



Adolescent drug use initiation and transition into other drugs: A retrospective longitudinal examination across race/ethnicity

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ABSTRACT

Background: Understanding adolescent drug use mechanisms is critical for drug use prevention. Although some theories such as the gateway theory suggest that drug users gradually transition into using more addictive drugs, there is no consensus about such a hypothesis. One important factor that hinders the advancement of knowledge in this area is the scarcity of longitudinal studies examining the type of drugs adolescents initially use and the different pathways adolescents take to transition into using other drugs as they grow older.

Methods: Using the pooled sample of adolescent drug users (14–17 years old; $n = 10,644$) from the National Survey on Drug Use and Health (2015–2018), we constructed longitudinal data on adolescents' illicit drug use history other than the use of tobacco and alcohol based on the age of drug initiation. This allowed us to investigate what drugs were initially used by adolescents, how the use of these drugs may have progressed into a new drug, and whether there were racial/ethnic differences in the initiation and progression. The retrospective longitudinal data analyses applied life table method and Cox regression models.

Results: Two thirds of the adolescent drug users initiated their drug use trajectories with marijuana, one quarter with inhalants, and the remaining with hallucinogens, prescription drugs, and hard drugs. Adolescent drug users who initiated with different drugs showed unique trajectories to the use of a new drug. By year 8, the probability of using a new drug was about 40% and 70% to 80% for adolescents who initiated with inhalants and other drugs, respectively. The probability of using a new drug for adolescents who initiated with marijuana and inhalants accumulated stably over time, and its difference with that of other drug users diminished over time. The multivariate Cox regression models suggest the observed discrepancies generally held after controlling for covariates. There were also racial/ethnic differences in adolescent drug use initiation and progression, with Black/African American adolescents being the least likely to switch to the use of a new drug.

Conclusion: Adolescents' initial use of marijuana and inhalants may lead to substantial risks of using other drugs over time. It is therefore important to screen adolescent drug use comprehensively and provide early interventions to prevent an escalation to more detrimental drugs. The findings provide new evidence to support aspects of both the gateway and generalized risk drug use theories.

1. Introduction

Substance use among adolescents is a significant public health concern in the United States. Although adolescents' use of alcohol and tobacco has dropped by about half and more than three quarters respectively in the past two decades (Substance Abuse and Mental Health Services Administration [SAMHSA], 2019), their use of illicit drugs has remained largely stable (Vaughn, Salas-Wright, Cordova,

Nelson, & Jaegers, 2018). Of the illicit drugs used by adolescents in the past year, marijuana (12.5%) was the most commonly used, followed by misused prescriptions (4.8%), opioids (2.8%), inhalants (2.7%), hallucinogens (1.5%), and hard drugs (e.g., cocaine, methamphetamine and heroin, <1%; SAMHSA, 2019). In addition, substance use co-occurrence is common among adolescent substance users. About two thirds of adolescent drug users use both alcohol and marijuana and about one fifth of them are using three and more drugs (Choi, Lu, Schulte, &

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Temple, 2018).

Substances use impairs adolescent wellbeing in an extensive way, leading to poor academic performance, aggravated physical and mental health problems, disruptions in family functioning, unhealthy peer relationships, and accidental deaths in childhood and throughout their lifetime (Brière, Fallu, Morizot, & Janosz, 2014; Hawkins, Catalano, & Miller, 1992; Pei, Wang, Wu, Shockley McCarthy, & Wu, 2020; Marsiglia, Wu, Ayers, & Weide, 2019; Spooner & Hetherington, 2004). The devastating consequences of substance use and misuse are exemplified in the current opioid epidemic, which has claimed nearly 43,000 lives and incurred \$95.8 billion in societal costs in 2016 alone (Normile, Hanlon, & Eichner, 2018).

Understanding the mechanism of adolescent drug use is critical for effective prevention strategy development and implementation. Gateway drug theory is often used to explain adolescent's drug use initiation and progression (Golub & Johnson, 2002; Kandel, 2002). The theory hypothesizes that drug users tend to start with soft drugs such as tobacco, alcohol, and marijuana and then progress to hard drugs such as heroine and crack (Fairman, Furr-Holden, & Johnson, 2018; Maldonado-Molina & Lanza, 2010; Nkansah-Amankra & Minelli, 2016). For example, Nkansah-Amankra and Minelli (2016) longitudinal study based on national data shows that early adolescence gateway drug (e.g., tobacco and alcohol) use was significantly associated with the use of marijuana, cocaine, and other illicit drugs in older adolescence. The theory has also been supported by evidence from prevention practices, in which the reduction of tobacco, alcohol, and marijuana use has lowered the probability of other illicit drug use (Botvin, Griffin, Diaz, & Fill-Williams, 2001; Maldonado-Molina & Lanza, 2010).

On the other hand, generalized risk theory argues that there are common risks underlying individuals' drug use behavior, especially drug use disorders. Common risks such as individual genetic and psychological traits and environmental factors like familial and peer influence render a sequential order in drug use unlikely (DuPont, Han, Shea, & Madras, 2018; Palmer et al., 2014; Xian et al., 2008). The theory has been supported by studies that do not find a sequential order in drug use (Rebblon & Van Gundy, 2006; Wu, Yan, Marsiglia, & Perron, 2020), and studies that suggest that genetic and environmental factors are linked to drug use and use disorders (Degenhardt et al., 2010; DuPont et al., 2018). In addition, studies have found racial/ethnic differences in drug use initiation and progression between and within groups (Park, McCoy, Erasquin, & Bartlett, 2018; Vaughn, Wallace, Perron, Copeland, & Howard, 2008). For example, Vaughn et al. (2008) found that Black adolescents were more likely to use marijuana before tobacco than Caucasian adolescents.

