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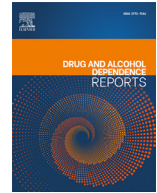
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Substance use patterns in 9 to 13-year-olds: Longitudinal findings from the Adolescent Brain Cognitive Development (ABCD) study

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ABSTRACT

Background: Though largely substance-naïve at enrollment, a proportion of the youth in the Adolescent Brain Cognitive Development (ABCD) Study are expected to initiate substance use (SU) as they transition into later adolescence. With annual data from youth 9–13 years-old, this study aims to describe their SU patterns over time. Here, prevalence rates of use are reported, along with predicted odds of use while analyzing common risk-factors associated with youth SU.

Methods: The ABCD Study® enrolled 11,876 participants at Baseline (ages 9–10) and has followed them annually. Data through half of the third follow-up visit are available (ages 12–13; $n = 6,251$). SU descriptives for all psychoactive substances over time are outlined. General estimating equations (GEEs) assessed whether sociodemographic factors, internalizing and externalizing symptoms, and parental SU problems were associated with SU between Baseline and Y2 follow-up.

Results: Across time, alcohol and nicotine remain the most used substances. Yearly rates of any SU increased (past-year use: 13.9% in Y1; 14% Y2, 18.4% Y3). Cumulatively, by Y3, 39.7% of the cohort reported experimenting (e.g., sipping alcohol) with SU within their lifetime, while 7.4% reported a “full use” (a full alcohol drink, nicotine use, cannabis use, or any other SU) in their lifetime (past-year: 1.9% alcohol, 2.1% nicotine, 1.1% cannabis, 1.2% other substances). GEEs revealed ongoing longitudinal associations between sociodemographic factors, greater externalizing symptoms, and parental drug problems with increased odds of initiating SU.

Conclusions: As ABCD participants transition into their teenage years, the cohort is initiating SU at increasing (though still low) rates.

1. Introduction

The Adolescent Brain Cognitive DevelopmentSM Study (ABCD Study®) is a landmark study designed to prospectively follow nearly 12,000 youth from early childhood through adolescence to examine factors that influence neurodevelopment broadly, including the impact of substance use (Jernigan et al., 2018; Lisdahl et al., 2018; Volkow et al.,

2018). Consistent with study aims to delineate developmental trajectories following the onset of substance use (SU), the ABCD Study successfully recruited a national, diverse cohort of 9–10 year-old youths who were almost exclusively substance naïve at study enrollment (2016–2018; <1% reporting SU beyond sipping alcohol) (Garavan et al., 2018; Lisdahl et al., 2021). These youth have since been followed with annual in-person assessments, including detailed SU patterns interviews

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(Lisdahl et al., 2018; Lisdahl et al., 2021) with data for the full cohort available through the second follow-up visit and half the cohort through the third follow-up visit (ages 12–13). Data are released yearly to the scientific community through an open-science model (Jernigan et al., 2018; Volkow et al., 2018).

As the ABCD Study cohort transitions into their teenage years, it is important to continue to document SU patterns and potential sociodemographic differences in early onset use; particularly as scientific teams accessing the data examine more nuanced predictors of SU trajectories. Participants within the ABCD study are beginning to reach the age that corresponds to other national datasets of substance use prevalence in adolescents (e.g., the National Survey on Drug Use and Health), which begins at age 12 (SAMHSA, 2021), or the Monitoring the Future (MTF) study, which begins at age 13 (Johnston et al., 2021). Estimates of lifetime prevalence of drug use in 2021 as measured in MTF indicate that, in 8th graders (often ages 13–14), 21.7% have ever used alcohol, 10.2% used cannabis, 7.0% used cigarettes, and 16.6% used electronic nicotine delivery systems (ENDS or vaping). The ABCD Study cohort was younger than the MTF Study surveys at Baseline and had minimal (<1%) use of full doses of any substance, though 22.5% of the cohort reported alcohol sipping at Baseline (Lisdahl et al., 2021). This substance experimentation (e.g., alcohol sipping; nicotine or cannabis puffing) may be an important predecessor to later substance use (Jackson et al., 2015a), thus continued tracking of low-level use is important during the early and middle adolescent years.

In addition to monitoring prevalence rates of early substance initiation, it is also important to identify early sociodemographic differences or risk factors associated with this onset and which may moderate later substance-related outcomes (Squeglia and Cservenka, 2017; Tapert and Ebersson-Shumate, 2022). Prior studies suggest sociodemographic characteristics [e.g., high SES, male sex, unmarried parents; (Pelham et al., 2021; Squeglia et al., 2017)] are significant predictors of substance use onset. Family history of alcohol and drug dependence, especially in parents, are linked to earlier substance initiation and increased problems and dependence in offspring (Chassin et al., 2002; Cox et al., 2021; Grant and Dawson, 1997; Henry, 2017; Schuckit and Smith, 1996; Tapert and Ebersson-Shumate, 2022). Early signs of psychopathology are also considered an early risk-factor. Externalizing symptoms are most commonly linked to substance use, including early initiation (Cox et al., 2021; Edwards et al., 2016; Ning et al., 2020; Squeglia et al., 2017), while internalizing symptoms are less frequently associated (Ning et al., 2020). Consistent with these results, Baseline data from the ABCD Study revealed being male, being older, having a familial history of substance problems, and greater externalizing symptoms were associated with early alcohol sipping behaviors (Lisdahl et al., 2021).

As the scientific community plans to engage in future data analytic studies around SU, the ABCD Study Substance Use Workgroup aims to describe the patterns of SU reported by youth at the ABCD Study Year 1 (ages 10–11), Year 2 (ages 11–12), and Year 3 (ages 12–13) follow-up sessions (for the whole-cohort and by sex at birth). In addition, in order to highlight important factors to consider longitudinally, this study seeks to identify the associations between previously identified common risk factors (e.g., sociodemographic, parental history of SU problems, mental health symptoms) and early substance use experimentation and initiation from Baseline to Year 2 follow-up sessions. It was hypothesized that previously identified predictors of use (i.e., males, older age, familial history of substance problems, and greater reported externalizing symptoms) will be robust predictors of odds of substance use (SU) initiation during the early adolescent years (Lisdahl et al., 2021).

2. Materials and methods

2.1. Participants and procedures

Participants in the current study included 11,876 youth who enrolled in the ABCD Study at Baseline (Y0), with all available yearly follow-up

(Y1, Y2, Y3) and Mid-Year (i.e., six-month) interval phone follow-up (follow-up months: M6, M18, M30) data included for analyses. Participants and their parents/guardians were recruited from 21 U.S. research sites between 2016–2018 using a stratified probability sample of eligible schools to match the sociodemographic profile of the American Community Survey (ACS) [for details: Garavan et al. (2018)]. All study procedures were approved by a centralized institutional review board (IRB) at the University of California, San Diego. Exclusion criteria for the ABCD Study at Baseline enrollment are detailed in the Supplement. Informed consent was obtained from parents/guardians and assent from youth at each session.

