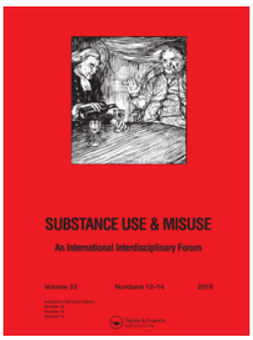

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ORIGINAL ARTICLE

Do Classes of Polysubstance Use in Adolescence Differentiate Growth in Substances Used in the Transition to Young Adulthood?

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ABSTRACT

Background: Past studies have differentiated classes of polysubstance use in adolescence, however, the associations of adolescent polysubstance use classes with longitudinal substance use trajectories from adolescence to young adulthood have not been studied. *Objective:* The current study examined substance use classes during adolescence and longitudinal trajectories of each substance used across the transition to young adulthood. *Method:* Data were collected biennially from 662 youth and followed 10 years across six measurement assessments. Using baseline data (T1), latent class analysis was used to identify classes of polysubstance use (cigarette, alcohol, marijuana, and illicit drug use) during adolescence. Using T2 through T6 data, we fit latent growth models for cigarette, alcohol, marijuana, and illicit drug use to examine longitudinal trajectories of each substance used by class. *Results:* A three-class model fit the data best and included a poly-use class, that had high probabilities of use among all substances, a co-use class, that had high probabilities of use among alcohol and marijuana, and a low-use class that had low probabilities of use among all substances. We then examined trajectories of each substance used by class. Strong continuity of substance use was found by class across 14 years. Additionally, for some substances, higher average levels of use of at age 14 were associated with change in growth of other substances used over time. *Conclusions/Importance:* Efforts that only target a single drug type may be missing an important opportunity to reduce the use and subsequent consequences related to the use of multiple substances.

KEYWORDS

Polysubstance use; cigarette; alcohol; marijuana; illicit drugs; latent class analysis; latent growth model

Previous research has found that early onset and chronic substance use in adolescence predicts substance use problems during young adulthood (Nelson et al., 2015). However, adolescence patterns of use vary widely within samples (Hix-Small, Duncan, Duncan, & Okut, 2004; Jackson, Sher, & Schulenber, 2008). To address heterogeneity in use patterns researchers have used person-centered approaches like latent mixture models to create homogenous groups of individuals with similar use patterns. Several cross-sectional latent class analysis (LCA) and longitudinal growth mixture models (GMM) have been used to examine patterns of single drug types, including tobacco (Colder et al., 2001; Henry & Muthén, 2010; Timberlake, 2008), alcohol (Chiauzzi, DasMahapatra, & Black, 2013; Colder, Campbell, Ruel, Richardson, & Flay, 2002; Li, Duncan, Duncan, & Hops, 2001; Schuckit et al., 2014; Sher, Jackson, & Steinley, 2011), marijuana (Pearson, Bravo, & Conner, 2017; Reboussin, Hubbard, & Ialongo, 2007; Walton et al., 2017), and illicit drugs (Baggio, Spilka, Studer, Iglesias, & Gmel, 2016; Lynskey et al., 2006; Monga et al., 2007). While studies that examine classes of a single drug type shed light on different patterns of use they do not address the use of multiple substances. The simultaneous use of substances is common in adolescence (Moss, Chen, & Yi, 2014) and young adult outcomes that are attributed to single drug types may be better explained by differences in polysubstance use.

Studies have shown that polysubstance use often is associated with more severe negative outcomes particularly if onset occurs earlier in adolescence (Connor, Gullo, White, & Kelly, 2014; Morley, Lynskey, Moran, Borschmann, & Winstock, 2015). As such, studies have differentiated classes of polysubstance use in adolescence to better understand differences in use patterns (Brière, Fallu, Descheneaux, & Janosz, 2011; Moss et al., 2014; Trenz et al., 2012). These studies focus on tobacco, alcohol, marijuana, and illicit drug use (Connell, Gilreath, Aklin, & Brex, 2010; Conway et al., 2013; Gilreath et al., 2015; Morean et al., 2016). Three to four polysubstance use classes are typically found but the proportion of substance users in each class varies widely across studies (for review see Tomczyk, Isensee, & Hanewinkel, 2016). Despite these sample differences, the finding of polysubstance use classes in adolescents may herald substance use problems in young adulthood (Nelson, Van Ryzin, &

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Dishion, 2015). However, the associations of adolescent polysubstance or co-use use classes with the longitudinal trajectories of substance use from adolescence to young adulthood have not been studied. Studies of cross-sectional outcomes associated with polysubstance use classes may obscure differences in the longitudinal trajectories and effects of single substance use from adolescence to young adulthood. In addition, it is not known whether using one type of substance in adolescence is associated with changes in growth in use of other substances for youth in co-use or polysubstance use classes.

Past research also shows differences in trajectory classes related to the co-use of two substances from adolescence to young adulthood (Cance, Talley, Morgan-Lopez, & Fromme, 2017; Hix-Small et al., 2004; Jackson, Sher, & Schulenberg, 2005; Jackson et al., 2008). Although these studies examined two substances, mainly tobacco or marijuana and alcohol use (Cance et al., 2017; Jackson et al., 2008; Schweizer, Roesch, Khoddam, Doran, & Myers, 2014), many adolescence use multiple substances simultaneously (Moss et al., 2014). A better understanding of the classes of use of multiple substances during adolescence and the longitudinal trajectories of each substance used across the transition to young adulthood could inform individualized approaches to prevention and intervention (Connor et al., 2014). As such, the current study estimates classes of polysubstance use in a large group of adolescents (ages 12–18 at baseline) and examines the longitudinal trajectories of cigarette, alcohol, marijuana, and illicit drug use from adolescence to young adulthood for each class. We also examine how adolescent levels of single substances relate to changes in use of other substances in the transition to young adulthood. **Research Questions.** Our research questions are: (1) What are the classes of polysubstance use in adolescence (T1: ages 12–18)?; (2) Are adolescent classes of polysubstance use associated with differences in the longitudinal trajectories of cigarette, alcohol, marijuana, and illicit drug use from ages 14 to 28 years (T2–T6)?; and (3) Are levels at age 14 of each substance associated with changes in the growth rates of other substances from adolescence to young adulthood (14–28 years)?