There are limitations in existing studies examining adolescent drug use initiation and progression. First, most studies used cross-sectional data and thus can only assess the co-occurrence rather than sequence of drug use (Nguyen et al., 2019; Winstanley, Stover, & Feinberg, 2020; Zuckermann et al., 2020). For example, Nguyen et al. (2019) found that the joint use of both tobacco and marijuana was most common among adolescents, but the cross-sectional data prevented investigating whether adolescents started from using tobacco or marijuana. Second, among a limited number of longitudinal studies that examined the drug use sequence, the focus was often to identify a gateway drug among tobacco, alcohol, and marijuana (Castaldelli-Maia et al., 2018; Cleveland & Wiebe, 2008; Park et al., 2020; Vaughn et al., 2008). However, some adolescents may initiate drug use with a different type such as inhalants (Castaldelli-Maia et al., 2014; Compton & Volkow, 2006; Kelly et al., 2013; Lankenau et al., 2012; Wu et al., 2020). There is a lack of in-depth investigation about drug use initiation and progression among a broad range of illicit drugs. A unique study examining a comprehensive list of illicit drugs, found that about one quarter of Brazil's college students initiated illicit drug use with inhalants (Castaldelli-Maia et al., 2014). Many previous studies primarily focused on the use of alcohol, tobacco, and marijuana, while there are less specifics about the initiation and progression of other illicit drugs. Third, for adolescents who

initiated drug use with different types of drugs, few studies have examined whether their trajectories into using a new drug vary. Finally, there may be racial/ethnic and related socioeconomic differences in adolescent drug use initiation and transition that deserve exploration (Park et al., 2018; Vaughn et al., 2008). The lack of a suitable longitudinal dataset with national representativeness may be a major barrier to overcome the aforementioned knowledge gaps.

Using adolescents' reported ages of initiation into different illicit drug use, the current study constructed a retrospective national longitudinal dataset to trace adolescents' initiation of a comprehensive list of illicit drugs and subsequent transition into using a new drug. We did not include adolescents' use of alcohol and tobacco in the current study because their use and relations with other drugs have been extensively studied (e.g., Fairman et al., 2018; Nguyen et al., 2019), and the social contexts related to their use may be somewhat different from that related to the use of other illicit drugs (Jackson, Henriksen, Dickinson, & Levine, 1997; Wenzel, Tucker, Golinelli, Green, & Zhou, 2010). The exclusion of these two types of drugs allows to investigate the initiation and transition among other illicit drugs with more depth and specificity (Castaldelli-Maia et al., 2014). The current study contributes to the literature by examining three questions related to drug use initiation and transition:

- When and what type of illicit drugs adolescents initially use?
- How does the initial drug type relate to the trajectory of using a new illicit drug?
- Are there any racial/ethnic differences in those drug use initiations and transitions?

When examining how adolescent drug users' initial drug types may contribute to the trajectory of using a new drug, factors that are commonly associated with adolescent drug use may confound the process, and thus it is important to control for these variables. Based on the existing literature and available data, we took into account multi-dimension covariates, including adolescent characteristics as indicated by race/ethnicity, age, gender, school attendance, health status, sensation seeking, depression, disability, peer substance use, and antisocial behavior (Donaldson, Nakawaki, & Crano, 2015; Nkansah-Amankra & Minelli, 2016; Siegel et al., 2014; Vaughn et al., 2018; Zimmerman & Farrell, 2017; Zuckermann et al., 2020); family characteristics as indicated by family structure, parenting, family income, and youth health insurance coverage (Donaldson et al., 2015; Hemovich, Lac, & Crano, 2012; Hemovich & Crano, 2009; Zimmerman & Farrell, 2017; Zuckermann et al., 2020); and place of residence.

2. Methods

2.1. Sample and data

The sample consisted of four years of pooled data (2015–2018) derived from the National Survey on Drug Use and Health (NSDUH), a nationally representative study which annually surveys about 70,000 noninstitutionalized individuals 12 years and older in the U.S. civilian population across all 50 states and the District of Columbia (Center for Behavioral Health Statistics and Quality, 2019). About one-fifth of the annual NSDUH survey respondents were adolescents of 12 to 17 years old ($N = 54,866$). The study focused on adolescents who reported ever using any illicit drugs at a specific age ($n = 12,795$). Because only a small fraction of adolescents aged 12 to 13 ever used illicit drugs, the sample was limited to adolescents 14 to 17 to allow a longer period of retrospective recall of their illicit drug use history ($n = 11,034$). The data only had a small number of missing values in a few variables. After excluding cases with missing values, the final sample consisted of 10,644 cases with completed data.

2.2. Measures

Initial drug and time to a new drug. In the NSDUH, respondents were first asked whether they ever used each of a comprehensive list of illicit drugs including marijuana, cocaine, crack, hallucinogens, inhalants, and methamphetamine, and misused prescription drugs (e.g., painkillers, tranquilizers, stimulants, and sedatives). When there was a positive response, a subsequent question would ask “How old were you the first time you used [mentioned drug]?” Based on this information, we were able to identify which drug was used in which year, sort the order of drug use, and calculate the interval between the initial drug and use of a new drug (if applicable). The period from the reported time of initial drug use up to the time of the NSDUH interview was used as the observation period. Two variables were created with the data for the survival analysis. *Initial drug* indicated the illicit drug used at an adolescent’s youngest age, if he/she ever used illicit drugs. To facilitate analyses, low frequency illicit drugs were combined to form five types of illicit drugs: marijuana, hallucinogens, hard drugs (cocaine, crack, and methamphetamine), inhalants, and misused prescriptions (e.g., painkillers, tranquilizers, stimulants, and sedatives). *Time to a new drug* indicated the interval between the age of initial drug use and the age of using a new drug, or the age at the time of interview if the adolescent drug users did not use a new drug. Only a small number of adolescents reported initial drug use earlier than 7 years old. These respondents were coded as initiating drug use at 7 years old. This allows a maximum of 10 years to observe the trajectory of adolescent drug users, except for the misuse of prescriptions. For this variable, the adolescents were asked to recall misuse in the past 12 months. Because only a small number of cases had an observation period of more than 8 years, the maximal observation period was truncated at 8 years.