At each yearly visit, youth and one parent/guardian participated in 1–2 sessions, which comprised of a comprehensive battery of biological and behavioral assessment modules, including: substance use (Lisdahl et al., 2018), mental and physical health (Barch et al., 2018), peer, family, culture, and environment (Zucker et al., 2018), biological markers (Uban et al., 2018), genetics (Iacono et al., 2018), neurocognitive (Luciana et al., 2018), and magnetic resonance brain imaging (Casey et al., 2018). All annual interviews were conducted in person up until the beginning of the COVID-19 pandemic; participants then completed interviews via private video calls or telephone calls, with only a select number completing in-person visits between March 2020 and February 2021. Questionnaires were primarily administered via iPad through REDCap (Harris et al., 2009), which was harmonized across sites (Auchter et al., 2018). Youth were interviewed separately from parents in private spaces (both during in-person and virtual visits). Mid-Year interval phone follow-up consisted of an abbreviated battery and contained past six-month substance use modules (Lisdahl et al., 2018). The current study utilized data from ABCD Data Release 4.0 (DOI: 10.15154/1523041, October 2021; data collected through February 15, 2021), which includes the full cohort for Y0–Y2 and half the Y3 cohort.

Importantly, confidentiality was reiterated to the youth prior to administration of the substance use module. Youth were asked if they had “heard of” a list of substances (in Y0–Y2 only; see details in Supplement) and, if so, tried/experimented with any substances (see below for comprehensive list); follow-up questionnaires were given only if the youth endorsed experimental use.

2.2. Measures

2.2.1. Sociodemographic factors

Identity and household sociodemographic factors were included in the statistical analyses as covariates: age at Y0 (in months), age_Δ at each follow-up (i.e., change in age relative to Y0), sex assigned at birth (herein referred to as “sex”), 4-levels of self-identified race (Asian, Black, White, Mixed/Other), ethnicity (Hispanic/Latinx, non-Hispanic/Latinx), parent/guardian educational attainment (<HS Diploma, HS Diploma, Some College, Bachelor Degree, Post Graduate Degree), parent/guardian marital status (married, not married), and household income (<\$50,000, \$50,000–\$100,000, >\$100,000) (Barch et al., 2018).

2.2.2. Alcohol, nicotine, and cannabis experimentation/low-level use measures

Youth annually completed the iSay Sipping Inventory (Jackson et al., 2013; Jackson et al., 2015b), an 8-item measure of recent alcohol sipping that characterized their first alcohol sipping experience (Lisdahl et al., 2018). First experimentation of nicotine or cannabis product was also assessed (Lisdahl et al., 2018). Follow-up questions about the circumstances around their first use (e.g., age of first use, type of product, from whom they received the substance) were only given at one time-point (i.e., their first use).

2.2.3. Lifetime & past 6-month (Y0)/yearly (Y1–Y3) SU patterns

At Baseline (Y0), youth were asked if they used each major drug category in their lifetime; multiple formal and informal names (includ-

ing popular names) of each substance were provided (Lisdahl et al., 2018). If youth endorsed using a full standard unit of the substance in the past six months (Y0) or since last study session (Y1-Y3), a web-based Timeline Follow-Back (TLFB) interview was administered for that timeframe (Lisdahl et al., 2018; Sobell and Sobell, 1992). Lifetime SU and TLFB interviews assessed for all substances, including: alcohol, nicotine products [i.e., cigarettes, ENDS/vaping (tobacco), smokeless tobacco, cigars, hookah, pipe, and nicotine replacement products], cannabis products [smoked flower, vaped flower, smoked blunts, edibles, smoked concentrates, vaped concentrates, oral tinctures, cannabis-infused alcohol drinks, and non-medical cannabidiol (CBD)], synthetic cannabinoids, cocaine, cathinones, methamphetamine, ecstasy/MDMA, ketamine, gamma-hydroxybutyrate (GHB), heroin, psilocybin, salvia, other hallucinogens [lysergic acid diethylamide (LSD), phencyclidine (PCP), synthetic hallucinogens], anabolic steroids, inhalants, and prescription misuse of stimulants, sedatives, opioid pain relievers, and over-the-counter (OTC) cough/cold medicine (Lisdahl et al., 2018). Further, at Mid-Year phone follow-up, youth are asked past 6-month substance use, which is integrated into following yearly visit (e.g., M6 + Y1) to create a more comprehensive “past-year” substance use for each yearly follow-up.

For current analyses, SU variables were defined in the following ways:

- **SU “Experimentation”** – low-level substance use (i.e., alcohol sipping, nicotine or cannabis puffing or trying).
- **SU “Initiation”** – reported ≥ 1 standard alcohol drink, >puff/taste cannabis or nicotine or any other occasion of other substance use.
- **“Any” SU** – either “experimentation” and/or “initiating” a substance (i.e., combines the two definitions above)
- **SU “Onset”** – the year at which substance use was reported.

2.2.4. Parental history of problematic alcohol or drug use

Parents/Guardians were administered a Family History Assessment Module Screener (FHAM-S) (Rice et al., 1995) at Y0 which obtained biological family history of mental health, alcohol, and drug problems. For analyses, variables for biological parent history of problematic alcohol or drug use were utilized (yes, no).

2.2.5. Internalizing and externalizing scale

Parents rated their child’s internalizing (includes withdrawn, somatic complaints, and anxiety/depressed problems) and externalizing behaviors (includes delinquent and aggressive behaviors) on the Child Behavior Checklist (CBCL) (Achenbach, 2009; Barch et al., 2018), which was administered at all yearly visits (Y0-Y3; See Supplementary Table 4). For analyses, raw scores for each scale were used.

2.3. Statistical analysis

Analyses were conducted in R (R Core Team, 2022) (v4.1.1) utilizing ABCD Data Release 4.0 (DOI: 10.15154/1523041, October 2021). First, descriptive statistics were computed for all variables described above (frequency and proportion of yes/no or means and standard deviations, where appropriate). Next, sex differences in “any” SU, SU “experimentation”, and SU “initiation” were investigated due to preestablished sex differences in use in this age range (Johnston et al., 2022); this was achieved through descriptive reporting, chi-square tests for dichotomous outcomes (Yate’s correction was employed if a cell is < 5), and t-test analyses for continuous outcomes. Lastly, in order to describe relationships between sociodemographic factors, parental history of problematic alcohol or substance use, or internalizing and externalizing behaviors, two Generalized Estimating Equations (GEEs) models [using *geepack* (Halekoh et al., 2006)] examined whether Y0 age, age_Δ (i.e., time), sex at birth, race, ethnicity, parent/guardian education, parent/guardian marital status, household income, parental history of problematic alcohol use, parental history of problematic drug use, CBCL internalizing scores, or CBCL externalizing scores were associated with

dichotomized (1) “Any” SU or (2) SU “Initiation” outcomes (Y0-Y2). Y3 visit was removed from all GEEs due to only half the cohort’s data being available; of note, this was decided because the first wave of the ABCD cohort is not fully representative of the entire cohort (e.g., sociodemographic variables). GEEs were fit with a binomial logistic regression, first-order autoregression correlational structure, and observations were clustered on participant to account for the repeated measures design. In the SU “Initiation” GEE, Asian-identifying youth were removed to improve model fit due to minimal SU initiation within this group. Results were considered significant if the Wald statistic ($W\chi^2$) was at the $p < .05$ level. In addition, standardized odds ratio (OR), and 95% confidence intervals (CI) were derived and included for interpretation with rescaling applied to continuous predictors (Gelman, 2008).

2.3.1. Missing data

Participants with study visit information had minimal missing data; however, some participants ($n = 1,229$) had missing sociodemographic information which prevented their inclusion in GEE models. SU Prevalence information was included for all participants, including those who were not able to be included in GEEs.

3. Results

3.1. Sociodemographic variables

For sample sociodemographic information of the ABCD participants at Y0, see Table 1; 11,876 youth completed Y0 (ages 9-10), 11,225 completed Y1 (ages 10-11), 10,414 completed Y2 (ages 11-12), and 6,251 completed Y3 (ages 12-13) (data collection still ongoing).

