih et al. 2017; Brick et al. 2018; Mason et al. 2017).

This study adds to the literature in three important respects. First, it examines co-use of both cannabis and tobacco and cannabis and alcohol to better understand factors that may contribute to these different types of co-use. Second, it examines different types of co-use, concurrent versus sequential, which is important given that the prevalence and risks vary for different types of co-use (Tucker et al. 2019; Patrick et al. 2018). Third, it focuses on predictors of co-use using 10 years of longitudinal data during two key developmental periods, early and late adolescence, which can provide important information on the different types of pressures adolescents may experience (e.g., Schuler et al. 2018), and determine which domains should be addressed in prevention programming across these timeframes.

Methods

Sample and Procedures

Participants were from two cohorts of students in 6th and 7th grade in 2008 (wave 1: mean age 11.5; $n = 6509$) to 2018 (wave 10: mean age 20.7; $n = 2429$), initially recruited from 16 middle schools in Southern California as part of a substance use prevention program, CHOICE (note: no significant effects of CHOICE intervention status were observed beyond study wave 2) (D'Amico et al. 2012). All participants consented to the study, and all procedures were approved by the RAND IRB. Study procedures are reported in detail elsewhere (D'Amico et al. 2012). Briefly, participants completed waves 1 through 5 (wave 1: Fall 2008; wave 2: Spring 2009; wave 3: Fall 2009; wave 4: Spring 2010; wave 5: Spring 2011) during physical education classes at 16 middle schools. Follow-up rates ranged from 74 to 90% during this time period, excluding new youth that could have come in at a subsequent wave. Adolescents transitioned from these middle schools 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. We retained 80% of the sample from waves 6–7, 91% of the sample from waves 7–8, 89% of the sample from waves 8–9, and 90% of the sample from waves 9–10. If a participant did not complete a wave of data collection, they were still eligible to complete all subsequent waves. That is, they did not "drop-out" of the study once they missed a survey wave; rather, we fielded the full sample at every wave so that all participants had an opportunity to participate in each individual survey. The majority of participants (78%) completed four or more survey waves. Participants receive $50 for completion of each web-based survey. Demographics (e.g., gender, race/ethnicity, employment) and substance use at the prior wave (alcohol, cigarettes, cannabis) did not predict attrition at wave 10,

similar to what we have found at earlier waves (D'Amico et al. 2018b; Dunbar et al. 2018).

Measures

Covariates

Covariate variables included self-reported age, gender, race/ethnicity, and CHOICE intervention status at Wave 1. Participants were classified into one of six racial/ethnic groups: non-Hispanic White (reference group), non-Hispanic Black, Hispanic, Asian, Multi-ethnic (more than one race/ethnicity), and Other (e.g., Native American, Native Hawaiian).

Individual Domain

Resistance Self-Efficacy (RSE)

Youth were asked: "Suppose you are offered alcohol [cigarette; marijuana] and you do not want to use it. What would you do in these situations: 1) your best friend is drinking alcohol [smoking; using marijuana]; 2) you are bored at a party; and 3) all your friends at a party are drinking alcohol [smoking; using marijuana]?" These three items were rated on a scale ranging from 1 = "I would definitely drink [smoke; use marijuana]" to 4 = "I would definitely not drink [smoke; use marijuana]." Higher scores indicate higher RSE (Ellickson et al. 2003). RSE scores were averaged between relevant substances (i.e., marijuana and alcohol RSE [alpha = 0.90]; marijuana and tobacco RSE [alpha = 0.92]) to form a single RSE measure for the particular co-use analysis.

Positive Expectancies

Positive and negative expectancies were assessed with three items for each substance that asked, for example, whether youth thought that using alcohol, tobacco, or marijuana will relax you or let you have more fun (1 = strongly agree to 4 = strongly disagree) (D'Amico and Edelen 2007; Tucker et al. 2003). Positive expectancy scores were averaged for relevant substances to form a single positive expectancy measure for the particular co-use analysis (i.e., cannabis and alcohol expectancies [alpha = 0.88]; cannabis and tobacco expectancies [alpha = 0.85]).