Sensation seeking was based on two questions: “How often do you get a real kick out of doing things that are a little dangerous” and “How often do you like to test yourself by doing something a little risky?” rated on a 4-point scale (1 = never to 4 = always). The mean of the two responses were calculated and dichotomized based on the median (1 = yes, and 0 = no), with yes indicating a respondent’s sensation seeking value larger than the median and no otherwise (Donaldson et al., 2015).

Past-year Major Depressive Episode (MDE) (1 = yes, and 0 = no) was measured using an adapted version of the depression section of the National Comorbidity Survey-Adolescents derived from the World Health Organization Composite International Diagnostic Interview—Short Form (CIDI-SF), which has been well validated (Kessler, Andrews, & Mroczek, 1998).

Disability was based on five questions asking whether adolescents had difficulties in hearing, seeing, thinking, walking, and dressing (e.g., “Are you blind or do you have serious difficulty seeing, even when wearing glasses?”). Adolescents with a positive response to any of the five questions would be coded as yes (1), otherwise coded as no (0).

Peer substance use was based on four questions asking the prevalence of peers at school smoking cigarettes, using marijuana or hashish, drinking alcoholic beverages, and getting drunk at least once a week, which were rated on a 4-point scale (1 = none of them; 2 = a few of them; 3 = most of them; and 4 = all of them). If an adolescent responded “most of them” or “all of them” to at least one of the four questions, the variable was coded as 1, otherwise coded as 0.

Antisocial behavior was based on questions that asked whether adolescents had any of the following antisocial behaviors: serious fight at school or work, group fights, carrying a handgun, selling illegal drugs, stealing or trying to steal an item more than \$50 and attacking with intent to seriously harm. The variable was dichotomized if an adolescent endorsed any of the antisocial behaviors (1 = yes, and 0 = no) (Vaughn, Nelson, Salas-Wright, DeLisi, & Qian, 2016).

Race/ethnicity was coded as Non-Hispanic White (“White” hereafter), Black/African American (“Black” hereafter), Hispanic, and Other. Other covariates include adolescent individual characteristics of *age* (14 to 15, and 16 to 17), *gender* (1 = boy, and 0 = girl), *school attendance* (1 = yes,

and 0 = no), self-rated *health status* (1 = good to excellent, and 0 = fair or poor); family characteristics of *family structure* (1 = two-parent family, 2 = single-parent family, and 3 = other), *positive parenting scale* (mean of seven questions rated on a 4-point scale regarding parental support and monitoring such as checking/helping homework, limiting time on TV/with friends, telling they were proud of things adolescents had done; Donaldson et al., 2015; Vaughn et al., 2016), *family income* (1 = equal or larger than \$50,000, 0 = less than \$50,000), *health insurance coverage* (1 = yes, and 0 = no), and *region* (1 = large metro, 2 = small metro, and 3 = non-metro).

2.3. Analytic strategies

First, descriptive analyses were conducted to present sample characteristics of all the variables. Then we conducted life table analysis (Allison, 2010) to show the cumulative probability for adolescent drug users’ transitioning into using a new drug over time across drug types and races/ethnicities. Last, we developed longitudinal models to predict the use of a new drug among adolescents who initiated drug use. Specifically, several Cox regression models were implemented to include predictors in a step forward manner (Allison, 2010). All analyses were performed using SAS 9.4 for Windows (SAS Institute Inc., 2018), and weights were incorporated for national representativeness (Center for Behavioral Health Statistics, 2018).

3. Results

3.1. Sample characteristics

Among the initially used illicit drugs by adolescents, marijuana accounted for more than two thirds (68.72%), followed by inhalants (26.76%), misused prescription drugs (2.80%), hallucinogens (1.25%), and hard drugs (0.47%). More than one third (37.44%) of the adolescents were 14 to 15 years old, and the remaining were 16 to 17 years old. Half were boys (50.49%). Most of the adolescents were in school (88.23%), and most (93.51%) rated their health status as good to excellent. Less than half of the adolescents had a sensation score above the median (41.75%). Approximately one quarter of respondents had reported an MDE (25.64%) in the past year. Approximately one quarter reported a disability (25.28%) and 35.20% reported being in a school where most or all of their peers used substances. More than one third of the adolescents reported delinquency (40.99%). The majority of the adolescents lived in two-parent families (63.17%), followed by single parent (30.40%) and other (6.43%) families. The positive parenting scale had a mean of 2.84 in the range of 1 to 4. Slightly more than half (55.10%) of the families had an income of \$50,000 or more. Most adolescents reported having health insurance (95.03%) and the majority of adolescents resided in large metro regions (56.72%), followed by small metro regions (29.63%) and non-metro regions (13.65%) (see Table 1).