3.2. “Heard Of” descriptives

By Y2, most youth endorsed hearing of alcohol (99.5%), nicotine (99.0%), cannabis (91.67%), prescription or over-the-counter drug misuse (70.8%), and inhalants (67.2%). Fewer youth heard of other drugs (Supplementary Table 3). At Y3, the study discontinued asking youth if they heard of substances.

3.3. Low-level substance use “experimentation”

The most commonly “experimented” (i.e., low-level) substance used across visits was alcohol sipping (Y3: 16.2% past-year, 36.9% lifetime) (Tables 2 and 3). Puffing nicotine products was the second most common (Y3: 2.8% past-year). Lastly, puffing or trying cannabis products remained uncommon from Y0-Y3 (Y3: 0.9% past-year) (Table 2). There were no sex differences in experimentation for each substance by Y3.

3.4. Substance use “initiation”

3.4.1. Substance use initiation

At Y0, 1.1% of youth reported lifetime use of a substance beyond sipping/experimenting (i.e., full standard alcohol drink, beyond singular puff or taste for nicotine, or cannabis, use of any other psychoactive substances). Rates of reported use at each follow-up are in Table 2, Supplementary Fig. 1b. At Y3, 7.4% of youth reported lifetime substance initiation (Fig. 1b), with 3.2% endorsed their first onset at Y3 (Table 3). More males reported SU initiation than females at Y0 and Y1, with no significant sex differences observed at Y2 or Y3.

3.4.2. Alcohol use

Full drinks of alcohol were the second most used substance (Y3 past-year: 1.9%) (Table 2 and Fig. 3), with lifetime rates increasing each year (1.3% by Y2 and 3.0% by Y3; Table 3). No sex differences were evident.

Table 1
Sociodemographic characteristics of the ABCD cohort at baseline (Y0).

Mean (SD) [Range] or N (%)	ABCD Participants (N = 11,876)
Age (months)	118.98 (7.5) [107,133]
Age (years)	9.47 (0.54) [8,11]
Sex assigned at birth (M/F)	6196/5680 (52.17%/47.83%)
Race	
White	7524 (63%)
Black	1869 (16%)
Asian	275 (2%)
Other and >1 category	2037 (17%)
Not reported	171 (1%)
Ethnicity	
Non-Hispanic/Latinx	9312 (78%)
Hispanic/Latinx	2411 (20%)
Not reported	153 (1%)
Parental Annual Household Income	
<\$50,000	3223 (27%)
\$50,000-\$100,000	3071 (26%)
>\$100,000	4564 (38%)
Not reported	1018 (9%)
Parental Highest Education	
<High School Diploma	593 (5%)
High School Diploma/GED	1132 (10%)
Some College	3079 (26%)
Bachelor's Degree	3015 (25%)
Post Graduate Degree	4043 (34%)
Not reported	14 (0.1%)
Parental Marital Status	
Married Families	7990 (67%)
Not Married Families	3790 (32%)
Not reported	96 (1%)
Twin/Singleton Status	
Singleton	7898 (67%)
Siblings	1810 (15%)
Twin	2138 (18%)
Triplet	30 (0.3%)
Parental History of Alcohol Problems ¹	
No Parent	9696 (82%)
≥1 Parent	1732 (15%)
Not reported	448 (4%)
Parental History of Drug Problems ¹	
No Parent	10166 (86%)
≥1 Parent	1271 (11%)
Not reported	439 (4%)

Notes: ¹ from FHAM-S; CBCL= Child Behavior Checklist. Parent sociodemographic variables include either parent or guardian.

3.4.3. Nicotine use

Nicotine was the most reported substance used (Y3 past-year: 2.1%, Table 2 and Fig. 3). ENDS remained the most common nicotine product (Y3 past-year: 1.7%; Table 4), and cigarettes were the second (Y3 past-year: 0.3%) (Fig. 4a). Males used more nicotine than females at Y1.

3.4.4. Cannabis use

At Y3, 1.1% reported past-year cannabis use (Table 2); smoked cannabis flower was the most common route of administration (Y3: 0.8%), see Table 4 and Figs. 3 and 4b. Males used more cannabis than females at Y1 and Y2.

3.4.5. Other substance use

Reports of other SU remains low through Y3 (1.2%) (Supplementary Table 2). Males reported more “other” SU than females at Y3 only. No youth reported using a “fake” drug.

3.5. “Any” substance use

3.5.1. Any substance use

At Y0, 23.1% of youth reported any substance use; follow-up rates were Y1: 13.9%, Y2: 14.0%, Y3: 18.4% (Table 2, Supplementary Fig.

Table 2
Lifetime (Y0) or past-year (Y1–3) substance use patterns (includes all substances, alcohol, nicotine, and cannabis).

	All	Males	Females	χ ²	p-value
“Experimentation”					
Sipped Alcohol					
Y0	22.51%	24.24%	20.62%	22.12	<.001
Y1	12.66%	14.48%	10.67%	36.39	<.001
Y2	12.62%	13.96%	11.14%	18.4	<.001
Y3	16.22%	16.17%	16.28%	0.01	0.937
Puffed Nicotine					
Y0	0.68%	0.89%	0.46%	7.46	0.006
Y1	0.56%	0.82%	0.28%	13.53	<.001
Y2	0.97%	1.16%	0.77%	3.71	0.054
Y3	2.78%	2.88%	2.67%	0.18	0.672
Puffed/Tasted Cannabis					
Y0	<0.1%	<0.1%	0%	1.17	0.28
Y1	0.11%	0.15%	<0.1%	1.65	0.199
Y2	0.29%	0.39%	0.18%	3.08	0.079
Y3	0.93%	0.91%	0.95%	0	0.983
Substance Use “Initiation” (i.e., reported ≥1 standard drink, > puff/taste cannabis or nicotine or any other substance use)					
All Substances					
Y0	1.06%	1.34%	0.76%	9.03	0.003
Y1	1.55%	2.03%	1.03%	17.67	<.001
Y2	1.98%	2.24%	1.69%	3.7	0.054
Y3	4.06%	4.40%	3.69%	1.84	0.175
Alcohol Use					
Y0	0.38%	0.48%	0.26%	0.87	0.352
Y1	0.33%	0.43%	0.22%	2.88	0.09
Y2	0.65%	0.66%	0.64%	0	1
Y3	1.89%	1.94%	1.83%	0.06	0.812
Nicotine Use					
Y0	0.59%	0.66%	0.51%	0.09	0.764
Y1	0.39%	0.54%	0.22%	6.58	0.01
Y2	0.71%	0.70%	0.73%	0	0.955
Y3	2.08%	2.12%	2.03%	0.03	0.866
Cannabis Use					
Y0	0.13%	0.19%	<0.1%	0	0.983
Y1	0.45%	0.63%	0.26%	7.62	0.006
Y2	0.64%	0.84%	0.42%	6.54	0.011
Y3	1.10%	1.15%	1.05%	0	0.983
“Any” Use (i.e., reported “experimentation” OR “initiation”)					
All Substances					
Y0	23.13%	25%	21.09%	25.24	<.001
Y1	13.90%	16.13%	11.45%	50.77	<.001
Y2	14.02%	15.54%	12.35%	21.55	<.001
Y3	18.43%	18.90%	17.90%	0.97	0.325
Alcohol					
Y0	22.58%	24.31%	20.70%	21.78	<.001
Y1	12.78%	14.63%	10.74%	37.62	<.001
Y2	12.77%	14.07%	11.35%	17.03	<.001
Y3	16.69%	16.81%	16.55%	0.06	0.809
Nicotine					
Y0	1.12%	1.32%	0.90%	4.47	0.035
Y1	0.77%	1.09%	0.41%	16.1	<.001
Y2	1.18%	1.32%	1.03%	1.67	0.197
Y3	2.96%	3.09%	2.81%	0.35	0.555
Cannabis					
Y0	0.14%	0.23%	<0.1%	5.06	0.024
Y1	0.46%	0.65%	0.26%	8.21	0.004
Y2	0.70%	0.94%	0.44%	8.34	0.004
Y3	1.15%	1.21%	1.08%	0.13	0.715

Notes: Chi-square and p-values represent comparisons between male and female use. Y0 represents lifetime use as of Baseline assessment, while Y1–3 represents past-year use at 1-, 2-, and 3-year follow-up assessments.

