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# Substance use patterns from late childhood to mid-adolescence: Updates on the Adolescent Brain Cognitive Development Study

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## HIGHLIGHTS

- Detailed prevalence of substance use in the ABCD Study are provided.
- Alcohol, cannabis, and nicotine are the most used substances in the cohort.
- Divergent reporting by sex is detailed for substance-specific rates.
- Polysubstance use analyses identify shared and evolving use patterns.
- Outlines approaches for utilizing ABCD substance use data.

## ARTICLE INFO

*Keywords:*
Substance Use
Cohort Study
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Cannabis
Nicotine
Polysubstance Use

## ABSTRACT

*Background:* Adolescent substance use is a continued public health concern. The objective of this manuscript is to detail the prevalence of substance use, polysubstance use, and investigate sex differences in the Adolescent Brain Cognitive Development (ABCD) Study from ages 9–17.
*Methods:* 11,880 youth across the U.S., recruited at ages 9–10, completed annual study visits from September 2016 to January 2024. The ABCD 6.0 data release comprises baseline to year-6 data. Lifetime and annual substance use prevalence rates, sex differences, and polysubstance use are described and analyzed.
*Results:* Past-year substance use prevalence increased with age; 38% report lifetime use by age 16. Alcohol, cannabis, and nicotine were the most reported substances. There were non-significant differences observed between unweighted trends and census-weighted trends. More boys reported substance use prior to age 12, then from age 13 onward, more girls reported use. Polysubstance use analyses detail the occurrence of the most shared substance use patterns and divergent reports across the sexes.
*Conclusions:* Descriptively, these prevalence rates mirror other national surveys showing increases in reported use across early adolescence, with alcohol, cannabis, and nicotine being the most used substances. Unique sex differences and polysubstance use prevalence rates are contextualized alongside prior national reports of these behaviors in the U.S. Understanding the latest prevalences, specifically in a well-phenotyped cohort, helps to guide knowledge for continued analysis of antecedents and sequelae of substance use on health.

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## 1. Introduction

The Adolescent Brain Cognitive Development (ABCD) Study[SM] is an ongoing, landmark National Institute of Health-initiative designed to prospectively study a cohort of nearly 12,000 youth across the U.S. from early childhood to late adolescence(Jernigan and Brown, 2018). The ABCD Study was designed in an open-science framework with yearly data releases to the scientific community(Volkow et al., 2017). A major research aim of the ABCD Study is to investigate risks for and consequences of adolescent substance use (SU) on neurodevelopment (Jernigan and Brown, 2018; Lisdahl et al., 2018; Volkow et al., 2017); thus, it is important to document the latest SU prevalence estimates in the cohort(Lisdahl et al., 2021; Sullivan et al., 2022) and communicate to the scientific community seeking to examine these nuanced, longitudinal relationships as the study data is released.

Adolescence is a key developmental period where SU can progress from naivety, experimentation, social use, regular use, to problematic use(Schneider et al., 2012; Volkow et al., 2021). In the U.S., other national datasets on adolescent SU exist—and can be compared against the ABCD Study—including Monitoring the Future(Miech et al., 2025) (MTF; cross-sectional surveys are conducted at grades 8, 10, 12) and the National Survey on Drug Use and Health(SAMHSA, 2025) (NSDUH; begins at 12 and reports across age-level data). Given these reporting differences between other studies, the ABCD Study dataset can be flexibly utilized for binning categories (i.e., age, grade, data collection year) to more exactly compare SU prevalence across other datasets. Moreover, the ABCD Study benefits from its design as a prospective cohort study rather than population-level surveys to examine changes in SU patterns within-individuals. In this vein, the ABCD Study is not a direct representation of the U.S. Incorporating techniques such as population-weighting can estimate how SU information in the ABCD dataset may correspond with national trends.

Importantly, adolescent SU tends to not consist of using a singular substance(Goodwin et al., 2022; Moss et al., 2014). Some youth who are engaging in SU are reporting use of multiple substances—or polysubstance use(Bunting et al., 2024; Crummy et al., 2020)—representing a potential higher-risk trajectory for negative outcomes(Carbonneau et al., 2023). It is important to detail prevalence of polysubstance use to describe what proportion of the cohort this represents and what substances are frequently being used together.