There was racial/ethnic variation in some of the examined variables. White, Black, and Hispanic adolescents were more likely to initially use marijuana than Other adolescents (68.14% to 71.43% vs. 63.19%, $p = 0.006$), but they were less likely to initially use inhalants (22.84% to 27.60% vs. 31.35%, $p = 0.006$). Hispanic adolescents were slightly less likely to rate their health status as good to excellent (91.51% vs. 92.30% to 94.57%, $p = 0.001$); Black adolescents were less likely to have a sensation seeking score above the median (31.54% vs. 39.73% to 45.58%, $p < 0.001$) and have a past-year MDE (17.07% vs. 26.21% to 27.44%, $p < 0.001$). However, they were more likely to report delinquency (45.91% vs. 39.63% to 41.07%, $p = 0.013$), live in a single parent family (54.09% vs. 24.44% to 30.70%, $p < 0.001$), rate higher on the positive parenting scale (mean = 2.93 vs. 2.76 to 2.84, $p < 0.001$) and were more likely to live in a large metro region (67.28% vs. 49.67% to 64.60%, $p < 0.001$). Hispanic adolescents were less likely to have health insurance coverage than adolescents from other racial/ethnic backgrounds were (89.95% vs. 95.48 to 96.94%, $p < 0.001$) (see

Table 1
Sample description.

	Non-Hispanic White (n = 5511)		Black/African American (n = 1496)		Hispanic (n = 2395)		Other (n = 1242)		Total (N = 10,644)		p-value
	%/Mean	SE	%/Mean	SE	%/Mean	SE	%/Mean	SE	%/Mean	SE	
Initial drug type											0.006
Marijuana	68.52	(0.77)	68.14	(1.39)	71.43	(1.51)	63.19	(2.13)	68.72	(0.64)	
Hallucinogens	1.19	(0.17)	0.85	(0.31)	1.47	(0.40)	1.68	(0.52)	1.25	(0.15)	
Hard drugs	0.33	(0.09)	0.48	(0.22)	0.69	(0.25)	0.74	(0.40)	0.47	(0.10)	
Inhalants	27.60	(0.83)	27.49	(1.01)	22.84	(1.41)	31.35	(2.14)	26.76	(0.68)	
Prescriptions (misuse)	2.36	(0.26)	3.04	(0.60)	3.56	(0.62)	3.05	(0.76)	2.80	(0.20)	
Age 14 to 15 (vs. 16 to 17)	36.22	(0.74)	39.16	(1.59)	39.37	(1.58)	36.81	(2.17)	37.44	(0.57)	0.18
Boy (vs. Girl)	50.27	(0.83)	51.90	(1.60)	48.18	(1.55)	56.11	(2.27)	50.49	(0.61)	0.027
Being in school (vs. not in school)	88.32	(0.50)	86.88	(1.05)	88.91	(0.81)	88.06	(1.49)	88.23	(0.37)	0.51
Health good to excellent (vs. fair and poor)	94.57	(0.35)	92.30	(0.78)	91.51	(0.83)	94.53	(1.23)	93.51	(0.33)	0.001
Sensation (yes vs. no)	45.58	(0.79)	31.54	(1.49)	39.73	(1.54)	40.37	(1.64)	41.75	(0.61)	<0.001
Past year MDE (yes vs. no)	27.44	(0.77)	17.07	(1.25)	26.21	(1.22)	27.07	(2.00)	25.64	(0.57)	<0.001
Disability (yes vs. no)	24.68	(0.63)	25.82	(1.53)	26.08	(1.22)	25.88	(1.43)	25.28	(0.50)	0.673
Most/all peer used substance (yes vs. no)	35.39	(0.78)	33.22	(1.52)	37.25	(1.32)	31.44	(1.82)	35.20	(0.55)	0.050
Delinquency (yes vs. no)	39.63	(0.78)	45.91	(1.68)	41.07	(1.41)	41.04	(2.26)	40.99	(0.61)	0.013
Family structure											<0.001
Two-parent	70.53	(0.76)	35.64	(1.77)	62.68	(1.41)	64.43	(1.82)	63.17	(0.53)	
Single parent	24.44	(0.67)	54.09	(1.77)	30.70	(1.48)	27.25	(1.45)	30.40	(0.57)	
Other caregiver	5.03	(0.38)	10.26	(0.91)	6.62	(0.66)	8.31	(1.14)	6.43	(0.30)	
Positive parenting scale (mean)	2.84	(0.01)	2.93	(0.02)	2.84	(0.02)	2.76	(0.03)	2.84	(0.01)	<0.001
Family income ≥ \$50000	69.26	(0.75)	29.25	(1.52)	37.48	(2.10)	59.03	(2.21)	55.10	(0.83)	<0.001
Insurance coverage (yes vs no)	96.94	(0.25)	95.48	(0.70)	89.95	(0.82)	96.63	(0.94)	95.03	(0.34)	<0.001
Region											<0.001
Large metro	49.67	(0.98)	67.28	(1.50)	64.60	(1.45)	61.35	(2.38)	56.72	(0.78)	
Small metro	32.58	(0.83)	22.33	(1.38)	28.84	(1.18)	25.40	(2.10)	29.63	(0.66)	
Non-metro	17.75	(0.76)	10.39	(0.97)	6.56	(0.68)	13.25	(1.28)	13.65	(0.50)	

Note. Positive parenting scale was measured by mean, and other variables were categorical and measured by percentages. Statistics were nationally weighted.

Table 1).