1a). **Cumulative:** By Y3, 39.7% of the cohort reported “experimentation” with at least one substance within their lifetime (Table 3, Fig. 1a). More males reported more SU than females at Y0, Y1, and Y2, but not Y3.

3.5.2. Alcohol use

By Y3, 16.7% of youth reported any past-year alcohol use. Males used more alcohol than females at Y0, Y1, and Y2.

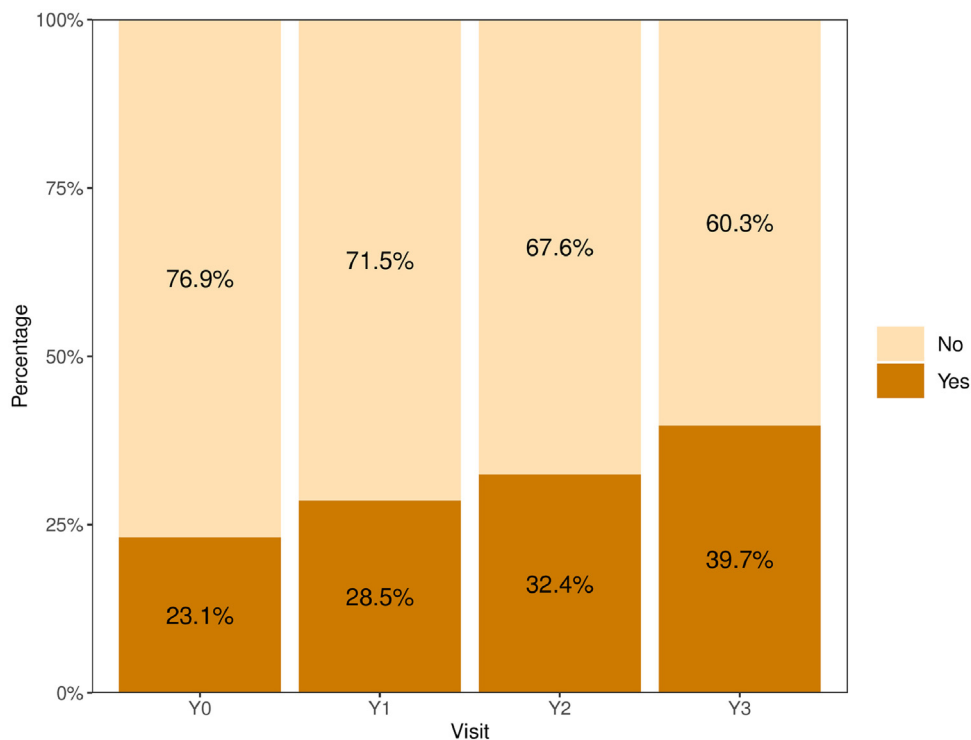


Fig. 1a. Cumulative lifetime rates of “any” substance use (i.e., reported “experimentation” OR “initiation”) for all substances. If a participant previously endorsed “any” substance use, their onset was carried forward regardless of subsequent reports of “any” substance use. Notably, Y3 contains half of the ABCD cohort and thus may not be generalizable to the full cohort.

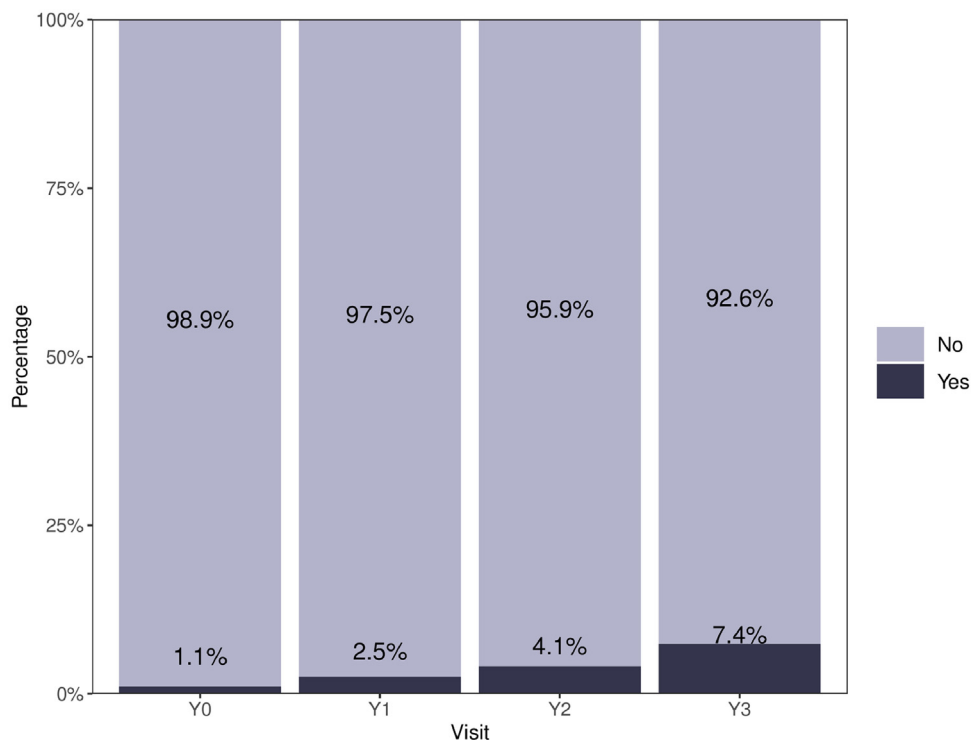


Fig. 1b. Cumulative lifetime rates of substance use “initiation” (i.e., reported ≥ 1 standard drink, > puff/taste cannabis or nicotine or any other substance use) for all substances. If a participant previously endorsed substance use “initiation”, their onset was carried forward regardless of subsequent reports of substance use “initiation”. Notably, Y3 contains half of the ABCD cohort and thus may not be generalizable to the full cohort.

3.5.3. Nicotine use

By Y3, 3.0% reported any past-year nicotine use. Males used more nicotine than females at Y0 and Y1.

3.5.4. Cannabis use

1.2% of youth reported any cannabis use by Y3. Males used more cannabis than females at Y0, Y1, and Y2.