Peer Domain

Norms

Participants were asked to think about a group of 100 youth their age and indicate how many youth had (1) consumed alcohol at least once a month and (2) ever tried marijuana, and (3) smoked cigarettes at least once a month (Pedersen et al. 2013). Response options ranged from 0 to 10 with multiples of 10 as anchors (e.g., 0 = None, 1 = 10, 2 = 20, 3 = 30). Norm scores were averaged for relevant substances to form a single norms measure for the particular co-use analysis (i.e., alcohol and cannabis norms correlation = 0.798; tobacco and cannabis norms correlation = 0.612).

Time Spent around Peers Who Use

Youth were asked how often they were around peers who drank alcohol, smoked cigarettes, or used marijuana from "Never" = 0, "Hardly ever" = 1, "Sometimes" =2, "Often" = 3 (D'Amico et al. 2008). Scores were dichotomized to 0 (never/hardly ever) and 1 (sometimes/often) and combined for relevant substances to form a single score reflecting time spent with peers who use either substance for each particular co-use analysis.

Family Domain

Youth reported both sibling substance use and adult substance use (Shih et al. 2010; Schuler et al. 2018). *Sibling substance use* was assessed with the following items: "Do any of your older brothers or sisters smoke cigarettes [drink alcohol; use marijuana] sometimes? Answers included "I don't have any older brothers or sisters," "yes," or "no." Participants without older siblings were coded as "no." Scores from pairs of substances (i.e., sibling marijuana use and sibling tobacco use or sibling marijuana use and sibling alcohol use) were combined and dichotomized such that a "yes" to either substance was coded as "yes" for any sibling use for that particular co-use analysis. *Adult substance use* was assessed with respect to "the adult who is most important to you and that you spend time with." This item was designed to focus on an influential adult figure, and is assumed to be a parent for many respondents. Items ask how often this adult smokes cigarettes (drinks alcohol, uses marijuana); responses included "never," "less than once a week," 1–3 days a week," and "4–7 days a week." Responses were dichotomized into "no use" and "any use." Similar to sibling use, scores from pairs of substances were combined and dichotomized such that a "yes" to either substance was coded as "yes" for any adult use for that particular co-use analysis.

Neighborhood Domain

We utilized a subjective measure of neighborhood focused on participants' perceptions of alcohol and drug problems in the neighborhood (e.g., alcohol use [drug use, cigarette use] among teens is a problem in my neighborhood (Troxel et al. 2017)). Note that this variable was only assessed for

adolescents who were less than 18 years old. Thus, we used data from wave 6 to wave 8 given that beyond wave 8, at least 99% of all adolescents were at least 18 years old.

Substance Use Outcomes at Wave 10

Past month use of cannabis, tobacco, and alcohol were assessed at wave 10 by asking: "During the past month, how many days did you use [substance]?" Responses ranged from 0 days to 20–30 days. Given that the focus was on any use, responses were dichotomized to indicate any (1) vs. no (0) use of each substance. Tobacco use was assessed with seven items and defined as use of any of these products in the past 30 days: cigarettes, smokeless tobacco (dip, chew, or snuff), electronic or e-cigarette (e.g., Blu e-cig), personal vaporizer ("vape pen" or "mod") filled with nicotine e-liquid or other type of tobacco/nicotine product, hand pipe to smoke tobacco, hookah, and cigar/little cigar/cigarillo. Cannabis use was assessed with two items and defined as use of either of these products in the past 30 days: "marijuana (pot, weed, grass, hash, bud, sins)" and "electronic or e-cigarette to smoke/vaporize marijuana (e-cigarette or "vape pen" filled with hash oil, THC wax, dried buds, or other type of marijuana product)." Alcohol use was assessed with a single item that asked about past-month use of "at least one drink of alcohol." Concurrent co-use at wave 10 was defined as reporting any use of cannabis in the past 30 days (yes to either cannabis item) *and* reporting use of either tobacco (yes to any tobacco item) or alcohol in the past 30 days. Two separate concurrent co-use measures were created: one for alcohol and cannabis (AC) and one for tobacco and cannabis (TC). Youth who reported concurrent co-use of either AC or TC were then asked questions to determine sequential co-use in the past month. Reports of sequential co-use were defined as using both products (e.g., alcohol and cannabis, or tobacco and cannabis) on the same occasion, one right after the other, but not mixing them together. Two separate sequential co-use measures were created: one for AC and one for TC. Given that participants who reported sequential AC or TC co-use would also have reported concurrent co-use, concurrent co-use was restricted to non-sequential co-use.