3.2. Life table analysis results

Fig. 1 shows the curve of cumulative probability based on the life table method for adolescent drug users to use a new drug in eight years. As shown in Fig. 1, by year 2, the probability of using a new drug was about 50% for hard drug users, followed by hallucinogen users (~45%), prescription misusers (~30%), marijuana users (~25%), and inhalant users (~10%). By year 3, the probability of using a new drug for hard drug and hallucinogen users reached about 60% and remained largely stable after that; however, the probability for marijuana and inhalants

users continued increasing throughout the whole observation period. By year 8, the probability of using a new drug was 50% for inhalant users, but about 70% to 80% for other drug users.

Fig. 2 presents the cumulative probability of using a new drug over time by adolescents' race/ethnicity. Black adolescents had a lower probability throughout the observation period. By year 2, the probability of transitioning into a new drug was about 10% for Black adolescent drug users and 20% for all other adolescent drug users; and by year 8, the probability of using a new drug was about 60%, 50%, 40% for White/Hispanic, "Other", and Black adolescent drug users, respectively.

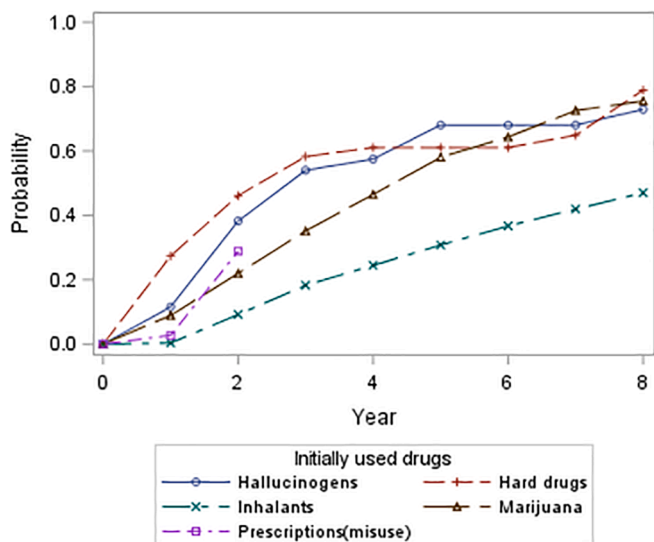


Fig. 1. Cumulative probability of using a new drug over time for initial drug users by initial drug type.

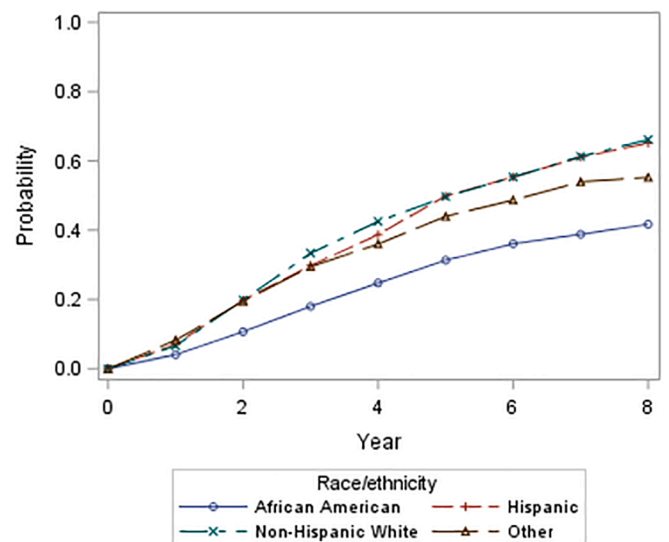


Fig. 2. Cumulative probability of using a new drug over time for initial drug users by race.

3.3. Results from multivariate analyses

Table 2 presents results from the Cox regression models predicting time to the use of a new drug among adolescents who initiated drug use. Model 1 to 3 include predictors in a step forward manner and model 4 is the full model. The results across the models show that the association between the predictors and the time to the use of a new drug was generally consistent and independent of other predictors. Compared with adolescents who initially used marijuana, adolescents who originally used hallucinogens (Hazard ratio [HR] = 1.50, $p = 0.004$) were more likely to use a new drug, while adolescents who initially used inhalants were less likely to use a new drug (HR = 0.49, $p < 0.001$). Compared with White adolescent drug users, Black adolescent drug users were less likely to use a new drug (HR = 0.59, $p < 0.001$). Adolescent drug users who had an over-median sensation seeking score (HR = 1.48, $p < 0.001$), a past-year MDE (HR = 1.25, $p < 0.001$), a disability (HR = 1.16, $p < 0.001$), and reported delinquency (HR = 1.50, $p < 0.001$) were more likely to use a new drug. However, boys (HR = 0.89, $p = 0.021$) and adolescents with more positive parenting (HR = 0.84, $p < 0.001$) were less likely (Model 4 of Table 2).

Table 3 presents a subset of results from the models presented in Table 2's Model 4 (excluding the race/ethnic variable) by racial/ethnic groups. These models allow further examination of whether the association between the initially used drug type and the time to the use of a new drug varied by race/ethnicity, after controlling for covariates. The results show that, compared with adolescents who initially used marijuana, adolescents who initially used inhalants were less likely to use a new drug regardless of race/ethnicity. The likelihood was lower for White and Other adolescents (HR = 0.33 to 0.46, $p < 0.001$) than Black and Hispanic adolescents (HR = 0.58 to 0.64, $p = 0.02$ to < 0.001). Compared with their counterparts who initially used marijuana, White and Hispanic adolescents who initially used hallucinogens (HR = 1.41 to 1.76, $p = 0.038$ to 0.042), and White and Other adolescents who initially used hard drugs were more likely to use a new drug (HR = 2.21 to 2.65, $p = 0.005$ to 0.006). Such associations, however, were not statistically significant among other racial/ethnic groups.