3.6. Multivariable predictors of substance use experimentation and substance use initiation

3.6.1. “Any” substance use (i.e., “experimentation” or “initiation”) GEE (Fig. 2a)

Significant sociodemographic predictors of higher odds of any SU included: *age at Y0* [$W\chi^2=48.4$, OR=1.15 (CI: 1.11–1.20), $p < 0.001$], *males* [$W\chi^2=30.9$, OR=1.22 (CI: 1.12–1.32), $p < 0.001$], *White youth*

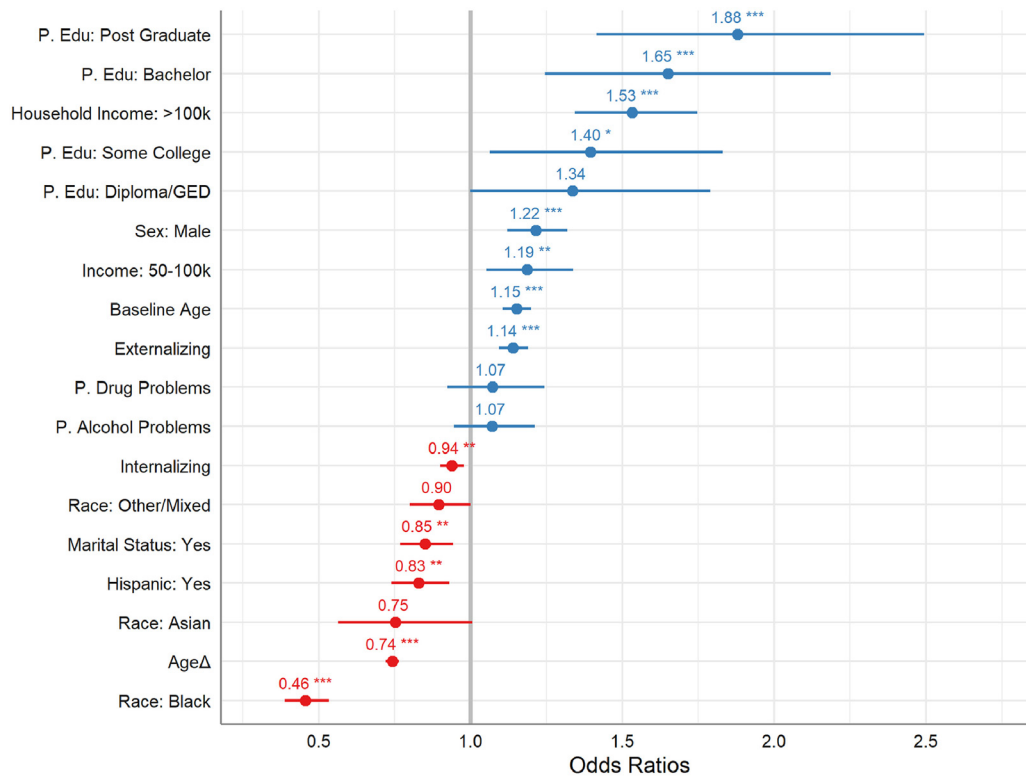


Fig. 2a. Odds ratio (OR) of “any” substance use (i.e., “experimentation” or “initiation”) GEE output. Blue represents positive ORs and red represents negative ORs. OR of the predictor is presented above 95% confidence interval bracket with asterisk denoting statistical significance. Notably, GEEs only analyzed Y0-Y2 data. “P.” = parental, “Edu” = education.

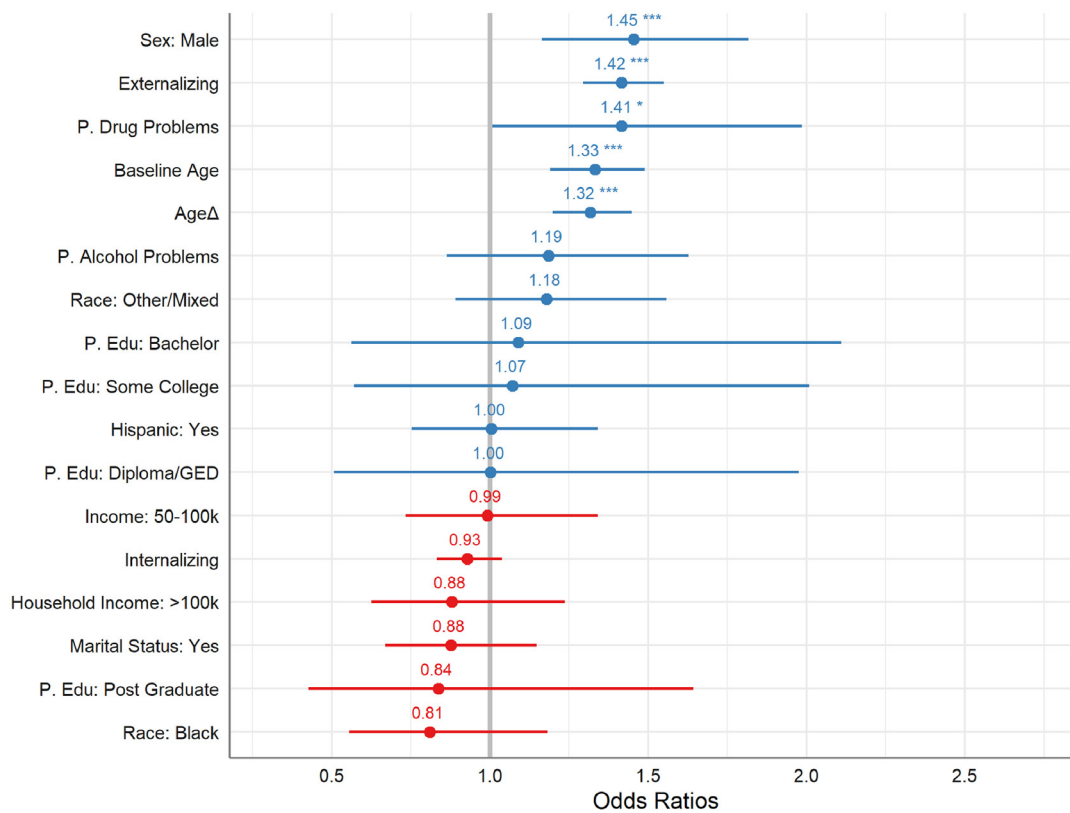


Fig. 2b. Odds ratio (OR) of substance use “initiation” GEE output. Blue represents positive ORs and red represents negative ORs. OR of the predictor is presented above 95% confidence interval bracket with asterisk denoting statistical significance. Notably, GEEs only analyzed Y0-Y2 data. “P.” = parental, “Edu” = education.

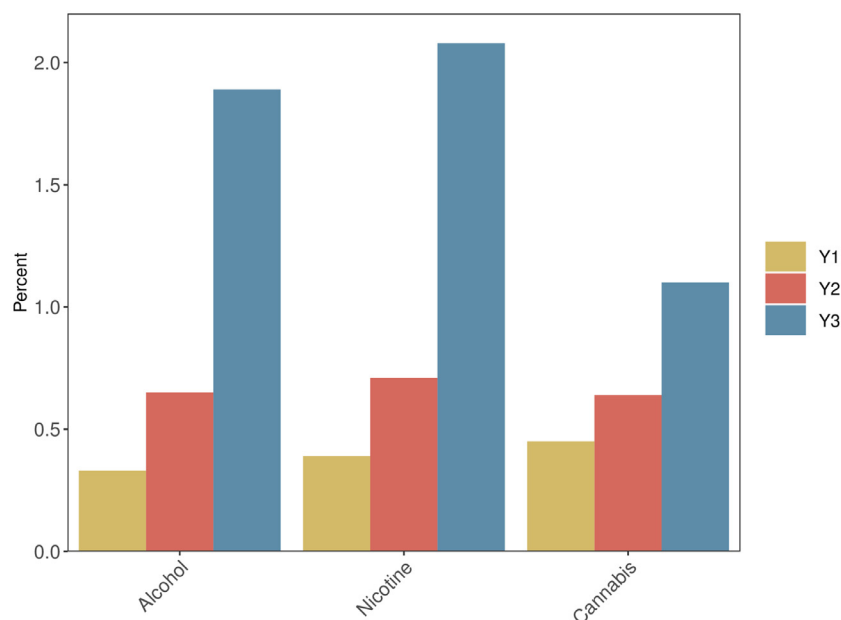


Fig. 3. Proportion of participants reporting past-year substance use “initiation” (i.e., reported ≥ 1 standard drink, > puff/taste cannabis or nicotine) for each alcohol, nicotine or cannabis at Y1-Y3 follow-up visits. Y0 was removed due to capturing lifetime substance use “initiation” rather than past-year use. Notably, Y3 contains half of the ABCD cohort and thus may not be generalizable to the full cohort.