Statistical Analysis

For each co-use combination (AC or TC), we estimated parallel process piecewise latent growth models (LGM) in a structural equation modeling framework using Mplus v8 (Muthén and Muthén 2012-2017). This framework extends the standard LGM (Meredith and Tisak 1990) by allowing for multiple longitudinal processes to be modeled simultaneously (Muthén 2002) while also allowing for each process to be segmented into separate but meaningful (e.g., developmental) trajectories (Hancock et al. 2006). Stated simply, multiple variables can be modeled over time simultaneously, and each longitudinal variable can be broken up into distinctive slopes. Moreover, this model allows for change, itself, to serve as both an outcome and a predictor. We used the weighted least squares with mean and variance adjusted estimator (WLSMV), which can accommodate categorical and ordinal data, missing data, and provide unbiased and consistent estimates (Asparouhov and Muthén 2010). In LGM, the model intercept represents the predicted value of the outcome when the predictor is equal to zero and thus represents a baseline level or probability. The slope represents the change in level or in the probability over time.

Using waves 1 through 10, an initial model was estimated for each domain (individual, peer, family, neighborhood) wherein all variables in that domain were included and modeled simultaneously (i.e., parallel process). For each longitudinal process variable within a domain (e.g., RSE), three growth factors were estimated: early adolescence slope (mean age at wave 1 = 11.5 years; mean age at wave 5 = 14.2 years), late adolescence slope (mean age at wave 6 = 16.2 years; mean age at wave 9 = 19.4 years), and an intercept. All growth factors were allowed to correlate. Moreover, given that multiple longitudinal processes within a domain were modeled simultaneously, cross-process growth factors were also allowed to correlate (e.g., early adolescent RSE slope with early adolescent positive expectancies slope). Each domain model was evaluated for model fit using conventional fit criteria: χ^2 (not significant), RMSEA (good ≤ 0.05; acceptable ≤ 0.10; bad > 0.10), and CFI (good ≥ 0.95; acceptable ≥ 0.90; bad < 0.90). For each domain model, a series of model constraints were imposed wherein non-significant paths were constrained to zero, and change in model fit evaluated for decrements in overall model fit. Nested models (models with and without constraints) were evaluated using the DIFFTEST model test function in Mplus given that with WLSMV estimation standard chi-square difference tests are not appropriate as the difference between nested models is not distributed chi-square (Asparouhov and Muthén 2006). The model refining process was terminated once all non-significant associations were constrained, or the DIFFTEST results indicated a significant decrement in model fit, thus resulting in the most parsimonious model. Results from domain-specific models were used to inform the final model specification wherein all domains and longitudinal piecewise processes were combined into a single model. Once again, all cross-process, and in this case, cross-domain growth factors (e.g., RSE slope and sibling substance use slope) were allowed to correlate. The final model was subjected to the same refining process using the DIFFTEST function to yield a final parsimonious model.

Results

Table 1 provides demographic and substance use information for the sample. Prior to examining associations between longitudinal measures and outcomes, LGMs for all longitudinal measures were examined for significant change over time. All models fit the data well by conventional model fit criteria. For all longitudinal measures (e.g., AC RSE), except perception of neighborhood alcohol and drug problems and AC adult use during early adolescence, there was significant change during both early and late adolescence. Table 2 presents growth factors for each longitudinal measure. During both developmental periods, TC adult use and both AC RSE and TC RSE were characterized by a significant decrease over time, whereas all remaining longitudinal measures were characterized by a significant increase over time. Based on these results, all longitudinal measures were examined in relation to co-use outcomes.

Individual Domain

The final AC co-use model fit the data well ($\chi^2_{(217)} = 1953.6$, $p < 0.01$; RMSEA = 0.035, CFI = 0.91). Table 3 shows that compared to the average decline in AC RSE during early and late adolescence, youth with a steeper decline in AC RSE during early adolescence were more likely to report sequential AC co-use at wave 10 (age 21), and youth with a steeper decline in AC RSE during late adolescence were more likely to report concurrent AC co-use at wave 10. Increases in AC positive expectancies during early adolescence were associated with a greater likelihood of concurrent AC co-use at wave 10, and increases in AC positive expectancies during late adolescence were associated with a greater likelihood of sequential AC co-use at wave 10.