This paper aims to report the raw and census-weighted (American Community Survey sociodemographic features) longitudinal age-binned prevalence, of lifetime and annual SU, in the large, diverse, U.S. ABCD Study. Sex-specific prevalence rates and differences are reported. The paper's Supplement includes raw and weighted SU prevalence rates by annual study visit, educational grade, and data collection year. The second aim is to measure prevalence of polysubstance use through association analyses(Lu et al., 2000), which quantify prevalence and shared probabilities of specific polysubstance use patterns within-observations. Results of these two aims inform prevalence of SU across late childhood to mid-adolescence in a well-phenotyped cohort and serve the scientific community by establishing best-practices for estimating SU in the ABCD Study. This creates a reference for future studies on optimal utilization of the SU data in analyses examining antecedents and sequelae of SU on adolescent health.

## 2. Methods

### 2.1. Participants and procedures

Data were leveraged from the ABCD Study Data Release 6.0 (https://www.nbdc-datahub.org/abcd-release-6-0), which covers data collection dates September 1, 2016, to January 15, 2024, and includes baseline (Y0) to year 5 (Y5) and half of year 6 (Y6) annual follow-up visits. The ABCD Study is a large, nationally diverse cohort of 11,868 U.S. youth (age 9–10 at Y0) and their caregivers, with planned annual follow-up for approximately 10 years. A centralized Institutional Review Board (IRB), located at University of California, San Diego, approved all study procedures. Participants were recruited across 21 U.S.-based catchment sites, utilizing stratified probability sampling of surrounding schools to enroll participants with similar sociodemographic characteristics to the American Community Survey (ACS)(Garavan et al., 2018). Exclusion criteria and additional information regarding The ABCD Study[SM] are provided in the Supplementary Methods.

Informed assent (<18-years-old) and consent were obtained from youth and caregivers at each visit, including reminders of confidentiality regarding self-reporting on SU, which was reiterated prior to SU interviews.(Lisdahl et al., 2018) The ABCD Study consists of a battery of behavioral and biological assessment modules.(Volkow et al., 2017) Annual study visits were predominantly in-person. Following 2020, the prevalence of remote/hybrid visits increased, if the visit was completed remote, private video/telephone calls were completed with youth apart from their caregiver, with modest impact on reporting noted (Wade et al., 2024). In addition, mid-year phone interviews (i.e., at 6-month intervals) were conducted.(Lisdahl et al., 2018) Overall retention in the ABCD Study is > 95%.(Feldstein Ewing et al., 2018) In the present analyses, all observations were included (Table S2 for observation counts).

### 2.2. Measures

#### 2.2.1. Sociodemographic

Sex (defined as sex assigned at birth) was investigated to determine sex-specific prevalence of SU. Weights derived from ACS [for detailed comparisons between ACS sample and ABCD cohort see: (Heeringa and Berglund, 2020)]—to sociodemographically match the ABCD cohort to the ACS sample and improve generalizability—were utilized to obtain weighted prevalences of SU. Sociodemographic factors are included in Table 1 to describe the sample: 4-levels of self-identified race (Asian, Black, White, Mixed/Other), ethnicity (Hispanic/Latinx, non-Hispanic/Latinx), caregiver educational attainment (<High School Diploma, High School Diploma, Some College, Bachelor Degree, Post-graduate Degree), household income (<$50k, $50–100k, >$100k), and continental U.S. location based on census region (Midwest,

**Table 1**
Sociodemographic characteristics of the ABCD cohort at Y0.

| % or M (SD) | N = 11,868 |
|---|---|
| Age (years) | 9.96 (0.6) |
| Sex | |
| Female | 47.8 |
| Male | 52.2 |
| Race/Ethnicity | |
| Asian | 1.9 |
| Black | 15.3 |
| Hispanic | 20.6 |
| White | 52.1 |
| Multi/Other | 10.1 |
| Household Income | |
| [< 50 K] | 27.1 |
| [> =50 K & < 100 K] | 25.9 |
| [> =100 K] | 38.4 |
| Not Reported | 8.6 |
| Parental Education | |
| <HS | 5.0 |
| HS/GED | 9.5 |
| Some College | 25.9 |
| Bachelors | 25.4 |
| Post Graduate | 34.1 |
| Not Reported | 0.1 |
| U.S. Region | |
| Midwest | 14.4 |
| Northeast | 17.0 |
| South | 28.3 |
| West | 40.3 |

Northeast, South, West).