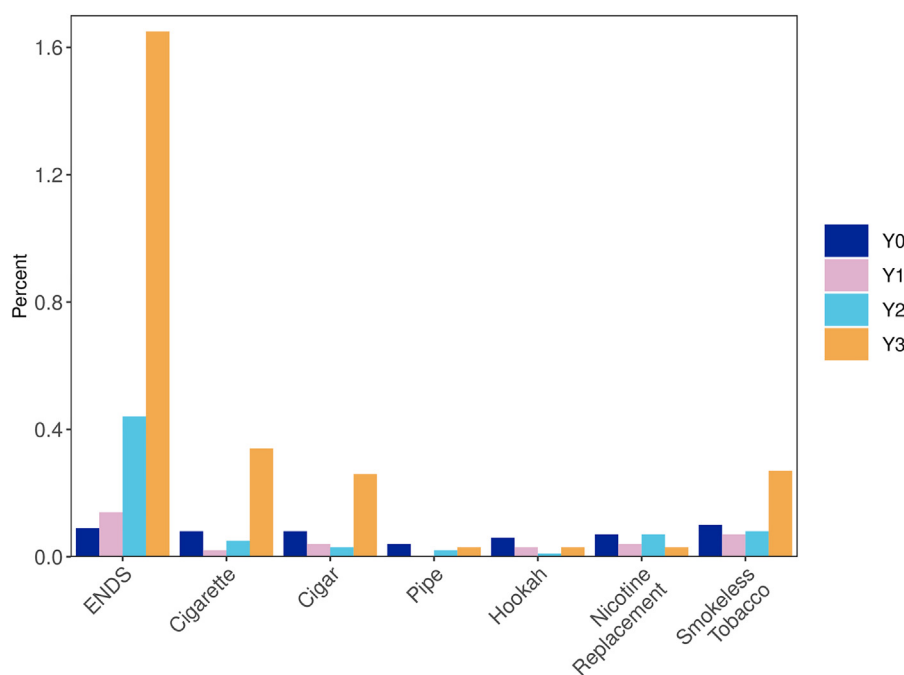


Fig. 4a. Proportion of participants reporting > puff/taste of specific nicotine products within study visits. Notably, Y3 contains half of the ABCD cohort and thus may not be generalizable to the full cohort, and Y0 is indicative of lifetime use rather than past-year use.

[$W\chi^2=183, p < 0.001$, vs. Black youth, $OR=0.46$ (CI: 0.39–0.53)], *non-Hispanic youth* [$W\chi^2=10.3, p = 0.001$ vs. Hispanic youth, $OR=0.83$ (CI: 0.74–0.93)], *higher household income* [$W\chi^2=85.2, p < 0.001$; <50k vs 50–100k, $OR=1.19$ (CI: 1.05–1.34); vs >100k, $OR=1.53$ (CI: 1.34–1.75)], *more parental education* [$W\chi^2=25.4, p < 0.001$; <HS vs some College, $OR=1.4$ (CI: 1.06–1.83); vs Bachelor, $OR=1.65$ (CI: 1.24–2.19); vs post-graduate degree, $OR=1.88$ (CI: 1.42–2.49)], and *non-married family status* [$W\chi^2=9.6, OR=0.85$ (CI: 0.77–0.94), $p = 0.002$]. Lower odds of any SU were significantly related to age_{Δ} (i.e., time) [$W\chi^2=362.6, OR=0.74$ (CI: 0.72–0.76), $p < 0.001$]; higher rates of any SU are evident at Y0, likely due to lifetime measurement, particularly of sipping alcohol (see Table 2). Parental history of alcohol [$W\chi^2=1.2, p = 0.28$] or drug [$W\chi^2=0.8, p = 0.36$] problems were not significantly associated with odds of any SU. Higher *internalizing scores* [$W\chi^2=8.6, OR=0.94$ (CI:

0.90–0.98), $p = 0.003$] were predictive of lower SU odds while higher *externalizing scores* [$W\chi^2=37.6, OR=1.14$ (CI: 1.09–1.19), $p < 0.001$] were predictive of higher SU odds. See Supplementary Table 1a for model output.

3.6.2. Substance Use “Initiation” GEE (Fig. 2b)

Significant sociodemographic predictors of higher odds of SU “initiation” included: higher *age at Y0* [$W\chi^2=25.1, OR=1.33$ (CI: 1.19–1.49), $p < 0.001$], *age $_{\Delta}$* (i.e., time) [$W\chi^2=32.4, OR=1.32$ (CI: 1.20–1.45)], *males* [$W\chi^2=10.9, OR=1.45$ (CI: 1.16–1.82), $p = 0.001$], and *lower household income* [$W\chi^2=15.1, p < 0.001$]. Parental history of *drug problems* [$W\chi^2=4.0, OR=1.4$ (CI: 1.01–1.99), $p = 0.045$] and higher *externalizing scores* [$W\chi^2=57.7, OR=1.42$ (CI: 1.29–1.55), $p < 0.001$] were

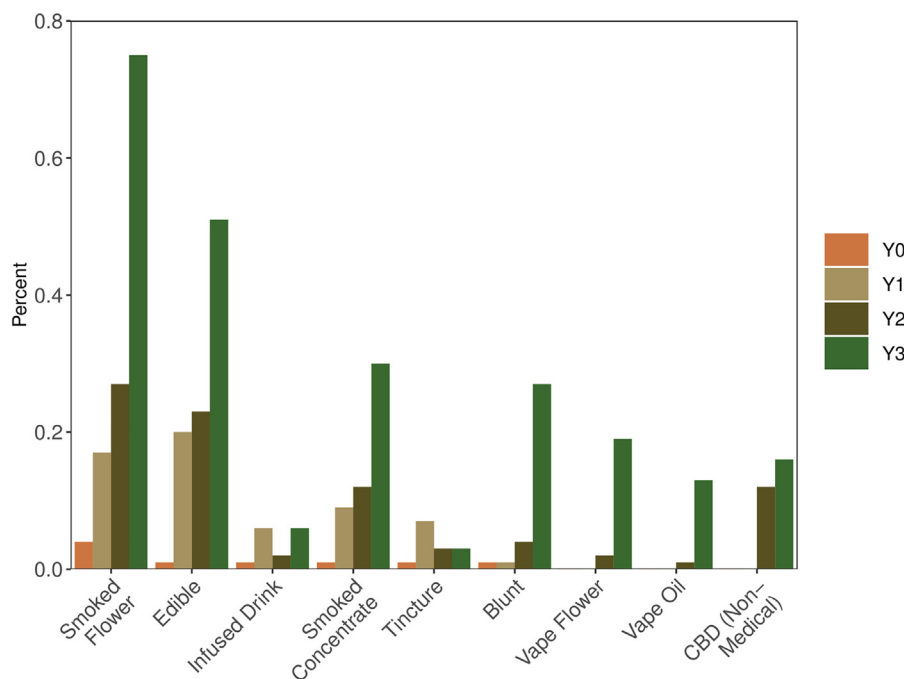


Fig. 4b. Proportion of participants reporting > puff/taste of specific cannabis product within study visits. Notably, Y3 contains half of the ABCD cohort and thus may not be generalizable to the full cohort and Y0 is indicative of lifetime use rather than past-year use.