The final TC co-use model fit the data well $\chi^2_{(215)} = 2290.80$ $p < 0.01$, RMSEA = 0.039, CFI = 0.90). Results indicate that compared to the average decline in TC RSE during early and late adolescence, youth whose TC RSE decreased more steeply during early and late adolescence were more likely to report sequential and concurrent TC co-use at wave 10. Further, increases in TC positive expectancies during late adolescence were significantly associated with a greater likelihood of sequential TC co-use at wave 10.

Table 1 Descriptive statistics for demographic and substance co-use measures

Variable	M/SD or %
Baseline demographics	
Gender (male)	51.2%
Race/ethnicity	
White	15.7%
Black	3.2%
Hispanic	53.7%
Asian	16.1%
Other	1.6%
Multiracial	9.5%
Wave 10 variables	
Age	20.7 (0.7)
Past month substance use	
Alcohol	61.5%
Tobacco	24.7%
Cannabis	33.7%
Alcohol and cannabis co-use	
Sequential	20.8%
Concurrent	10.0%
Tobacco and cannabis co-use	
Sequential	14.1%
Concurrent	6.3%

Sequential counts reflect only sequential co-use (i.e., use of one substance right after the other substance); concurrent counts reflect only concurrent co-use (i.e., use of either substance in the past month) with no report of sequential co-use

Peer Domain

The final AC co-use model fit the data well, $\chi^2_{(216)} = 2001.72$, $p < .01$; RMSEA = 0.036, CFI = 0.92. We found that an increase in time spent around peers using AC in both early and late adolescence was significantly associated with an increased likelihood of both sequential and concurrent AC co-use at wave 10. Results also showed that an increase in perceived norms during late adolescence was associated with lower likelihood of concurrent AC co-use.

The final TC co-use model fit the data well, $\chi^2_{(216)} = 2110.26$, $p < 0.01$, RMSEA = 0.037, CFI = 0.92. Similar to the AC model, an increase in time spent around peers using TC in both early and late adolescence was significantly associated with an increased likelihood of both sequential and concurrent TC co-use at wave 10.

Family Domain

The final AC co-use model fit the data well, $\chi^2_{(101)} = 375.84$, $p < 0.001$, RMSEA = 0.021, CFI = 0.99. Increases in sibling AC use during early adolescence and increases in adult AC use during late adolescence were both significantly associated with a greater likelihood of sequential AC co-use at wave 10. Increases in adult and sibling AC use during early and late adolescence were not associated with concurrent AC co-use.

The final TC co-use model fit the data well, $\chi^2_{(100)} = 224.97$, $p < 0.01$, RMSEA = 0.014, CFI = 1.0. Increases in sibling TC use during early adolescence and increases in adult TC use during late adolescence were associated with a greater likelihood of sequential TC co-use. Increases in sibling

Table 2 Estimated growth factors for each longitudinal measure without outcomes

	Intercept (95% CI)	EA slope (95% CI)	LA slope (95% CI)
Alcohol and Cannabis			
Individual			
RSE	3.75*	− 0.14*	− 0.09*
	(3.73, 3.76)	(− 0.15, − 0.13)	(− 0.10, − 0.09)
Positive expectancies	1.38*	0.20*	0.12*
	(1.36, 1.39)	(0.19, 0.21)	(0.11, 0.12)
Peer			
Norms	1.38*	0.82*	0.64*
	(1.35, 1.41)	(0.79, 0.85)	(0.62, 0.66)
Time spent with peers	0.04*	0.09*	0.08*
	(0.04, 0.05)	(0.09, 0.10)	(0.07, 0.08)
Family			
Most important adult	− 0.23*	0.01	0.13*
	(− 0.26, − 0.19)	(− 0.01, 0.03)	(0.11, 0.14)
Sibling	− 1.10*	0.16*	0.15*
	(− 1.14, − 1.06)	(0.14, 0.18)	(0.13, 0.17)
Neighborhood	3.66*	–	− 0.03
	(3.63, 3.70)		(− 0.07, 0.01)
Tobacco and Cannabis			
Individual			
RSE	3.81*	− 0.08*	− 0.04*
	(3.80, 3.83)	(− 0.08, − 0.07)	(− 0.05, − 0.04)
Positive expectancies	1.36*	0.16*	0.08*
	(1.35, 1.38)	(0.15, 0.17)	(0.08, 0.09)
Peer			
Norms	1.32*	0.67*	0.46*
	(1.29, 1.35)	(0.64, 0.69)	(0.45, 0.48)
Time spent with peers	0.04*	0.07*	0.05*
	(0.03, 0.04)	(0.07, 0.08)	(0.05, 0.06)
Family			
Most important adult	0.22*	− 0.01*	− 0.01*
	(0.21, 0.23)	(− 0.01, − 0.002)	(− 0.01, − 0.001)
Sibling	− 1.38*	0.13*	0.09*
	(− 1.42, − 1.33)	(0.11, 0.15)	(0.07, 0.11)
Neighborhood	3.66*	–	− 0.03
	(3.63, 3.70)		(− 0.07, 0.01)