#### 2.2.2. Substance Use Interview

(Lisdahl et al., 2018) From Y0-Y2, SU questions were gated by whether youth "heard of" substances; if familiar, participants were asked if they had used said substance. Y3 onward, this gating was removed and participants were queried directly about use, including alcohol (sipping/full drink), nicotine products [cigarettes, electronic nicotine delivery systems (ENDS), smokeless tobacco, cigars, hookah, pipe, and nicotine replacement products], cannabis products (smoked flower, vaped flower, smoked blunts, edibles, smoked concentrates, vaped concentrates, tinctures, cannabis-alcohol drinks, and nonmedical cannabidiol), synthetic cannabinoids, cocaine, cathinones, methamphetamine, ketamine, gamma-hydroxybutyrate, heroin, psilocybin, salvia, hallucinogens, anabolic steroids, inhalants, and prescription misuse of stimulants, sedatives, opioids, and dextromethorphan.(Lisdahl et al., 2018) Data from this interview results in dichotomized yes/no use and age of first use onset.

#### 2.2.3. Timeline Followback

If youth endorsed SU, detailed web-based Timeline Followback (TLFB) interviews(Sobell and Sobell, 1992) were conducted to retrospectively measure quantity of use for the past-year. For dates beyond the past-year, to cover time periods between annual visits, estimated use amounts were measured.(Lisdahl et al., 2018) This approach allows for estimation of "total dose" consumed between visits.

#### 2.2.4. Mid-year Phone Interview

In between annual visits, youth were contacted via telephone for a brief interview including yes/no questions regarding use of the aforementioned drugs since their last annual study visit.(Lisdahl et al., 2018) For the present analyses, data from this source were combined with the subsequent annual visit (e.g., 6-month data contributed to SU prevalence at Year 1).

### 2.3. Statistical analysis

All analyses were completed in R (v4.4.2).(R Core Team, 2022) This analytic approach was pre-registered on Open-Science Framework [https://osf.io/dwtey/] and code to replicate these prevalence rates, analyses, tables, and figures are publicly available: [https://doi.org/10.17605/OSF.IO/DGQC9].

#### 2.3.1. Substance use prevalence (Aim 1a)

Data across the Substance Use Interview, TLFB, and Mid-year Phone Interview were coalesced to obtain (a) *annual* reporting of SU (i.e., reported use between annual study visits). Then, any reports of SU prior to the study visit were clustered within-subject to characterize (b) *lifetime* endorsement of a particular SU at that study visit and subsequent observations. This was computed for each individual full unit of substance (alcohol, cannabis, nicotine, and "other" substances are detailed in the main text) and additional prevalence rates are provided on modality of use (for nicotine and cannabis). Prevalence rates are reported by the following categories: chronological age, ABCD study visit (Supplement), educational grade (Supplement), and data collection year (Supplement), and broken down by sex. Random draws reconciled individuals with multiple observations within a bin (e.g., >1 observation at age 13). Chi-square tests investigated differences in prevalence between sexes within each category (e.g., age); statistical significance was determined at $\alpha = 0.05$.

In the ABCD dataset, there are, at minimum, three ways to calculate age of SU onset: (a) using "age of onset" question in the Substance Use Interview; (b) leveraging the day-level TLFB data (age of first reported use can be estimated from the timestamped day of first reported use); and, (c) capturing the age from the annual visit when use was first indicated (i.e., "yes" to yes/no question). Due to known factors influencing self-report of SU (i.e., social desirability), at times these answers conflict as youth retrospectively report earlier age of onset at later dates(Kosgolla et al., 2023). Therefore, these were combined to determine the *earliest* age of onset captured across methods (within each substance).

#### 2.3.2. Census-weighted prevalence (Aim 1b)

Using the *survey*(Zimmer et al., 2024) package in R, ABCD-provided ACS weights calculated at baseline were utilized to propensity weight each participant's SU prevalence data nested within shared family identification numbers. Census-weighted estimated prevalence weights are reported with 99% confidence intervals based on Wald-type intervals from logistic regression models. Chi-squares tests were utilized to examine differences between unweighted and census-weighted prevalence estimates.