Methods

Participants and procedure

The Victoria Healthy Youth Survey (V-HYS) is a 10-year prospective longitudinal study of youth followed biennially for six assessments from 2003 (T1; $N = 662$; 48% male) to 2013 (T6; $N = 478$; 45% male). The mean age of participants was 15.02 (range 12–18) at T1, 17.11 (range 14–20) at T2, 19.03 (range 16–22) at T3, 21.85 (range 18–24) at T4, 23.76 (range 20–26) at T5, and 25.82 (range 22–28) at T6. The sample was randomly recruited and represent the population surveyed (see Leadbeater, Thompson, & Gruppuso, 2012). Males were slightly more likely to be lost to follow-up compared to females (i.e., males comprised 48% of the sample at T1 and 45% at T6; χ^2 (1, 662) = 8.77, $p = .003$). Participants from higher socioeconomic status (SES) families (T1: $M = 6.79$, $SD = 1.66$; $F(1, 636) = 19.39$, $p < .001$) were more likely to be retained in the study compared to participants from lower SES families ($M = 6.05$, $SD = 1.94$).

Youth and the parent or guardian for youth under age 18 gave written consent for participation at each wave and youth received a gift certificate at each interview. A trained interviewer administered the V-HYS individually in the youth's home or other private place. To enhance privacy, the portion of the V-HYS questionnaire dealing with drug and alcohol use was self-administered and placed in a sealed envelope not accessible to the interviewer. Retention rates were good at each assessment: 87% (T2), 81% (T3), 69% (T4), 70% (T5), and 72% (T6). The university's research ethics board approved the research protocol.

Measures

Demographic

Sex (Reference = Male), Socioeconomic status (SES), and Age in years was used in all analysis. SES was assessed using participant reported parent occupations and was coded from 1 to 9 using the Hollingshead Occupational Status Scale (Bornstein et al., 2003). The highest level of occupational prestige for either parent was used as a measure of SES.

Cigarette use

Youth indicated how many cigarettes they smoked in the past week. Response items include, 0 = *none*, 1 = *1 per week*, 2 = *less than half a pack*, 3 = *less than a full pack*, 4 = *more than a full pack*.

Heavy episodic drinking

Heavy episodic drinking (HED) was assessed using a single item that asked, "how often they had five or more drinks on one occasion in the past year." Response options ranged from 0 = *never*, 1 = *a few times a year*, 2 = *a few times a month*, 3 = *once a week*, and 4 = *more than once a week*. The definition of a standard drink was provided (see Evans-Polce, Vasilenko, & Lanza, 2015).

Marijuana use

Youth indicated their amount of marijuana use over the past year. Response items include, 0 = *never*, 1 = *a few*

times per year, 2 = *a few times per month*, 3 = *once a week*, 4 = *more than once a week*.

Illicit drug use

Using both formal and street names, participants were asked how often they used each of the following six illicit drugs in the past year: hallucinogens, amphetamines, club drugs, inhalants, cocaine, and heroin as 0 = *never*, 1 = *a few times a year*, 2 = *a few times a month*, 3 = *once a week*, and 4 = *more than once a week*. For the latent class analysis responses were dichotomized to 0 (none) or 1 (used at least one illicit drug in the past year). For the LGM, items for illicit drug use were summed.

Analysis plans

To create classes of polysubstance use we used LCA using T1 data. Following Asparouhov and Muthén's (2014) manual three-step approach using Mplus 7.4, we fitted a series LCA models to determine the number of classes that fit the data best (Lanza, Tan, & Bray, 2013; Masyn, 2013; Nylund-Gibson, Grimm, Quirk, & Furlong, 2014; Vermunt, 2010). We used categorical indicators of cigarette use, HED, marijuana use, and illicit drug use.

To establish the best fitting solution, we started with a 1-class solution and added classes until we no longer obtained good fit or convergence. We fit four separate LCA models–1 through 4 class solutions. We used several model fit indices that included -2 Log Likelihood (-2LL), Akaike Information Criteria (AIC), Bayesian Information Criteria (BIC), Consistent Akaike Information Criteria (CAIC), Approximate Weight of Evidence Criterion (AWE), the Lo-Mendell-Rubin adjusted likelihood ratio test (LMRT), and the bootstrapped likelihood ratio test (BLRT). Low values of -2LL, AIC, BIC, CAIC, and AWE indicate better model fit. (Nylund, Asparouhov, & Muthén, 2007). The LMRT and BLRT tests whether a model with k classes fits better than a model with k–1 classes (Lo et. al., 2001). Entropy indicates the degree of separation between classes, however, it was not used to assess model fit because it is not a fit index (Nylund-Gibson et al., 2014).

After identifying the adolescent polysubstance use classes, we added covariates (Sex, Age, SES, cigarette use, HED, marijuana use, and illicit drug use) using *auxiliary* command in Mplus. Doing this created a data set that includes all specified variables in the auxiliary command, latent class probabilities, and modal class assignments. Logits were then calculated from the classification probabilities and used to fix the classes. This ensured that covariates added to the model did not characterize the polysubstance use classifications (Nylund-Gibson et al., 2014).