Parameters denoted (*) are significant at $p < 0.05$. Parameters not estimated due to unavailable data are denoted (–)

EA early adolescence, *LA* late adolescence, *RSE* resistance self-efficacy

TC use and adult TC use during early adolescence were significantly associated with greater likelihood of concurrent TC co-use at wave 10.

Neighborhood Domain

The final AC co-use model fit the data well, $\chi^2_{(3)} = 9.18$, $p = 0.03$, RMSEA = 0.026, CFI = 0.99. Increases in perception of neighborhood alcohol and drug problems were associated with a greater likelihood of sequential AC co-use, but not concurrent use at wave 10. For TC co-use, the final model fit the data well, $\chi^2_{(3)} = 9.078$, $p = 0.03$, RMSEA = 0.025, CFI = 0.99; however, perception of neighborhood alcohol and drug problems was not associated with sequential or concurrent TC co-use at wave 10.

Combined Domains

The final overall AC co-use model combined all of the individual, peer, family and neighborhood domain variables and fit the data well, $\chi^2_{(1576)} = 7128.93$, $p < .001$, RMSEA =

Table 3 Associations between growth factors and outcomes for each domain

Domain		AC co-use models		TC co-use models	
		SAC (95% CI)	CAC (95% CI)	STC (95% CI)	CTC (95% CI)
Individual					
RSE	Intercept	–	−0.39 (−0.60, −0.18)	−0.66 (−1.05, −0.28)	–
	EA slope	−2.83 (−3.17, −2.49)	–	−3.03 (−3.73, −2.34)	−1.70 (−2.21, −1.18)
	LA slope	–	−2.18 (−2.76, −1.59)	−3.31 (−5.08, −1.68)	−3.10 (−3.93, −2.27)
Positive expectancies	Intercept	1.09 (0.94, 1.24)	–	0.49 (0.18, 0.80)	0.40 (0.21, 0.60)
	EA slope	–	1.18 (0.85, 1.51)	–	–
	LA slope	5.82 (5.09, 6.54)	–	2.60 (0.37, 3.83)	–
Peer					
Time spent with peers	Intercept	0.84 (0.77, 0.96)	0.33 (0.18, 0.48)	0.68 (0.57, 0.80)	0.65 (0.44, 0.86)
	EA slope	1.31 (0.92, 1.69)	1.29 (0.87, 1.71)	1.63 (1.25, 2.02)	1.03 (0.48, 1.57)
	LA slope	4.99 (4.17, 5.81)	2.95 (1.62, 4.28)	4.33 (3.65, 5.01)	2.56 (3.65, 5.01)
Norms	Intercept	–	–	–	−0.29 (−0.49, −0.08)
	EA slope	–	–	–	–
	LA slope	–	−0.45 (−0.83, −0.06)	–	–
Family					
Sibling	Intercept	0.17 (0.07, 0.27)	–	0.32 (0.19, 0.44)	–
	EA slope	0.98 (0.36, 1.60)	–	0.96 (0.05, 1.86)	2.73 (1.16, 4.29)
	LA slope	–	–	–	
Most important adult	Intercept	0.30 (0.20, 0.40)	0.11 (0.01, 0.21)	–	0.17 (0.03, 0.31)
	EA slope	–	–	–	−1.85 (−3.45, −0.26)
	LA slope	1.02 (0.57, 1.47)	–	1.77 (0.53, 3.01)	–
Neighborhood					
	Intercept	–	–	–	–
	LA slope	0.37 (0.03, 0.72)	–	–	–