4. Discussion

Based on retrospective data of adolescent illicit drug use history, this study conducted longitudinal analyses to examine the trajectory of initial adolescent drug users' transition into a new drug. This is the first study based on the U.S. adolescent population data to examine the pathways from drug use initiation into using other drugs. The findings show that adolescents are most likely to initiate illicit drug use with marijuana and inhalants and the initial drug types are related to different trajectories of using a new drug. There are racial/ethnic differences in the trajectories. The findings advance the understanding of adolescent drug use initiation and progression, which has meaningful theory, prevention and treatment implications.

4.1. Initial drug use

Research focusing on the U.S. adolescent population has shown that marijuana is the most widely used illicit drug (SAMHSA, 2019; Zhang, Lim, Boyas, & Burlaka, 2020) and that inhalants are popular among younger adolescents (Kurtzman, Otsuka, & Wahl, 2001; Nonnemaker, Crankshaw, Shive, Hussin, & Farrelly, 2011). However, most of these studies did not investigate adolescent drug use history longitudinally; therefore, it remains a question to what extent different types of illicit drugs are initially used among U.S. adolescents. The findings show that among adolescent illicit drug users, more than two thirds started with marijuana and more than one quarter started with inhalants. The remaining (~5%) started from prescription misuse, hallucinogens, and hard drugs. The findings from the current study confirm previous research conducted in Brazil (Castaldelli-Maia, Nicastrì, de Oliveira, de

Andrade, & Martins, 2014) about adolescents initiating drug use largely with marijuana and inhalants.

The findings may offer some support to the gateway theory that individuals tend to start drug use from less harmful drugs (Kandel, 2002; Kandel & Kandel, 2015). However, using marijuana and inhalants as initial drugs may be affected by adolescents' personal traits and social contexts (e.g., drug availability and peer group norms) rather than an intentional choice (Degenhardt et al., 2010; DuPont et al., 2018). This is relevant in the US context, where both marijuana and inhalants are quite accessible and popular among adolescents (Garland, Howard, Vaughn, & Perron, 2011; Nonnemaker et al., 2011). Given the prevalence of marijuana and inhalants among adolescent initial drug users, it is thus important to understand how their initial use is potentially related to the use of other drugs in the future.

4.2. Trajectory to new drug use

There are interesting findings concerning the trajectories to the use of a new drug for adolescents who initiated drug use with different drugs. Most (~70%) adolescent drug users who started their drug use with a drug other than inhalants would use a new drug by year 6, and the rate approached about 80% by year 7 or 8. For adolescents who initiated drug use with inhalants, the probability of using a new drug was comparatively lower and was in the range of about 30% to 40% by years 6 and 8. When observing the trajectories throughout the period, in the first three years, adolescents who initiated their drug use with hard drugs or hallucinogens were most likely to use a new drug and then the increasing slope was minor in the following years. However, adolescents who initiated drug use with marijuana and inhalants reported an increasing trend of using new drugs throughout. As a result, adolescents who initially used marijuana, hard drugs and hallucinogens were similarly likely to use a new drug since year 6. Adolescents who started with inhalants or other drugs had lower probabilities of using a new drug in the later stage of the observation period.

It is not surprising that adolescents who initiated their drug use with hard drugs and hallucinogens may quickly move to use other drugs. It is less clear about the potentially long term harm of other drugs (Dills, Goffard, & Miron, 2017). However, the findings show that adolescents who initiated drug use with marijuana and inhalants were both gradually more likely to use new drugs in the following years. This usually means moving to use more harmful drugs (Castaldelli-Maia et al., 2014). The findings offer support to the gateway theory (Golub & Johnson, 2002; Kandel, 2002). Previously, the gateway theory often referred to the notion that most hard drug users had used marijuana before (Kandel, 2002; Kandel & Kandel, 2015). There is little research in a prospective perspective to examine how adolescents who initiated gateway drug use may progress to the use of other drugs over time. The current findings report such important trajectories. The continuously increasing risk for these adolescent to use a new drug, especially those who initiated with marijuana and inhalants, provides support for the likelihood of a "brain priming" effect of these initial drugs (Kandel, 2002; Kandel & Kandel, 2015).

The findings also have important practice implications such as that for adolescents, no drug's harm can be underestimated. Even though the use of a drug such as marijuana might be less detrimental at the beginning, our findings suggest that it is likely to pave the way to using more detrimental drugs over time. In recent years, because of the change of social norms about marijuana legalization, increasingly fewer adolescents view marijuana use as a great risk (Schuermeyer et al., 2014), which may contribute to increased marijuana use among adolescents (Cerdá et al., 2017; Schuermeyer et al., 2014). Current developmental differences in the negative effects of marijuana on young adolescents (Jacobus & Tapert, 2014) merit further research from a gateway theory perspective. The harm produced by inhalants is even less known (Kurtzman et al., 2001; Nonnemaker et al., 2011; Williams et al., 2007). This may result in the resistance of adolescent illicit drug use reduction

Table 2
Cox regression models predicting adolescent time to use of a new illicit drug.