Latent growth

To examine whether adolescent classes of polysubstance use were associated with differences in longitudinal trajectories of each substances used, we fit LGM using T2 through T6 data for cigarette use, HED, marijuana use, and illicit drug use within each of the latent classes. We modeled time as age in years (rather than assessment wave) to assess the development of each substance by adolescent polysubstance use class from 14 to 28 years of age. We examined the functional form of the data within each class and determined that quadratic growth functions fit the data best. We used Wald tests to assess differences in intercepts and slopes between classes. We examined the intercept differences for each class (e.g., conditional mean of illicit drug use at age 14). We then examined the extent to which the intercept of one drug predicted changes in the growth (slope) of each other substance used. For example, we examined whether illicit drug use at age 14 predicted changes in the growth rate of marijuana use from 14 to 28 years within each class.

Missing data

To minimize bias due to missing data, we used Full Information Maximum Likelihood (FIML) available in Mplus 7.4 (Muthén & Muthén, 1998–2012). FIML treats all observed indicators as latent factors allowing individuals to contribute whatever data they have available to the liklihood function.

Additionally, we improve on past methodologies by incorporating Tomczyk et al. (2016) recommendations for substance use research using mixture modeling strategies by (1) using categorical rather than binary variables for cigarette use, binge drinking, and marijuana use, (2) defining polysubstance use as three or more substance and co-use as two substances, and (3) including various fit indices and relevant statistics that demonstrate our process of identifying the optimal number of substance use classes.

Results

Classes of poly-substance use (LCA)

A three-class solution was the best fitting latent class model (see Table 1). Of the models with a significant LMRT, the three-class solution had the lowest -2LL, AIC, BIC, CAIC, and AWE. Entropy for the three-class model was .83, indicating acceptable class separation (Grimm, Ram, & Estabrook, 2016). As recommended by Tomczyk et al. (2016), Table 2 presents the indicator probabilities for each class.

The item probabilities of cigarette use, HED, marijuana use, and illicit drug use for each class are shown

Table 1. Model fit indices for 1 through 4 latent class models.

Classes	−2LL	AIC	BIC	CAIC	AWE	LMRT *p* Value	BLRT *p* Value
1	8205.180	8215.18	8241.175	8246.175	8292.169	–	–
2	7295.528	7317.528	7374.716	7385.716	7486.904	.001	.001
3	**7093.278**	**7127.278**	**7215.660**	**7232.66**	**7389.042**	**.001**	**.001**
4	3406.316	3452.316	3571.891	3594.891	3806.467	.977	NC

Note. −2LL = Negative 2 log likelihood; AIC = Akaike Information Criteria; BIC = Bayesian Information Criteria; CAIC = Consistent Akaike Information Criteria; AWE = Approximate Weight of Evidence Criterion; LMRT = Lo-Mendell-Rubin Test; BLRT = Bootstrapped Log Likelihood Ratio Test; NC= No Convergence.

in Figure 1. The high use class (11%), labeled Poly-use, had the highest probabilities of cigarette use (0.62), HED (0.90), marijuana use (1.0), and illicit drug use (0.72). The moderate use class (26%), labeled co-use, had high probabilities of HED (0.69) and marijuana use (0.86), but low probabilities of cigarette use (0.11) and illicit drug use (0.14). The low use class (63%), labeled low-use, had low probabilities of cigarette use (0.02), HED (0.07), marijuana use (0.03), and illicit drug use (0.01).

Descriptive statistics by class

Descriptive statistics for the three polysubstance use classes are shown in Table 3. There were similar proportions of males and females in the poly-use (Male: 5.9%; Female: 5.4%) and co-use (Male: 13.3%; Female: 12.5%) classes; however, the low-use class had more females (33.7%) than males (29.2%). Average age at T1 was significantly lower in the low-use class ($\bar{x} = 14.32$) compared to the poly-use ($\bar{x} = 16.40$) and co-use ($\bar{x} = 16.11$) classes. SES did not significantly differ across classes. Mean differences among baseline levels of cigarette use, HED, marijuana use, and illicit drug use for each class are given in Table 3.

Growth in substance use over time (LGM)

We used LGM to examine trajectories of each substance used from age 14 to 28 (see Figures 3 to 5) to assess changes in substances used for the three classes (poly-use, co-use, low-use). All models controlled for sex and SES (see Table 4). In the poly-use class, females reported lower levels of illicit drug use (b = –2.59, $p = .048$) at age 14 years compared to males. Similarly, females in the co-use class reported significantly lower initial levels of cigarette use (b = –1.16, $p = .02$) compared to males, but higher initial increases (b = .54, $p = .004$) and lower subsequent decreases (b = –.03, $p = .003$) over time compared to males. Further, females in the low-use class also reported significantly lower increases in cigarette use (b = –.13, $p = .016$) and HED (b = –.12, $p = .015$) compared to males.

In the poly-use class, individuals with higher SES reported higher average levels of marijuana use at 14 years old (b = 0.66, $p = .043$), and lower declines in marijuana use (b = –0.17, $p = .052$) over time compared to individuals with lower SES. In the co-use class, higher SES was associated with lower initial levels of HED (b = –0.46, $p = .021$) and marijuana use (b = –0.88, $p < .001$), but higher levels of illicit drug use (b = 0.95, $p = .008$) at age 14.

Table 2. Indicator probabilities by class.

	Poly-use (11%)		Co-use (23%)		Low-use (63%)	
	Estimate	*p* Value	Estimate	*p* Value	Estimate	*p* Value
Cigarette						
None	0.38	0.001	0.89	0.001	0.98	0.001
1 per week	0.03	0.181	0.03	0.025	0.01	0.226
Less than half a pack	0.24	0.001	0.02	0.443	0.01	0.090
Less than a full pack	0.05	0.052	0.01	0.571	0.00	1.0
More than a full pack	0.30	0.001	0.05	0.074	0.00	0.27
HED						
Never	0.10	0.009	0.31	0.041	0.93	0.001
A few times a year	0.18	0.001	0.34	0.001	0.06	0.001
A few time a month	0.33	0.001	0.26	0.001	0.00	0.796
Once a week	0.25	0.001	0.09	0.100	0.01	0.324
More than once a week	0.15	0.005	0.00	1.0	0.00	1.0
Marijuana						
Never	0.00	1.0	0.14	0.205	0.97	0.001
A few times per year	0.10	0.225	0.54	0.001	0.02	0.608
A few times a month	0.17	0.007	0.27	0.001	0.01	0.831
Once a week	0.09	0.065	0.05	0.165	0.00	1.0
More than once a week	0.65	0.001	0.00	1.0	0.00	1.0
Illicit Drugs						
None	0.28	0.001	0.86	0.001	0.99	0.001
At least one in the past year	0.72	0.001	0.14	0.058	0.01	0.057

Note. HED = Heavy Episodic Drinking.