#### 2.3.3. Polysubstance use (Aim 2)

Association analyses—using the *arules*(Hahsler et al., 2005) package—were utilized to discern unique polysubstance use patterns (i.e., rulesets) across three key metrics. (a) Support $[\frac{frequency\ of(X \cup Y)}{number\ of\ occurrences}]$ represents the frequency of X and Y occurring relative to the number of total observations (e.g., frequency of a given participant reporting both cannabis and alcohol). (b) Confidence $[\frac{Support(X \cup Y)}{Support(X)}]$ is the conditional probability of two items (e.g., frequency of alcohol reporting among those reporting cannabis). Lastly, (c) Kulczynski $0.5 * [P(X|Y) + P(Y|X)]$ represents the average of both sides of the Confidence metrics, with larger values representing higher conditional probabilities in both directions (e.g., relative correlation between alcohol reporting among cannabis use, and cannabis reporting among alcohol use). These three metrics were calculated across the entire sample (i.e., regardless of visit) with 3 maximal items per rulesets (i.e., no more than 3 substances/item set). Rulesets with $\geq 0.05$ Support (i.e., $\geq$5% of reporting within the sample) were retained and re-calculated using annual endorsement within each bin for age and ABCD visit, and by sex.

#### 2.3.4. Missing data

All observations were included in the present analysis. Observations with missing SU data could not estimate SU prevalence, thus were listwise deleted at that visit; however, this did not preclude a participants' data being included in subsequent visits.

## 3. Results

### 3.1. Participant characteristics

The ABCD Study cohort is a demographically-diverse sample of 9–10-year-olds followed for 10 + years; current data release covers up to the Y6 study visit. Table 1 details sociodemographic variables at Y0. Table S1 displays the number of observations at each age group.

### 3.2. Substance use prevalence: Raw data

#### 3.2.1. Lifetime

Overall reporting of SU in the cohort followed an upward trajectory from minimal use at age 9 (0.8%) to over one-third reporting any lifetime SU by age 16 (37.5%). These same trends existed for alcohol (25.6%), cannabis (22.1%), and nicotine (20.4%) by age 16 (Fig. 1a). A combined category of other SU (i.e., recreational use/misuse of any substance other than alcohol, cannabis, and nicotine) represented 8.1% of the sample by age 16. Boys reported significantly more SU than same-aged girls from ages 9–12; however, from ages 14–16, girls reported significantly more SU than boys (Fig. 1b). This was predominantly driven by larger disparities of nicotine use between sexes (age 14: Female, 11.3%; Male, 8.0%; $\chi^2$=26.3, $p < .001$); however, alcohol (age 14: Female, 8.3%; Male, 6.5%; $\chi^2$=10.1, $p < .001$) and cannabis (age 14:

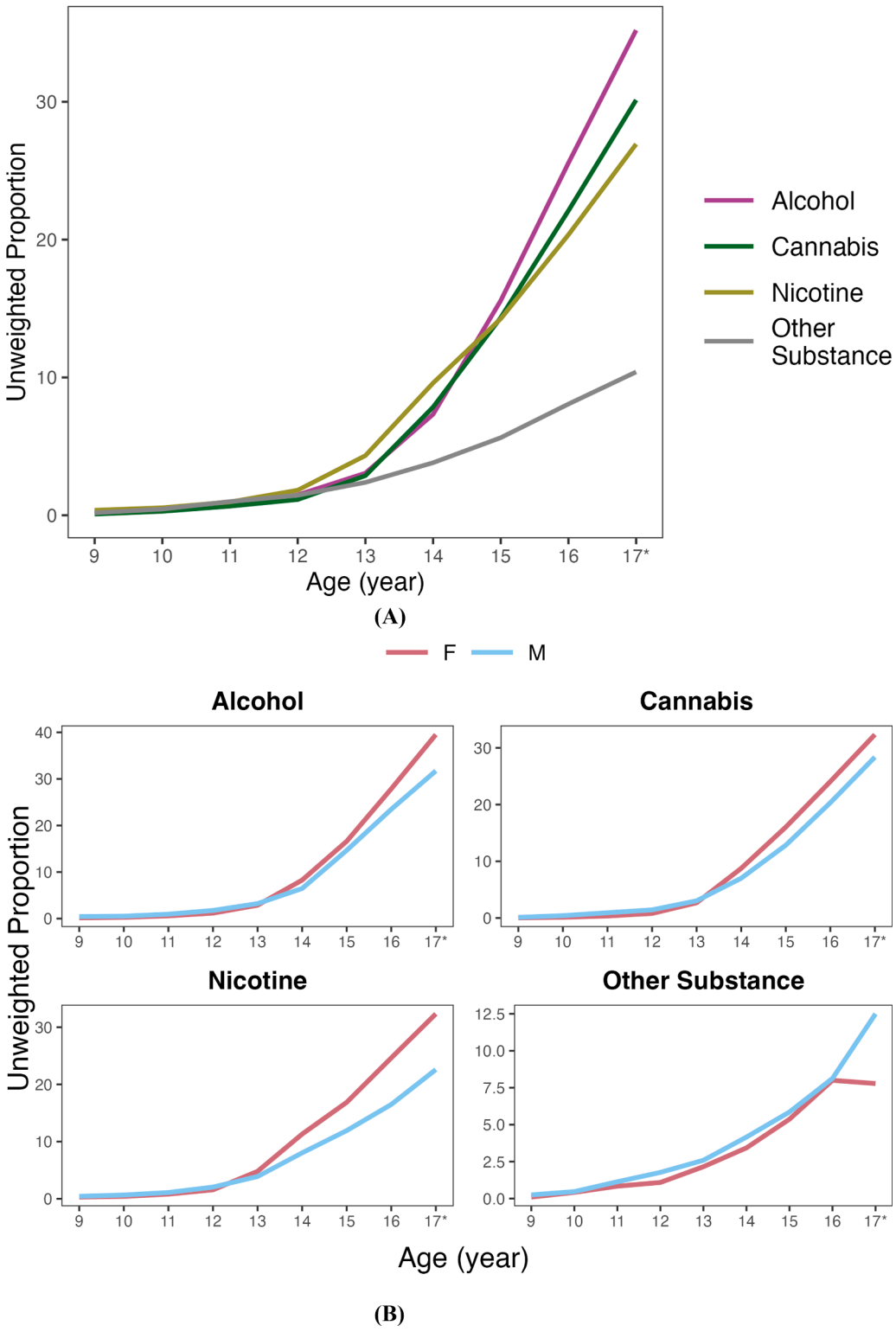


**Fig. 1.** (A) Unweighted prevalence of lifetime alcohol, cannabis, nicotine, and "other" substance use (i.e., all additional use categories collapsed) by chronological age and (B) split by sex. *Note: Age 17 has a smaller cell size (n = 375).

Female, 8.8%; Male, 7.0%; $\chi^2$=8.8, $p$ = .003) prevalence were additionally greater in girls from age 14 onward. "Other" SU was largely non-significantly different across the sexes, except with boys reporting more use at age 12 ($\chi^2$=7.4, $p$ = .007). Tables S5-S24, S66 & Figures S1-S7.

### 3.2.2. Annual

Annual SU prevalence rose from 0.8% at age 9 to 30.0% at age 16. The greatest amount of annual use was alcohol (age 16: 20.1%), followed by cannabis (age 16: 18.1%), and nicotine (age 16: 15.3%). Annual other SU was 4.2% by age 16. Similar to lifetime SU prevalence, significantly more boys reported annual SU compared to girls from ages 9–11, and more girls reported annual use from ages 13–16. Annual differences at earlier ages were due to more boys reporting cannabis use (age 10–11) (compared to null alcohol and nicotine differences at

similar ages), but significantly more girls reporting alcohol (age 14–16), cannabis (age 14–16), and nicotine (age 13–17) use in mid-adolescence. No sex differences were observed for other SU. Tables S25-S48, S66 & Figures S8-S14.

#### 3.2.3. Prevalence of cannabis modalities

Smoked cannabis flower was the most prevalent lifetime cannabis modality (age 16: 15.2%), but other forms were used as well: 13.6% vaped cannabis concentrates/oil, 13.1% edibles, 11.7% vaped cannabis flower, 7.2% blunt, 6.3% smoked concentrates/oil, 4.4% recreational cannabidiol, and all other modalities < 1.0%. Annual prevalence at age 16 was similar: 12.0% smoked flower, 11.2% vaped cannabis concentrates/oil, 10.2% edible, 9.1% vaped cannabis flower, 4.7% blunt, 4.3% smoked concentrates/oil, and 2.1% recreational cannabidiol, and all other modalities < 1.0%. Tables S57-S64 & Figures S17-S18.