All tabled estimates are significant at $p < 0.05$. Parameters denoted (−) were constrained to zero for non-significant associations with outcomes and statistically tested for decrements in model fit using the DIFFTEST function in Mplus

EA early adolescence, *LA* late adolescence, *RSE* resistance self-efficacy, *SAC* sequential AC co-use, *CAC* concurrent AC co-use, *STC* sequential TC co-use, *CTC* concurrent TC co-use

0.023, CFI = 0.93. Table 4 shows that compared to the average decline in AC RSE during early and late adolescence, youth whose AC RSE decreased more steeply during early adolescence were more likely to report sequential AC co-use at wave 10; a steeper decline in AC RSE during late adolescence was associated with a greater likelihood of concurrent AC co-use at wave 10. Increases in time spent around peers who used AC during both early and late adolescence were significantly associated with a greater likelihood of both sequential and concurrent AC co-use at wave 10. Lastly, increases in AC positive expectancies during late adolescence were significantly associated with a greater likelihood of sequential AC co-use at wave 10.

The final overall TC co-use model combining all domains fit the data well, $\chi^2_{(1598)} = 6669.19$, $p < 0.01$, RMSEA = 0.022, CFI = 0.93. Compared to the average decline in TC

RSE during early and late adolescence, youth whose TC RSE decreased more steeply during both early and late adolescence were more likely to report sequential TC co-use at wave 10. Increases in time spent around peers who used TC in late adolescence were associated with a greater likelihood of both sequential and concurrent TC co-use at wave 10. Lastly, increases in sibling TC use during early adolescence were associated with a greater likelihood of concurrent TC co-use at wave 10.

Discussion

This is the first longitudinal study to examine antecedents of concurrent and sequential co-use of cannabis with both tobacco and alcohol among young adults using 10 years of data across two important developmental periods: early and late adolescence. Four predictor domains were chosen based on the extensive alcohol and other drug use prevention and intervention literature: individual, peer, family, and neighborhood. Overall, findings highlight that adolescent predictors across all four domains were associated with co-use in young adulthood. However, when examined simultaneously, certain domains were more important in predicting co-use, and to some extent, differed by developmental period.

We first assessed each domain separately to determine which factors within a domain would be most influential in predicting concurrent or sequential co-use of AC and TC. For the individual domain, we found that RSE, or one's ability to turn down offers of substances, was highly predictive in both early and late adolescence for concurrent and sequential AC and TC co-use in young adulthood. This is perhaps not surprising as prevention and intervention programming have shown that when RSE increases youth tend to report less alcohol and other drug use (Schwinn et al. 2017; Velasco et al. 2017). However, it is noteworthy that RSE was influential across both developmental periods. This highlights the significance of providing skills training for both younger and older adolescents, as both age groups may often feel internal and external pressures to use substances. As expected, positive expectancies were also influential across both developmental periods in predicting concurrent and sequential co-use of AC in young adulthood, although only positive expectancies in late adolescence were associated with sequential co-use of TC. This is consistent with other work showing that expectancies are associated with an individual's substance use (e.g., Montes et al. 2017), but highlights that there may be developmental differences in how expectancies affect certain types of co-use. Overall, results from the individual domain emphasize that prevention programming for these age groups must address co-use of both alcohol and tobacco with cannabis when providing skills training and when discussing the positive effects of substances. This is particularly important as teens view cannabis as less harmful than tobacco (Johnston et al. 2019), and co-administration with cannabis and tobacco is sometimes done explicitly to enhance the high or buzz of the other drug (Berg et al. 2018). Similarly, many teens do not view cannabis to be as dangerous as alcohol (D'Amico et al. 2015; Friese 2017), and thus may not understand the added impairment that can occur when co-using cannabis with alcohol (Swift et al. 2010).