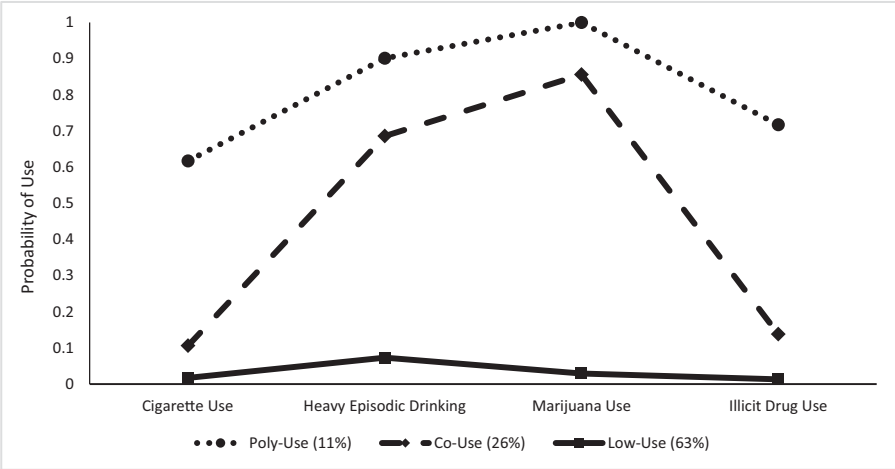

Figure 1. Substance use item probabilities for 3-class latent class model.

Also in the co-use class, individuals with higher SES had higher increases (b = 0.14, $p = .004$) and less decreases (b = –0.01, $p = .005$) in HED, and lower increases (b = –0.20, $p = .01$) and more decreases (b = 0.01, $p = .011$) in illicit drug use, compared to individuals with lower SES.

Cigarette use

For cigarette use, initial levels of cigarette use at age 14 did not differ significantly between poly-use and co-use classes ($\chi^2 = 0.44$, $df = 1$, $p = .506$), poly-use and low-use classes ($\chi^2 = 0.73$, $df = 1$, $p = .392$), or between co-use and low-use classes ($\chi^2 = 0.03$, $df = 1$, $p = .873$). Tests of differences in rate of change in cigarette use indicated that the poly-use class had significantly higher increases ($\chi^2 = 4.20$, $df = 1$, $p = .040$) and greater decreases ($\chi^2 = 5.77$, $df = 1$, $p = .017$) compared to low-use class. Linear growth ($\chi^2 = 2.25$, $df = 1$, $p = .134$) in the poly-use class was not significantly different from the co-use class, however, quadratic growth differed ($\chi^2 = 3.31$, $df = 1$, $p = .069$), indicating that cigarette use decreased more rapidly for the poly-use class. No differences in growth rates were found between co-use and low-use classes (Figure 2).

Heavy episodic drinking

For HED, the poly-use and co-use classes had similar intercepts ($\chi^2 = 0.44$, $df = 1$, $p = .507$), and linear ($\chi^2 = 0.02$, $df = 1$, $p = .879$) and quadratic ($\chi^2 = 0.17$, $df = 1$, $p = .678$) rates of change. The poly-use ($\chi^2 = 25.47$, $df = 1$, $p = .001$) and co-use classes ($\chi^2 = 17.65$, $df = 1$, $p = .001$) reported significantly higher levels of HED compared to the low-use class. Further, the poly-use ($\chi^2 = 3.18$, $df = 1$, $p = .075$) and co-use classes ($\chi^2 = 4.38$, $df = 1$, $p = .036$) reported lower increases in HED then the low-use class, and the co-use class ($\chi^2 = 4.13$, $df = 1$, $p = .042$) reported less rapid declines in HED compared to the low-use class. See Figure 3.

Marijuana use

For marijuana use, levels of marijuana use at age 14 did not significantly differ between the poly-use and co-use classes ($\chi^2 = 1.89$, $df = 1$, $p = .169$) or between the co-use and low-use classes ($\chi^2 = 0.32$, $df = 1$, $p = .569$). The poly-use class had significantly higher levels of marijuana use at age 14 ($\chi^2 = 24.06$, $df = 1$, $p = .001$) compared to the low-use class. Linear or quadratic changes

Table 3. Means (or n) and standard deviations (or %) of baseline characteristics (T1) and comparisons across substance use classes.

	Total sample ($N = 662$)	Poly-use 75 (11%)	Co-use 171 (26%)	Low-use 416 (63%)	F-test	*p* Value
Demographics						
Female *n* (%)	342 (51.7%)	36 (5.4%)	83 (12.5%)	223 (33.7%)	–	–
Male *n* (%)	320 (48.3%)	39 (5.9%)	88 (13.3%)	193 (29.2%)	–	–
Baseline Age in Years	15.02 (1.92)	16.40^a (1.27)	16.11^a (1.50)	14.32^b (1.83)	F = 95.97	$p < .001$
Socio-economic Status	6.54 (1.77)	6.22^a (1.99)	6.70^a (1.80)	6.54^a (1.71)	F = 1.87	$p = .154$
Substance Use						
Cigarette Use	0.32 (.98)	2.05^a (1.65)	0.24^b (.86)	0.04^b (.34)	F = 226.2	$p < .001$
Heavy Episodic Drinking	0.60 (1.00)	2.23^a (1.19)	1.09^b (.96)	0.11^c (.39)	F = 347.9	$p < .001$
Marijuana Use	0.73 (1.21)	3.39^a (1.01)	1.33^b(.67)	0.00^c (.00)	F = 1765.4	$p < .001$
Illicit Drug Use	0.13 (.34)	0.75^a (.44)	0.14^b (.35)	0.01^c (.12)	F = 275.6	$p < .001$

Note. Identical superscript represents nonsignificant differences. Different superscripts represent significant differences at $p < .01$.