	Model 1				Model 2				Model 3				Model 4			
	b	SE	p-value	HR	b	SE	p-value	HR	b	SE	p-value	HR	b	SE	p-value	HR
Initial drug type (marijuana)																
Hallucinogens	0.42	0.16	0.011*	1.52	0.39	0.14	0.006**	1.48	0.44	0.16	0.007**	1.55	0.40	0.13	0.004**	1.50
Hard drugs	0.47	0.28	0.102	1.59	0.57	0.29	0.055	1.76	0.48	0.28	0.096	1.61	0.51	0.29	0.089	1.66
Inhalants	-0.71	0.06	<0.001***	0.49	-0.72	0.06	<0.001***	0.49	-0.71	0.06	<0.001***	0.49	-0.71	0.06	<0.001***	0.49
Prescriptions (misuse)	-0.35	0.26	0.188	0.70	-0.24	0.27	0.382	0.79	-0.30	0.27	0.27	0.74	-0.21	0.27	0.438	0.81
Adolescent Characteristics																
Race/ethnicity (Non-Hispanic White)																
Black/African American					-0.55	0.07	<0.001***	0.58					-0.53	0.07	<0.001***	0.59
Hispanic					-0.09	0.06	0.121	0.91					-0.07	0.06	0.24	0.93
Other					-0.07	0.08	0.381	0.93					-0.08	0.09	0.358	0.92
Age 14 to 15 (vs. 16 to 17)					0.05	0.05	0.349	1.05					0.07	0.05	0.221	1.07
Boy (vs. girl)					-0.12	0.05	0.012*	0.88					-0.11	0.05	0.021*	0.89
Being in school (vs. not in school)					-0.06	0.07	0.389	0.94					-0.04	0.07	0.563	0.96
Health good to excellent (vs. fair/poor)					-0.10	0.09	0.277	0.90					-0.09	0.10	0.357	0.91
Sensation (yes vs. no)					0.40	0.05	<0.001***	1.50					0.39	0.05	<0.001***	1.48
Past year MDE (yes vs. no)					0.26	0.05	<0.001***	1.29					0.22	0.05	<0.001***	1.25
Disability (yes vs. no)					0.15	0.04	<0.001***	1.16					0.15	0.04	<0.001***	1.16
Most/all peer used substance (yes vs. no)					0.03	0.05	0.572	1.03					0.03	0.05	0.567	1.03
Delinquency (yes vs. no)					0.41	0.05	<0.001***	1.51					0.40	0.05	<0.001***	1.50
Family and Community Characteristics																
Family structure (two-parent)																
Single parent									-0.01	0.06	0.889	0.99	0.05	0.06	0.333	1.06
Other caregiver									-0.10	0.12	0.382	0.90	-0.03	0.11	0.743	0.97
Positive parenting scale									-0.28	0.04	<0.001***	0.76	-0.17	0.04	<0.001***	0.84
Family income ≥ \$50000									0.13	0.05	0.008**	1.13	0.07	0.05	0.174	1.07
Insurance coverage (yes vs no)									0.06	0.10	0.58	1.06	0.06	0.10	0.567	1.06
Region (large metro)																
Small metro									0.11	0.06	0.057	1.11	0.06	0.06	0.257	1.07
Non-metro									0.03	0.05	0.582	1.03	-0.06	0.06	0.324	0.94

Note. Categories in parentheses are reference groups; b = coefficient, se = standard error, HR = hazard ratio; Models were run with PROC SURVEYPHREG in SAS to account for survey design weights. * <0.05 ** <0.01 *** <0.001.

Table 3

Cox regression models predicting adolescent time to use of a new illicit drug by race/ethnicity.

	Non-Hispanic White				Black/African American				Hispanic				Other			
	b	SE	p-value	HR	b	SE	p-value	HR	b	SE	p-value	HR	b	SE	p-value	HR
Initial drug type (Marijuana)																
Hallucinogens	0.35	0.17	0.042*	1.41	0.47	0.68	0.494	1.59	0.56	0.26	0.038*	1.76	0.56	0.33	0.089	1.76
Hard drugs	0.97	0.34	0.006**	2.65	-0.61	1.14	0.592	0.54	-0.02	0.76	0.978	0.98	0.79	0.27	0.005**	2.21
Inhalants	-0.77	0.08	<0.001***	0.46	-0.45	0.19	0.02*	0.64	-0.54	0.13	<0.001***	0.58	-1.11	0.20	<0.001***	0.33
Prescriptions (misuse)	-0.27	0.40	0.497	0.76	-0.27	0.78	0.73	0.76	-0.21	0.65	0.749	0.81	0.06	0.62	0.923	1.06

Note. Categories in parentheses are reference groups; b = coefficient, se = standard error, HR = hazard ratio; Models were run with PROC SURVEYPHREG in SAS to account for survey design weights; covariates (except race/ethnicity) in each model were controlled as in Model 4 in Table 2. * <0.05 ** <0.01 *** <0.001.

efforts (Chadi & Levy, 2017; DuPont et al., 2018) when compared with the dramatic decline of adolescent tobacco and alcohol use in the past years (SAMHSA, 2019). It is important to further review the potentially long-term effects of these gateway drugs on adolescents' development and consider more responsive prevention strategies in the changing social environment.

Findings from the multivariate Cox regression models suggest discrepancies observed in the survival curve analyses generally held, even after controlling a series of covariates. Adolescents who initially used hallucinogens had a higher hazard ratio in the time to use a new drug than adolescents who initially used marijuana, while adolescents who initially used inhalants had a lower hazard ratio. Among the covariates, being a boy and having a higher level of positive parenting were associated with a lower hazard ratio in the time to use a new drug. Research typically found that boys are more likely to use all types of drugs than girls (SAMHSA, 2019) so this finding is surprising. The findings from the current study may suggest that once girls start using drugs, they may be more likely than boys to try new drugs. Therefore, their risk of progressing toward more severe drugs is as important to understand as it is for boys. The effect of positive parenting on adolescent drug use prevention confirms previous research showing a robust linkage between parental monitoring and adolescent marijuana use (Lac & Crano, 2009; Zhang et al., 2020). Findings from the current study also support previous findings that positive parenting prevents adolescents who initiated drug use from escalating into using new drugs (Marsiglia et al., 2019).