Table 3
Onset of substance use across annual ABCD study follow-up visits.

N (%)	Y0 ¹	Y1	Y2	Y3
“Any” Substance Use (i.e., reported “experimentation” OR “initiation”)				
Total Lifetime Onset	23.13%	28.54%	32.43%	39.67%
First onset identified at visit ²	23.13%	5.18%	4.07%	5.20%
Cumulative Onset	NA	23.36%	28.36%	34.47%
No Onset at this visit	76.87%	71.46%	67.57%	60.33%
Substance Use “Initiation” (i.e., reported ≥1 standard drink, > puff/taste cannabis or nicotine or any other substance use)				
Total Lifetime Onset	1.06%	2.49%	4.06%	7.41%
First onset identified at visit ²	1.06%	1.42%	1.59%	3.17%
Cumulative Onset	NA	1.08%	2.47%	4.24%
No Onset at this visit	98.94%	97.51%	95.94%	92.59%
First Alcohol Sip				
Total Lifetime Onset	22.51%	27.18%	30.47%	36.92%
First onset identified at visit ²	22.51%	4.45%	3.48%	4.24%
Cumulative Onset	NA	22.73%	26.99%	32.68%
No Onset at this visit	77.49%	72.82%	69.53%	63.08%
First Alcohol Drink				
Total Lifetime Onset	0.38%	0.71%	1.30%	2.98%
First onset identified at visit ²	0.38%	0.32%	0.60%	1.49%
Cumulative Onset	NA	0.39%	0.70%	1.49%
No Onset at this visit	99.62%	99.29%	98.70%	97.02%

Notes: NA, not applicable.

¹ Baseline visit (Y0) captured any use throughout lifetime with higher rates of alcohol sipping identified.

² No previous report of use.

predictive of higher SU “initiation” odds. See Supplementary Table 1b for model output.

4. Discussion

Given a primary aim of the ABCD Study is to examine the influence of substance use onset on biological, psychosocial, psychiatric, and neurodevelopment outcomes, it is important to document and describe substance use as this cohort ages. In the present analyses, we reported patterns that emerged from when these youth were 9-10 (Baseline) to 12-13 (Year 3 Follow-Up). Past-year experimental substance use (sipping,

puffing/tasting) was stable at each time point for alcohol and cannabis, with increases in nicotine puffing over time. By the third follow-up visit, nearly 40% of the cohort had at least *experimented with* a substance in their lifetime, while past-year rates for any use were 18% (17% alcohol, 3% nicotine, 1% cannabis). Despite hypothesized differences, prevalence rates by Year 3 follow-up did not generally vary by sex.

As expected, reported substance use is increasing as ABCD participants out of early adolescence (i.e., ages 12-13). While only 1% of youth had ever used a full unit of any substance at Baseline, 7% had by Year 3. An increase in the rate of initiation of use beyond “experimentation” was also observed at each annual visit (Y1=1.4%, Y2=1.6%, Y3=3.2%). Alcohol remains the most used substance overall, with 37% of youth reported sipping alcohol and 3% reported having their first full alcohol drink by Y3. While recent MTF findings suggest 21.7% of 8th graders have used any alcohol (defined as more than just a sip) in their lifetime (NIDA, 2021); variance in rates may be due to the present study’s delineation of alcohol sips v. full standard drink, with MTF rates falling between the ABCD reporting levels, and the fact that many ABCD participants are still below the minimum age of MTF participants. As pre-clinical and clinical research shows risky alcohol use during adolescence is associated with a range of neural and cognitive deficits (Lees et al., 2020), continued documentation and investigation into adolescent alcohol use will be important for informing future prevention and intervention efforts.

Also consistent with Baseline ABCD findings, nicotine remains the next most reported substance used in the ABCD Study cohort. Prevalence increased from 1.1% of youth reported using a nicotine product in their lifetime at Baseline to 3% using nicotine within the past year at Year 3. Vaping nicotine products remained the most popular mode of use across time-points. This is notable as evidence suggests nicotine can be particularly neurotoxic in the developing brain (Yuan et al., 2015) and that early vaping (the most common method of nicotine use in this sample) is correlated with later combustible cigarette and other substance use (McCabe et al., 2018; Staff et al., 2020; Yoong et al., 2021). Notably, these rates were lower than those reported in the most recent MTF study, which reported 12.1% of 8th graders used ENDS in 2021 (Johnston et al., 2022). This is likely due to different recruitment strategies and methodologies that are employed; MTF uses an

Table 4
Lifetime (Y0) or past-year (Y1–3) nicotine and cannabis product-specific patterns according to full cohort and sex.

N (%)	All	Males	Females
Nicotine Products			
ENDS Use			
Y0	<0.1%	0.13%	<0.1%
Y1	0.14%	0.20%	<0.1%
Y2	0.44%	0.44%	0.44%
Y3	1.65%	1.55%	1.76%
Cigarette Use			
Y0	<0.1%	0.10%	<0.1%
Y1	<0.1%	<0.1%	0%
Y2	<0.1%	<0.1%	<0.1%
Y3	0.34%	0.27%	0.41%
Cigar Use			
Y0	<0.1%	0.10%	<0.1%
Y1	<0.1%	<0.1%	<0.1%
Y2	<0.1%	<0.1%	<0.1%
Y3	0.26%	0.27%	0.24%
Pipe Use			
Y0	<0.1%	<0.1%	<0.1%
Y1	0%	0%	0%
Y2	<0.1%	<0.1%	0%
Y3	<0.1%	0%	<0.1%
Hookah Use			
Y0	<0.1%	<0.1%	<0.1%
Y1	<0.1%	<0.1%	<0.1%
Y2	<0.1%	<0.1%	0%
Y3	<0.1%	<0.1%	<0.1%
Nicotine Replacement			
Y0	<0.1%	<0.1%	<0.1%
Y1	<0.1%	<0.1%	<0.1%
Y2	<0.1%	<0.1%	<0.1%
Y3	<0.1%	<0.1%	<0.1%
Smokeless Tobacco (Chew)			
Y0	0.10%	0.16%	<0.1%
Y1	<0.1%	<0.1%	<0.1%
Y2	<0.1%	0.11%	<0.1%
Y3	0.27%	0.39%	0.14%
Vape Flower (No Nicotine)			
Y0	NA	NA	NA
Y1	NA	NA	NA
Y2	NA	NA	NA
Y3	0.63%	0.97%	0.24%
Cannabis Products			
Smoked Flower Use			
Y0	<0.1%	<0.1%	0%
Y1	0.17%	0.24%	<0.1%
Y2	0.27%	0.35%	0.18%
Y3	0.75%	0.73%	0.78%
Edible Use			
Y0	<0.1%	<0.1%	0%
Y1	0.20%	0.26%	0.13%
Y2	0.23%	0.31%	0.14%
Y3	0.51%	0.49%	0.54%
Infused Drink Use			
Y0	<0.1%	<0.1%	0%
Y1	<0.1%	0.10%	<0.1%
Y2	<0.1%	<0.1%	0%
Y3	<0.1%	<0.1%	<0.1%
Smoked Concentrate Use			
Y0	<0.1%	<0.1%	0%
Y1	<0.1%	0.14%	<0.1%
Y2	0.12%	0.15%	0.10%
Y3	0.30%	0.33%	0.27%
Tincture Use			
Y0	<0.1%	<0.1%	0%
Y1	<0.1%	0.12%	<0.1%
Y2	<0.1%	<0.1%	0%
Y3	<0.1%	<0.1%	0%
Blunt Use			
Y0	<0.1%	<0.1%	0%
Y1	<0.1%	<0.1%	0%
Y2	<0.1%	<0.1%	<0.1%
Y3	0.27%	0.18%	0.37%