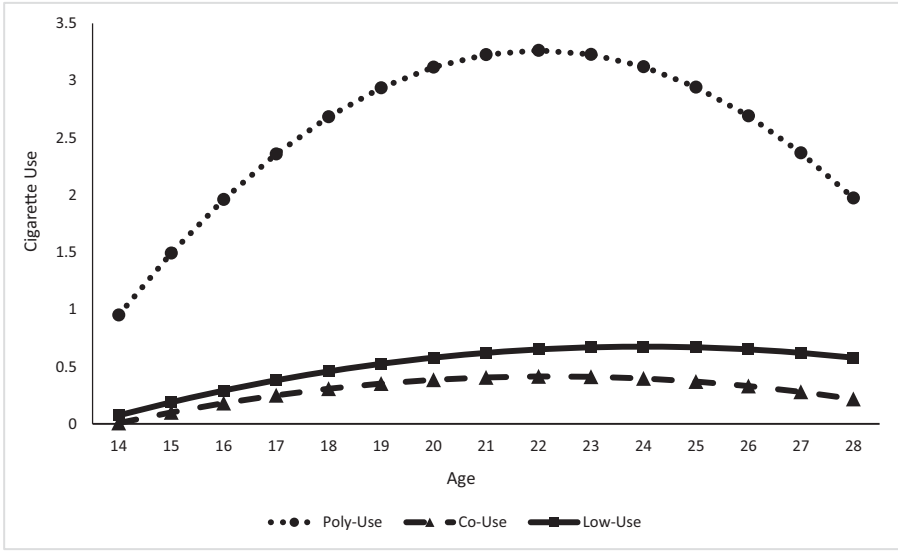

Figure 2. Latent growth of cigarette use over time by latent class.

in Marijuana use did not significantly differ across classes (Figure 4).

Illicit drug use

For illicit drug use, the poly-use ($\chi^2 = 5.78$, $df = 1$, $p = .007$) and co-use ($\chi^2 = 5.94$, $df = 1$, $p = .015$) classes reported significantly higher levels of illicit drug use at age 14 compared to the low-use class. The poly-use and co-use classes had similar initial levels of illicit drug use at age 14 ($\chi^2 = 0.22$, $df = 1$, $p = .641$) and linear ($\chi^2 = 0.05$, $df = 1$, $p = .830$) and quadratic ($\chi^2 = 0.30$, $df = 1$, $p = .587$) rates of change. The poly-use (Linear: $\chi^2 = 3.11$, $df = 1$, $p = .078$; Quadratic: $\chi^2 = 4.49$, $df = 1$, $p = .034$) and co-use (Linear: $\chi^2 = 132.61$, $df = 1$, $p < .001$; Quadratic: $\chi^2 = 75.67$, $df = 1$, $< .001$) classes had higher linear and quadratic rates of change compared to the low-use class (Figure 5).

Intercepts predicting changes in growth over time

Table 5 displays the results for intercepts of one substance predicting changes in linear growth of another substance over time. Examining whether levels of HED, marijuana use, and illicit drug use at age 14 predicted changes in growth rates in cigarette use overtime revealed one significant association. For the low-use class, higher initial levels of illicit drug use at age 14 was associated with increases in cigarette use over time (b = .15, $p < .001$). Examining the extent to which levels of cigarette, marijuana, and illicit drug use at age 14 predicted changes in growth rates in HED revealed two significant associations. For the co-use class, higher initial levels of marijuana use was associated with decreases in HED over time (b = -.11, $p = .024$), and higher initial levels of illicit drug use was associated with increases in HED over time (b = .23, $p = .049$). The associations between intercepts of cigarette use,

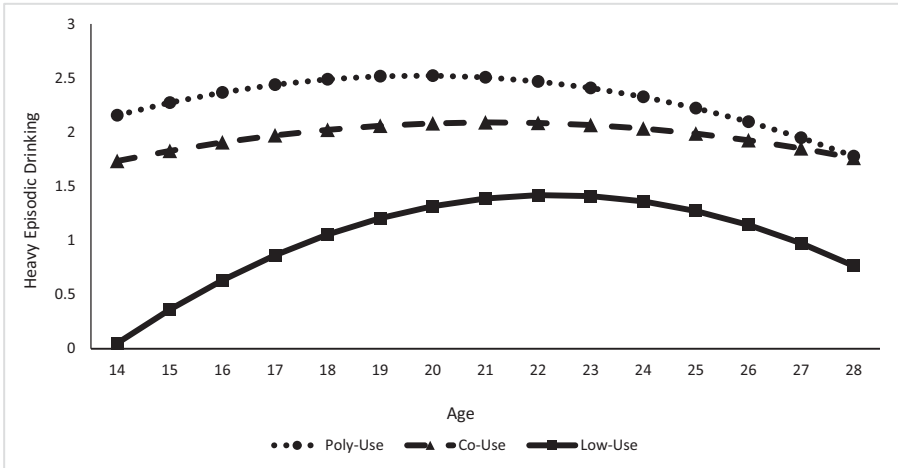

Figure 3. Latent growth of heavy episodic drinking over time by latent class.