Among other covariates, having a higher level of sensation seeking, a past year MDE, a disability, and delinquency were all associated with a higher hazard ratio in the time to use new drugs. Previous studies have shown that these factors are robustly associated with elevated risks of adolescent substance use (Hall, Patton, Stockings, Weier, & Morley, 2016). The findings from this study further suggest that adolescent drug users with these vulnerabilities are more likely to use new drugs once they initiate drug use. The findings that many of the individual and contextual traits are related to adolescent drug users' progression toward the use of new drugs also resonate with perspectives based on the generalized risk theory (Degenhardt et al., 2010; DuPont et al., 2018). It is possible that both of the gateway theory and generalized risk theory have explanatory power in better understanding certain aspects of adolescent drug use initiation and progression.

4.3. Racial/ethnic differences in drug use initiation and progression

Across racial/ethnic groups, Hispanic adolescents drug users were most likely to start with marijuana and least likely to start with inhalants; however, "Other" adolescent drug users were the opposite. There were also racial/ethnic discrepancies in the trajectories to the use of new drugs. Across racial/ethnic groups, White and Hispanic adolescents had the highest probability of moving to using new drugs throughout the observation period, while Blacks had the lowest probability (Fig. 1). In the Cox regression models that controlled for covariates, Blacks had a hazard ratio that was about 40% lower than Whites in the time to use new drugs. These findings support national

estimations that Black adolescents have the lowest rate of illicit drug use (Vaughn et al., 2018). Our findings confirm that Black adolescents are less susceptible to illicit drugs during both early and late adolescence.

The Cox regression models based on racial/ethnic subgroup analyses further revealed how trajectories to the use of new drugs may vary. Across racial/ethnic groups and using adolescents who started drug use with marijuana as a reference, adolescents who started drug use with inhalants were less likely to use new drugs and the difference was most prominent for Whites and Others. Whites and Hispanics who started drug use with hallucinogens were more likely to use new drugs. White and Other adolescents who initiated drug use with hard drugs were much more likely to use new drugs. These findings suggest that racial/ethnic background is not only associated with adolescent drug users' choice of initial drugs but also their subsequent use of new drugs. The underlying causes for such disparities deserve further investigation and may help develop more culturally competent prevention programs targeting racially/ethnically diverse adolescents.

4.4. Limitations

Several limitations need to be acknowledged. First, the NSDUH is a household-based survey, which might exclude adolescents who were institutionalized (e.g., incarcerated or in temporary shelter) or homeless. However, these adolescents may have a potentially high risk of drug use (Greene, Ennett, & Ringwalt, 1997; Snyder & Howard, 2015; Vaughn, Ollie, McMillen, Scott, & Munson, 2007), and therefore, we need to be cautious when generalizing the research findings. Second, the initial time of illicit drug use and the type of illicit drug use at the first and transition might be underestimated because of the self-report data collection approach of NSDUH. The social desirability could bias the results. Last, the survey asked participants to recall their initial drug use information, which might also bias the results due to recall accuracy. However, retrospective data are widely used in research, including research on youth substance use. Retrospective data provide a valuable venue to examine youth drug use history when prospective longitudinal data are not available (Castaldelli-Maia et al., 2018; Derefinko et al., 2016; Gallagher, Webster, & Aschengrau, 2017). Previous studies suggest that life events recall is generally reliable when appropriately implemented (Caspi et al., 1996), and the reliability still remain moderate even the recall occurs decades later (Bell & Bell, 2018; Bornstein, Putnick, Costlow, & Suwalsky, 2020).

5. Conclusion

This study demonstrates that more than two thirds of adolescent drug users initiated with marijuana, one quarter with inhalants, and the remaining with hallucinogens, prescriptions, and hard drugs. Adolescent drug users who initiated with different drugs showed different trajectories to the use of new drugs. By the end of the observation period (year 8), about 40% of those who initiated with inhalants would use a new drug and about 70% to 80% of those who initiated with marijuana and other drugs would use a new drug. Adolescents who initiated with

marijuana and inhalants had a lower probability of using a new drug in the first several years than adolescents who initiated with hard drugs or hallucinogens. The cumulative rate for marijuana and inhalant users, however, remained largely stable over time, so that they caught-up or diminished the difference with the probability of other drug user in the later stage of the observation period. Findings from the multivariate Cox regression models suggest discrepancies observed in the life table analyses generally hold. In addition, being a boy and having a higher level of positive parenting were associated with a lower probability of using a new drug, while having a higher level of sensation, a past year MDE, a disability, and delinquency were associated with a higher probability of doing so.

There were also racial/ethnic differences. Compared across racial/ethnic groups, Hispanic adolescent drug users were most likely to start from marijuana and least likely to start from inhalants, but Other adolescent drug users were the opposite. Black adolescent drug users were less likely to use a new drug than their counterparts were. The findings suggest that adolescents' initial use of marijuana and inhalants may have a substantial impact on other drug use in the future. It is therefore important to screen adolescent drug use comprehensively and provide early intervention to prevent escalation to more harmful drugs. The findings provide new evidence to support aspects of both the gateway and generalized risk drug use theories.

6. Author declaration

The study has not been published previously (except in the form of an abstract and academic conference presentation), is not under consideration for publication elsewhere, is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and, if accepted, will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

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CRedit authorship contribution statement

Saijun Zhang: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Shiyu Wu:** Writing - original draft, Writing - review & editing. **Qi Wu:** Writing - original draft, Writing - review & editing. **Daniel W. Durkin:** Writing - review & editing. **Flavio F. Marsiglia:** Conceptualization, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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