Findings from the peer domain underscore the importance of time spent around peers who use substances—in both early and late adolescence—as a key driver of future co-use behavior. The more time teens spent around peers that used during these two developmental periods, the greater the likelihood that they reported both concurrent and sequential co-use of AC and TC in young adulthood. Interestingly, perceptions of the prevalence of peer use were generally not associated with co-use of AC and TC in young adulthood. We found one inverse association with increased norms associated with lower AC co-use. We did not expect this effect given that the majority of research in this area shows that norms are positively associated with use (Neighbors et al. 2007; Davis et al. 2019), and this effect was no longer significant in the presence of other domain factors in the combined model. In general, perceived norms are important in substance use behavior (Pedersen et al. 2013); however, this study suggests that being with peers who are using, and likely seeing them use and using with them, is more important than teens' perceptions of use in predicting concurrent and sequential AC and TC co-use in young adulthood. This maps onto our results for RSE in the individual domain, as being able to resist offers of use is likely associated with how often teens are around peers who use; thus, addressing both factors during adolescence is crucial to reduce the likelihood of co-use in young adulthood.

In the family domain, both older sibling and adult use were associated with concurrent and sequential AC and TC co-use in young adulthood; however, sibling use was only influential in early adolescence, whereas adult use tended to be more influential in late adolescence. This is consistent with recent research showing that concordance between teen use and sibling use is highest during middle school, and tends to decline with age, whereas concordance with adult use remains stable during high school (Schuler et al. 2018). This is likely due to older siblings moving away from home and being a less consistent presence in the teen's life than the "most important adult" across both developmental periods (Schuler et al. 2018). Finally, we found that perception of greater problems in one's neighborhood during late adolescence (the only period it was assessed) was predictive of co-use in young adulthood, although this was limited to sequential AC co-use.

When all domains were combined, the strongest predictors of co-use in young adulthood (both concurrent and sequential) continued to be RSE and time spent

Table 4 Associations between growth factors and outcomes for combined domains

Domain		AC co-use models		TC co-use models	
		SAC (95% CI)	CAC (95% CI)	STC (95% CI)	CTC (95% CI)
Individual					
RSE	Intercept	–	–	–	–
	EA slope	− 1.50 (− 1.99, − 1.01)	–	− 3.23 (− 3.66, − 2.79)	–
	LA slope	–	− 1.39 (− 2.26, − 0.52)	−2.20 (− 3.37, − 1.03)	–
Positive expectancies	Intercept	0.60 (0.40, 0.79)	–	0.85 (0.69, 1.01)	–
	EA slope		–	–	–
	LA slope	2.97 (2.00, 3.95)	–	–	–
Peer					
Time spent with peers	Intercept	0.50 (0.36, 0.64)	0.40 (0.30, 0.51)	–	–
	EA slope	1.03 (0.65, 1.42)	1.35 (1.07, 1.62)	–	–
	LA slope	3.06 (2.35, 3.78)	1.09 (0.24, 1.94)	3.12 (2.22, 4.01)	1.36 (0.59, 2.14)
Norms	Intercept	–	–	–	–
	EA slope	–	–	–	–
	LA slope	–	–	–	–
Family					
Sibling	Intercept	–	–	–	
	EA slope	–	–	–	3.80 (2.53, 5.08)
	LA slope	–	–	–	
Most important adult	Intercept	–	–	–	0.21 (0.10, 0.32)
	EA slope	–	–	–	–
	LA slope	–	–	–	–
Neighborhood					
	Intercept	–	–	–	–
	LA slope	–	–	–	–

All tabled estimates are significant at $p < 0.05$. Parameters denoted (−) were constrained to zero for non-significant associations with outcomes and statistically tested for decrements in model fit using the DIFFTEST function in Mplus

EA early adolescence, *LA* late adolescence, *RSE* resistance self-efficacy, *SAC* sequential AC co-use, *CAC* concurrent AC co-use, *STC* sequential TC co-use, *CTC* concurrent TC co-use

around peers who use substances, and these were significant across both early and late adolescence. Only two other significant predictors remained in the final model. Older sibling use during early adolescence was associated with concurrent TC co-use in young adulthood, and positive expectancies during late adolescence were associated with sequential AC co-use in young adulthood. Associations of adult use, norms, and perceptions of alcohol and other drug use in one's neighborhood were no longer significantly associated with co-use when adjusting for other factors.