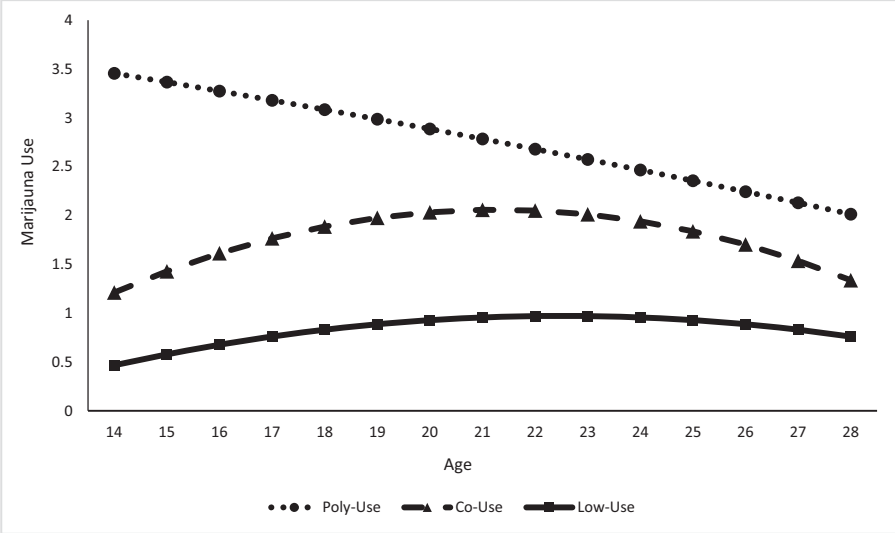

Figure 4. Latent growth of marijuana use over time by latent class.

HED, and illicit drug use and changes in growth in marijuana use were not significant. Examining whether levels of cigarette use, HED, and marijuana use at age 14 predicted changes in growth rates in illicit drug use overtime revealed two significant associations. For the co-use class, higher levels of cigarette use at age 14 was associated with increases in illicit drug use over time (b = 1.24, $p = .04$) and higher levels of marijuana use was associated with significant decreases in growth of illicit drug use over time (B = –0.27, $p = .05$).

Discussion

This study identified three classes of substance use in adolescence (ages 12–18). Important class differences in the levels and trajectories of substances used were found and are described below. Sex and SES differences in substances used were found. Further, in a few instances, levels of use of a single substance in adolescences predicted changes in the use of other substances over time. Findings from the current study extend previous research by examining longitudinal trajectories of substance use within each of the adolescent classes across 14 years (14–28 years).

What are the adolescent classes of polysubstance use?

The first goal of this study was to examine adolescent classes of polysubstance use. We found three classes of polysubstance use that included, a poly-use class (n = 75, 11%) that used all four substances (cigarette, alcohol, marijuana, and illicit drugs) at high levels, a co-use class (n = 171, 26%) that primarily used alcohol and marijuana, and a low-use class (n = 416, 63%) that were low

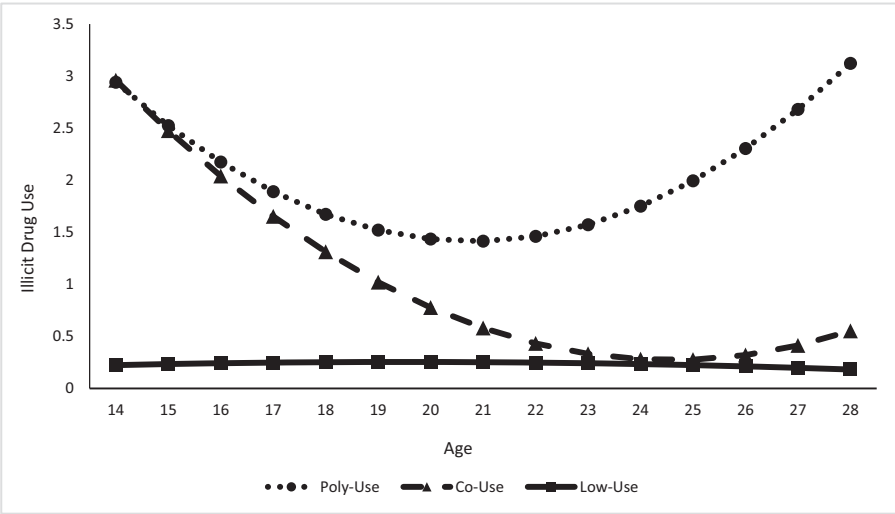

Figure 5. Latent growth of illicit use over time by latent class.

Table 4. Sex and socio-economic status predicting substance use intercepts and slopes by class.

	Poly-use	Co-use	Low-use
Intercepts			
Cigarette Use on SES	0.25	− 0.31	− 0.06
Cigarette Use on Sex	1.99	− 1.16*	0.25
Linear Slopes			
Cigarette Use on SES	0.06	0.10	0.02
Cigarette Use on Sex	− 0.34	0.54**	− 0.13*
Quadratic Slopes			
Cigarette Use on SES	− 0.01	− 0.01	− 0.00
Cigarette Use on Sex	0.01	− 0.03**	0.01
Intercepts			
Heavy Episodic Drinking on SES	0.04	− 0.46*	0.01
Heavy Episodic Drinking on Sex	0.69	− 0.95	0.07
Linear Slopes			
Heavy Episodic Drinking on SES	− 0.00	0.14**	− 0.01
Heavy Episodic Drinking on Sex	− 0.19	0.06	− 0.12*
Quadratic Slopes			
Heavy Episodic Drinking on SES	0.00	− 0.01**	0.00
Heavy Episodic Drinking on Sex	0.01	− 0.00	0.01
Intercepts			
Marijuana Use on SES	0.66*	− 0.88***	0.03
Marijuana Use on Sex	− 1.53	− 0.05	− 0.23
Linear Slopes			
Marijuana Use on SES	− 0.17*	0.19	− 0.02
Marijuana Use on Sex	0.26	− 0.12	0.00
Quadratic Slopes			
Marijuana Use on SES	0.01	− 0.01	0.00
Marijuana Use on Sex	− 0.02	0.01	− 0.00
Intercepts			
Illicit Drug Use on SES	− 0.24	0.95**	− 0.05
Illicit Drug Use on Sex	− 2.59*	− 0.30	− 0.01
Linear Slopes			
Illicit Drug Use on SES	0.08	− 0.20**	0.02
Illicit Drug Use on Sex	0.53	0.08	0.03
Quadratic Slopes			
Illicit Drug Use on SES	− 0.01	0.01**	− 0.00
Illicit Drug Use on Sex	− 0.02	− 0.00	− 0.00