#### 3.2.4. Prevalence of nicotine modalities

ENDS (i.e., e-cigarettes) were the predominant nicotine modality with 19.1% lifetime endorsement at age 16, versus 4.3% for cigarettes, 2.5% cigar, and all other modalities < 2.0%. This trend is mirrored in annual prevalence with electronic nicotine delivery systems at 14.7%, 3.3% cigarettes, 1.5% cigars, 1.1% hookah, and all other modalities < 1.0%. Tables S49-S56 & Figures S15-S16.

#### 3.2.5. Age of onset

Age of onset was calculated for all substances (and modalities) and coalesced across the three calculation methods (i.e., "age of onset" question in Substance Use Interview, day-level Timeline Follow-back data, and age at first report). Given the maximum range of the sample (age 17) at the present data release, age of onsets averaged around 14–15. Generally, the earliest age of onset was observed for nicotine use (M=14.0, SD=1.8), compared to cannabis (M=14.4, SD=1.5), alcohol (M=14.4, SD=1.9), and other SU (M=14.3, SD=1.9). Table S65.

### 3.3. Substance use prevalence: Census-weighted

Census-weighted prevalence estimates are included in Table 2. Across lifetime and annual SU prevalence, census-weighted estimates did not differ compared to unweighted prevalence rates (all p-values >0.9) with one exception; unweighted prevalence of nicotine use at age 17 (lifetime: $\chi^2$=0.17, $p = .68$; annual: $\chi^2$=0.24, $p = .63$) (lifetime: 26.9%; annual: 20.5%) were lower than weighted (lifetime: 30.6%; annual: 24.4%), however, this was not statistically significant and likely due to small cell sizes of 17-year-olds (n = 375). Figures S19-S28.

### 3.4. Polysubstance use/Association analyses

14.9% of the cohort reported ≥ 2 substances used across all observations. Utilization of association analyses revealed nine rulesets that were retained with Support values ≥ 0.05 across the entire cohort (i.e., unique polysubstance use patterns occurring in ≥5% of the cohort) in descending order: (1) Nicotine = > Cannabis; (2) Cannabis = > Nicotine; (3) Alcohol = > Cannabis; (4) Cannabis = >Alcohol; (5) Alcohol = > Nicotine; (6) Nicotine = > Alcohol; (7) [Alcohol, Nicotine] = > Cannabis; (8) [Alcohol, Cannabis] = > Nicotine; and, (9) [Nicotine, Cannabis] = > Alcohol. Table S70-S71.

#### 3.4.1. Support

Prevalence of these polysubstance use patterns are similar up to age 15, when alcohol/nicotine/cannabis (i.e., endorsement of using all three substances) prevalence is lower compared to the use of just two of these substances (i.e., nicotine/cannabis, alcohol/cannabis, and alcohol/nicotine), Fig. 2a. The most prevalent polysubstance use pattern is nicotine/cannabis, with stepwise increases observed with age: 9 = 0%, 10 = 0%, 11 = 0.1%, 12 = 0.2%, 13 = 1.3%, 14 = 4.2%,15 = 7.5%, 16 = 11%, 17 = 15%. Regarding sex-differences, Support values are similar up to age 13; however, beyond age 13 girls self-reported more polysubstance use than boys, with larger disparities observed for rulesets that specifically contain nicotine use (e.g., age 16, Nicotine/Cannabis: Female Support=0.13; Male Support=0.09; Nicotine/Alcohol: Female Support=0.13; Male Support=0.08), Fig. 2b and Table S72-S77 & Figures S29-S37.