(continued on next page)

Table 4 (continued)

N (%)	All	Males	Females
Vaped Flower Use			
Y0	NA	NA	NA
Y1	0%	0%	0%
Y2	<0.1%	<0.1%	0%
Y3	0.19%	0.21%	0.17%
Vaped Oil Use			
Y0	NA	NA	NA
Y1	0%	0%	0%
Y2	<0.1%	<0.1%	0%
Y3	0.13%	0.18%	<0.1%
CBD (Non-Medical) Use			
Y0	NA	NA	NA
Y1	NA	NA	NA
Y2	0.18%	0.19%	0.18%
Y3	0.16%	0.18%	0.14%

Notes: ENDS = electronic nicotine delivery system, CBD = cannabidiol, NA = Not assessed. Rates reflect youth who reported use beyond experimental use (i.e., beyond “taste or puff.”) Chi-square and p-values represent comparisons between male and female use. Y0 represents lifetime use as of Baseline assessment, while Y1–3 represents past-year use at Year 1, Year 2, and Year 3 follow-up assessments.

anonymous, national school-based survey, whereas the ABCD Study recruited in school communities and uses an interviewer-administered TLFB calendar approach combined with numerous other surveys assessing mental and physical health, culture and environment, and includes bioassay collection and MRI brain scans (Garavan et al., 2018; Jernigan et al., 2018; Volkow et al., 2018). Further, during the years reported here, the ABCD Study cohort is still mostly younger than the MTF Study participants; thus, prevalence rates between the two may become more comparable over time. Additionally, timing of the data collection during the pandemic may influence differential cohort SU rates, as pandemic surveys have generally reported lower SU rates in teens (NIDA, 2021). Rates of use reported and timing of the ABCD data collection were also impacted by the pandemic. During the COVID-19 pandemic (spring/summer 2020), all ABCD Study participants were invited to complete online surveys every 4–11 weeks and report past-month substance use (Pelham et al., 2021). These surveys found that past-month alcohol use decreased in the early pandemic months (May–June 2020), while nicotine use increased during this period, with the cumulative nicotine use rate reaching 3.6%. It is challenging to compare findings, as fewer participants opted in to the COVID-19 surveys and non-random factors and methodological differences may explain differences in prevalence rates. Future ABCD Study analyses will monitor the potential influence of data collection methodologies and pandemic-related effects on substance use reporting.

Several risk factors were associated with early substance use in the ABCD Study cohort. Experimentation and initiating any substance use were associated with multiple sociodemographic variables and externalizing symptoms. Analyses revealed relationships between being older at Baseline, male at birth, having a parental history of drug use problems, and parental report of increased externalizing symptoms increasing odds of a “full use” (one full dose of standard drink, nicotine/cannabis use beyond puffing or other occasions of substance use). These results are consistent with previously reported ABCD Cohort Baseline findings of increased early alcohol sipping significantly related to being older, White, male, and parental reports of higher externalizing symptoms (Lisdahl et al., 2021), suggesting consistency of very early risk factors for substance use initiation in this cohort over time. The largest increase in odds of SU initiation was in males (OR=1.45) and externalizing symptoms (OR=1.42), followed by youth with parent drug use problems (OR=1.4). Results are thus consistent with prior research (e.g., externalizing symptoms have been linked to substance use onset; Cox et al., 2021; Edwards et al., 2016; Loeber et al., 2018; Ning et al., 2020). Notably, there were fewer sex differences as the ABCD Study participants

aged, which is consistent with the MTF survey finding fewer sex differences in 8th graders (Miech et al., 2020). Here, we found parental history of drug problems, but not alcohol problems, predicted increased odds of substance use. Mixed results are noted from prior analyses in the ABCD Study, suggesting parental history of alcohol or drug problems were not associated with curiosity about substance use at Baseline (Martz et al., 2022), but parental history of alcohol problems contributed to a latent factor which was significantly associated with alcohol curiosity at Year 1 (Wade et al., 2021) and was previously linked with early alcohol sipping (Lisdahl et al., 2021). Overall, these findings once again suggest that sociodemographic factors, externalizing symptoms, and parental history of substance use problems need to be considered when others are utilizing the ABCD data to examine predictors of adolescent substance use trajectories.

Results should be considered within the context of their limitations. As noted, estimates of self-reported substance use prevalence varies (Pelham et al., 2021) and hair toxicology data collected on a subset of youth enrolled in the ABCD Study indicate potential underreporting of substance use, especially in high-risk youth (Wade et al., 2022). In addition, while the ABCD Study withdrawal rate is minimal (1.1%), missed study visits may contribute to the relatively lower prevalence of SU reported here than in other national studies. Though beyond the scope of this paper to fully analyze factors influencing missing visits, the ABCD Retention Workgroup found race, parental education, and parental employment predicted missed visits (Feldstein Ewing et al., 2022). GEEs were limited to Baseline through Year 2 data (NDA 4.0) as only half of Year 3 data is released; continued monitoring of risk factors for substance use onset is needed. The current analysis aimed to report the pattern of substance use in the initial waves of the ABCD Study and examine basic sociodemographic, parental history of substance use problems, and internalizing/externalizing symptoms to inform the scientific community. Numerous other factors were not examined and will be considered by multiple investigators in future analyses [e.g., culture and environmental factors (Zucker et al., 2018), more detailed psychopathology (Barch et al., 2018), physical health (Palmer et al., 2021), SU attitudes (Lisdahl et al., 2018), biological functioning (Uban et al., 2018), genetics (Iacono et al., 2018), and neurocognitive (Casey et al., 2018; Luciana et al., 2018) factors]. The COVID-19 pandemic impacted data collection in that almost all data was collected remotely or in hybrid-fashion for an extended period of time. Given there was limited in-person data collection after March 2020 in this data release, it is not possible here to investigate remote v. in-person reporting differences in SU reporting, though this will be important to consider in future investigations.

5. Conclusions

Early substance initiation is associated with quicker transition to, and increased prevalence of, substance use disorders (Volkow et al., 2021). Thus, monitoring early substance use onset patterns and identifying associated risk factors are key to preventing long-term consequences of substance use onset (Tapert and Ebersson-Shumate, 2022). The ABCD Study cohort has reported increased use of substances as they transition to teenage years (ages 12-13), though rates are generally lower than seen in other national samples (i.e., MTF). Across Baseline and through Year 3 follow-up, alcohol use is the most used substance, followed by nicotine use (specifically, ENDS) in the ABCD Study cohort. Externalizing symptoms and parental history of drug problems predicted increased odds of substance experimentation and initiation, while sex differences in prevalence rates were less apparent at later follow-up points. Continuing to follow this large, diverse cohort through adolescence will provide a unique and extraordinary opportunity to investigate these and other multifaceted risk and resiliency factors associated with SU onset and consequences in teens.

Declaration of Competing Interest

The authors have no conflict of interest or competing interests to declare.

CRedit authorship contribution statement

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.dadr.2022.100120.

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