Note.
*$p < .05$,
**$p < .01$,
***$p < .001$. Sex is coded such that male = 0 and female = 1.

on all substances. The three classes of polysubstance use are consistent with previous LCA studies that examined adolescent classes of polysubstance use, such that the low-use class made up the largest class, followed by co-use, and poly-use classes (Conway et al., 2013; Gilreath et al., 2015; Morean, el. al., 2016; Tomczyk et al., 2016). Similar to our findings that found that 37% of the sample used multiple substances (poly-use or co-use), using an adolescence sample, Connell and colleagues (2010) reported that 39% of their sample used multiple substances. Our findings provide further evidence that several adolescents use multiple substances at a time (Moss et al., 2014; Tomczyk et al., 2016). Prevention and intervention efforts may find greater success by addressing the use of multiple substances and identifying different use patterns in order to employ tailored strategies depending on one's patterns of use.

It should also be noted that we did not find tobacco only or marijuana only classes that have previously been found in some studies (Tomczyk et al., 2016). This may have been due to our ability to detect these single use classes based on the limited size of the current sample. Although, several adolescent and adult substance use studies have failed to identify a single substance use class which may suggest that polysubstance use is more common among adolescence. More work is need to identify the extent of adolescence that use multiple substances.

Are adolescent classes of polysubstance use associated with differences in the longitudinal trajectories of cigarette, alcohol, marijuana, and illicit drug use?

We also examined longitudinal trajectories of substance use (cigarette, alcohol, marijuana, and illicit drug use) within each substance use class and found considerable stability of substance use trajectories from adolescence to young adulthood. Individuals in the poly-use class continued to use all substances from 14 to 28 years. Specifically, in this class, cigarette use increased, peaked at 22 years of age, and decreased slightly over time. HED remained stable over time decreasing slightly by 28 years. Marijuana use steadily declined over time, but, remained the highest among all substance use classes, and illicit drug use decreased until 21 then increased until 28 years of age. In the co-use class cigarette use remained low across the entire study. Trajectories of HED and marijuana use were stable over time. Illicit drug use decreased steadily during adolescence and remained low. The low-use classes were low on the use of all substances over time except for HED, which peaked at 22 years of age and then decreased. Consistent with past research (Hair et al., 2017; Nelson et al., 2015; Terry-McElrath et al., 2017) the trajectories found in the current study show that substance use patterns are established in adolescence and are strongly associated with the use of substances later in life. The increases in HED for the low-use class may reflect widely accepted norms for alcohol use in adolescence (Borsari & Carey, 2001; Brooks-Russell, Simons-Morton, Haynie, Farhat, & Wang, 2014). This is a time when individuals are experiencing transitions (e.g., attending university) with considerable stress, increasing demands, peer pressures, and greater independence that together may also influence drinking behaviors. Further, emerging adulthood is a developmental period characterized by increasing opportunities for exploration including engaging in greater risk behaviors like heavy episodic drinking (Arnett, 2005; Sussman, & Arnett, 2014). The normative beliefs around some drugs coupled with the developmental stage may help explain the stability of use overtime.

Gender and SES differences were found among the three classes. Specifically, in the low-use class, females reported less growth in cigarette use and HED over time

Table 5 . Intercepts (age 14) predicting changes in linear growth in substance use from ages 14 to 28.

	Poly-use	Co-use	Low-use
Linear Slopes			
Cigarette Use on Heavy Episodic Drinking	− 0.07	− 0.01	− 0.02
Cigarette Use on Marijuana Use	− 0.18	− 0.02	0.03
Cigarette Use on Illicit Drug Use	0.58	N/A	0.15***
Heavy Episodic Drinking on Cigarette Use	0.14	− 0.04	0.09
Heavy Episodic Drinking on Marijuana Use	0.13	− 0.11*	0.13
Heavy Episodic Drinking on Illicit Drug Use	− 0.54	0.23*	− 0.38
Marijuana Use on Cigarette Use	− 1.67	− 1.18	1.74
Marijuana Use on Heavy Episodic Drinking	− 0.54	− 0.40	0.59
Marijuana Use on Illicit Drug Use	2.92	2.10	− 3.04
Illicit Drug Use on Cigarette Use	0.09	1.24*	− 0.09
Illicit Drug Use on Heavy Episodic Drinking	− 0.03	0.06	− 0.01
Illicit Drug Use on Marijuana Use	− 0.02	− 0.27*	0.01

Note.
*$p < .05$,
**$p < .01$,
***$p < .001$. N/A could not be estimated.