Overall, findings suggest that a good deal of contemporary prevention and intervention programming content is on target—that is, the focus that many programs have on

addressing peer influence across adolescence is crucial to reducing use in young adulthood. However, programs must begin to do a better job of addressing the effects of both cannabis and the effects of co-use of cannabis with other substances. This is particularly important as among US high school students, perceived safety of cannabis use is at its highest rate in two decades, with almost 60% of 10th graders reporting beliefs that smoking cannabis regularly (> 1–2 times/month) does not carry great risk (note that this survey only asks about smoking cannabis, not other types of use such as edibles or vaping) (Johnston et al. 2019). In addition, almost one in five teens reports that they have driven under the influence of cannabis, with one third saying that their driving ability improves after using cannabis (Loehrke 2013). Despite declining risk perceptions, recent work has shown that cannabis use during adolescence is associated with more problems than drinking alcohol (D'Amico et al. 2016b). In addition, a recent study found that the rate of cannabis use disorder (14%) among a general population of teens age 14–18 ($N = 1573$) in a primary care setting was three times the rate of alcohol use disorder (4%) (D'Amico et al. 2016a), highlighting that many teens are reporting significant problems from cannabis use. Given increasing rates of co-use among youth (Schauer and Peters 2018; Yurasek et al. 2017), research showing that consequences increase as youth report co-use of more substances (Mallett et al. 2017), and studies finding that sequential use is particularly problematic and associated with greater risk behaviors and consequences (Patrick et al. 2019; Tucker et al. 2019), providers and clinicians must begin to incorporate discussions of co-use into their conversations with youth to better understand their beliefs about co-use, how co-use is occurring, and the types of consequences they may be experiencing from co-use. For example, they may want to convey that the combined effects of alcohol and cannabis on psychomotor and cognitive functions have additive, or possibly synergistic, effects on impairment (e.g., Dubois et al. 2015), which can significantly increase the consequences compared to either substance alone (Bramness et al. 2010; Patrick et al. 2019; Tucker et al. 2019). In addition, given recent evidence of the potentially very harmful effects of vaping cannabis with tobacco/nicotine, efforts to communicate the potential risks of co-use of TC to youth are urgently needed to protect public health (CDC 2019; Layden et al. 2019).

One limitation of the current study includes reliance on self-report of substance use. However, the limits of self-report are often exaggerated (Chan 2008), and recent work with young adults 18–21 has shown, for example, that self-reported alcohol use can be corroborated by biomarkers (Simons et al. 2015). In addition, our sample's use rates over time have mapped onto rates seen for national samples, such as Monitoring the Future (Johnston et al. 2012). It is also important to note that we chose specific predictors within each of the four domains based on theory and the prevention literature; however, other factors within these domains might be important in predicting co-use in young adulthood, such as mental health. Finally, this sample was limited geographically to adolescents living in southern California; thus, generalizability may be restricted.

In sum, findings provide crucial information on factors during the important developmental periods of both early and late adolescence that are strongly predictive of co-use at age 21. Across all domains, an individual's RSE and the time that he/she spent around peers who use substances across adolescence were most predictive of subsequent AC and TC co-use. Both factors are typically targeted in prevention and intervention programming for younger and older adolescents by focusing on skills training and planning for risky situations and discussing the effects of peer influence. Results highlight that providers and clinicians should continue to address these factors when working with adolescents to lessen the chances of increased substance use and co-use during young adulthood. In addition, prevention efforts should explicitly address co-use of cannabis with other substances. Such efforts may be critical for mitigating potential harms for individuals coming of age in an era of unprecedented legal access to cannabis.

Acknowledgements The authors wish to thank the districts and schools who participated and supported this project. We would also like to thank Kirsten Becker and Jennifer Parker for overseeing the school survey administrations and the web-based surveys.

Funding Information Work on this article was supported by funds from the Tobacco-Related Disease Research Program of the University of California, Grant Number 26IR-0011 to Joan Tucker, and three grants from the National Institute of Alcohol Abuse and Alcoholism (R01AA016577; R01AA020883; R01AA025848) to Elizabeth D'Amico.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Informed Consent Informed consent was obtained from all individual participants included in the study.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee (RAND Human Subjects Protection Committee; Project Number d0206-06-01) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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