compared to males. Females in the co-use class reported lower levels of cigarette and HED at age 14 than males, however, over time cigarette use increased more rapidly and subsequently did not decline as fast as males. Females in the poly-use class reported lower levels of illicit drug use at age 14 compared to males. These findings suggest that there may be higher early risk for males, however, over time females tend to catch up. Some studies have found that males report higher levels of alcohol use during adolescence (Patrick & Schulenberg, 2014), and this difference continues into adulthood (Johnston, O'Malley, Bachman, & Schulenberg, 2012). Further, recent studies also find that males use more marijuana than females (Carliner et al., 2017), however, this difference was not found in our sample. Findings for SES were mixed. For the co-use class, individuals with higher SES reported lower levels of HED and marijuana, and higher levels of illicit drug use at age 14, but increased more rapidly in HED and subsequently declined more slowly than individuals with lower SES. In the co-use class individuals with higher SES increased less rapidly and subsequently declined more in illicit drug use. For the poly-use class individuals with higher SES had higher levels of marijuana use at age 14 but decreased more rapidly over time than individuals with lower SES. The extant literature is mixed in terms of SES, some studies find that tobacco, alcohol, marijuana use, and illicit drugs are associated with lower SES (Casswell, Pledger, & Hooper, 2003; Daniel et al., 2009; Volkow, Baler, Compton, & Weiss 2014), while other studies find that alcohol, marijuana, use are associated with higher SES, and in some cases no differences have been found (e.g., illicit drug use; Humensky, 2010). Further research is needed to further understand sex and SES difference among longitudinal patterns of substance use.

Taken together, given the considerable amount of continuity that was found among the different substance use patterns future studies should examine why adolescents are choosing to use certain substances over others. Individual and social ecological factors could help characterize differences between substance use classes which could inform prevention and intervention efforts about the characteristics of different patterns of use. For example, differences in individual factors like attitudes and values towards drugs, or social factors like peer deviance and peer use, parental monitoring and supervision efforts, and availability of substances could help contextualize different use patterns.

Are early levels of substance use associated with changes in the growth rates of other substances?

The third goal of the current study was to examine whether the use of one substance predicted changes in growth in other substances across adolescence. Researchers have long been interested in the developmental sequences of drug initiation (Degenhardt et al., 2009, 2010; Fredriksson et al., 2017; Kandel & Faust, 1975; Kirby & Barry, 2012; Nkansah-Amankra, & Minelli, 2016; Miller & Hurd, 2017; Vanyukov et al., 2012). In the current study, levels of one substance was not associated with the rate of change in other substances, except in the co-use class higher levels of illicit drug use at 14 predicted increases in HED, and higher levels of cigarette use at age 14 predicted increases in illicit drug use. However, also in the co-use class, higher initial levels of marijuana use were associated with decreases in HED and illicit drug use over time indicating that marijuana use may lead to less use in other drugs for the co-use class. Additionally, for the low-use class, higher levels of illicit drug use at 14 were associated with higher rates of cigarette use over time. The poly-use class already used all substances and the low-use class used substances at a low rate which may explain the few significant findings. It is also possible that biennial assessments are too far

apart to assess short-term effects of using one substance on another.

Implications for prevention

Prevention and intervention efforts used among adolescents show some success at reducing substance use (for review see Ennett et al., 2003; Stockings et al., 2016). However, most interventions focus on single drug types, as a result, their effects on polysubstance use are not known (Conor et al., 2014). Substance use harms and risks for dependency may be related to the use of multiple substances. Risk for addiction, related to tobacco, alcohol, marijuana, and heroin (see Anthony, Warner, & Kessler 1994) may compound over time complicating efforts to treat dependencies on single substances. Our findings show strong continuity in early adolescent patterns of substance use and use of substances in young adulthood, as such, prevention programs need to target polysubstance use in adolescences and should include harm reduction and safe use strategies. Given many adolescence will use multiple substances, to reduce potential harms it is important for efforts to include safer use strategies and protocols for responding to emergencies.

Implications for policy

Several states have legalized recreational marijuana in the United States and the legalization of recreational marijuana in Canada is planned for 2018. The current study found that marijuana is co-used with other substances, however, current discourse around marijuana policies do not consider harms or dependency related to the use of multiple substances (e.g., see Canadian Public Health Association, 2016; US Surgeon General's report on addictions, 2016). The debate on age restrictions for marijuana use to prevent harms to adolescences have not considered that trajectories of use may be well established before age 18. Policies limiting access and advertising to children and adolescents are needed. Evidence-based education aimed at clarifying myths of marijuana use, reducing co-use with other substances, and harm reduction strategies need to target early adolescences.

Limitations

Despite the notable findings and the unique modeling approach, this study had several limitations that should be noted. The sample came from an ethnically homogenous group of adolescents in Canada restricting the generalizability of the findings. Further, many of the youth had already been exposed to substances during adolescence. Examining the initiation of drugs in a younger sample could provide better insight into the sequence and progression of drug initiation. Our biennial assessments may be too far apart to show the sequence of drug initiation. Additionally, the current study classified substance use during adolescence, and did not examine whether youth transition into different substance use classes across young adulthood. It is likely that younger adolescents in the low-use class may not have established a pattern of use that was evident as youth who were older at T1. This limitation could be addressed in future studies by examining the extent of which individuals remained in the same class or transitioned to a different class over time.

Conclusion

Notwithstanding these limitations, the current study has several strengthens. While several efforts have leveraged various mixture models to clarify classes of adolescent polysubstance use and longitudinal trajectories of substance co-use (typically alcohol and tobacco), no studies to our knowledge have considered the constellations of polysubstance use (including cigarette, HED, marijuana, and illicit drugs) over the transition from adolescence to young adulthood. In line with previous research, our findings confirmed the presence of various polysubstance use classes during early adolescence, and found strong continuity in longitudinal substance use trajectories within these differential polysubstance use classes. Additionally, we found some evidence of one substance predicting changes in the rate of growth in other substances used. However, the direction of the effects was mixed with some predicting increases and others predicting decreases in growth. Finally, this study adds to the extant literature that examines associations with adolescent classes of substance use and substance use problems as an adult. Prevention, intervention, and policy efforts around substance use would benefit by a focus on polysubstance use. Efforts that only target a single drug type may be missing an important opportunity to reduce the use and subsequent consequences related to the use of multiple substances.

Declaration of interest

The authors report no conflicts of interest.

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