#### 3.4.2. Confidence and Kulczynski

Prevalence of polysubstance use within given use categories (i.e., Confidence) also increase after age 12, with 79.0% of alcohol and nicotine endorsers also reporting cannabis use; 71.7% of nicotine endorsers also report cannabis use; 64.7% of nicotine endorsers also report alcohol use; and, 60.0% of cannabis endorsers also report nicotine use by age 16. The strongest conditional probabilities between unique polysubstance use patterns (i.e., Kulczynski) were observed between nicotine/cannabis use (Whole-sample Kulczynski=0.68), which was

**Table 2**
Prevalence of Census-weighted Substance Use Rates in the ABCD Study by age with 99% Confidence Intervals.

| % [99% C.I.] | 9 years-old | 10 years-old | 11 years-old | 12 years-old | 13 years-old | 14 years-old | 15 years-old | 16 years-old | 17 years-old |
|---|---|---|---|---|---|---|---|---|---|
| *Lifetime* | | | | | | | | | |
| All | 1.0 [0.7,1.5] | 1.5 [1.2,1.9] | 3.1 [2.7,3.7] | 5.2 [4.6,5.9] | 9.1 [8.3,9.9] | 17.8 [16.7,19] | 27.3 [25.9,28.8] | 38.1 [35.8,40.5] | 49.7 [42.6,56.9] |
| Alcohol | 0.3 [0.2,0.6] | 0.4 [0.2,0.5] | 0.7 [0.5,1] | 1.5 [1.2,1.8] | 3.1 [2.6,3.6] | 7.4 [6.7,8.2] | 15.6 [14.4,16.8] | 25.4 [23.4,27.6] | 35.2 [28.7,42.4] |
| Cannabis | 0.1 [0,0.3] | 0.2 [0.1,0.4] | 0.7 [0.5,1] | 1.2 [1,1.6] | 3 [2.5,3.5] | 8.6 [7.8,9.5] | 15.3 [14.2,16.6] | 23.1 [21.1,25.2] | 31.1 [24.9,38] |
| Nicotine | 0.5 [0.3,0.9] | 0.7 [0.5,0.9] | 1.2 [0.9,1.6] | 2.3 [1.9,2.8] | 4.8 [4.2,5.5] | 10.7 [9.8,11.7] | 15.5 [14.3,16.8] | 21.9 [19.9,24] | 30.6 [24.1,37.8] |
| Other Substances | 0.2 [0.1,0.4] | 0.5 [0.3,0.7] | 1.0 [0.8,1.3] | 1.6 [1.3,2] | 2.5 [2.1,3] | 4.0 [3.5,4.7] | 5.7 [5.0,6.4] | 8.4 [7.2,9.9] | 11.0 [7.2,16.6] |
| *Annual* | | | | | | | | | |
| All | 0.9 [0.7,1.4] | 1.1 [0.9,1.4] | 1.8 [1.4,2.1] | 2.5 [2.1,3] | 5.5 [4.9,6.2] | 12.5 [11.5,13.6] | 20.5 [19.2,21.9] | 30.2 [28.1,32.5] | 40.1 [33.3,47.4] |
| Alcohol | 0.3 [0.2,0.6] | 0.2 [0.1,0.3] | 0.5 [0.3,0.7] | 0.8 [0.6,1] | 2.1 [1.8,2.6] | 5.5 [4.9,6.2] | 12 [11.0,13.1] | 19.6 [17.8,21.5] | 30.0 [23.8,37] |
| Cannabis | 0.1 [0,0.3] | 0.2 [0.1,0.3] | 0.5 [0.3,0.7] | 0.7 [0.5,1] | 2.1 [1.7,2.5] | 6.9 [6.2,7.7] | 12.6 [11.5,13.7] | 18.6 [16.8,20.5] | 26.7 [20.7,33.7] |
| Nicotine | 0.5 [0.3,0.9] | 0.4 [0.3,0.7] | 0.6 [0.4,0.9] | 1.2 [0.9,1.6] | 3.4 [2.9,4] | 7.8 [7.0,8.7] | 11.7 [10.6,12.8] | 16.3 [14.6,18.2] | 24.4 [18.5,31.5] |
| Other Substances | 0.2 [0.1,0.4] | 0.4 [0.3,0.6] | 0.5 [0.3,0.7] | 0.7 [0.5,0.9] | 1.1 [0.8,1.5] | 1.9 [1.5,2.4] | 3.0 [2.5,3.6] | 4.4 [3.5,5.5] | 6.0 [3.6,9.7] |

*Notes*: Age 17 has a cell size of 375, contributing to larger Confidence Intervals.

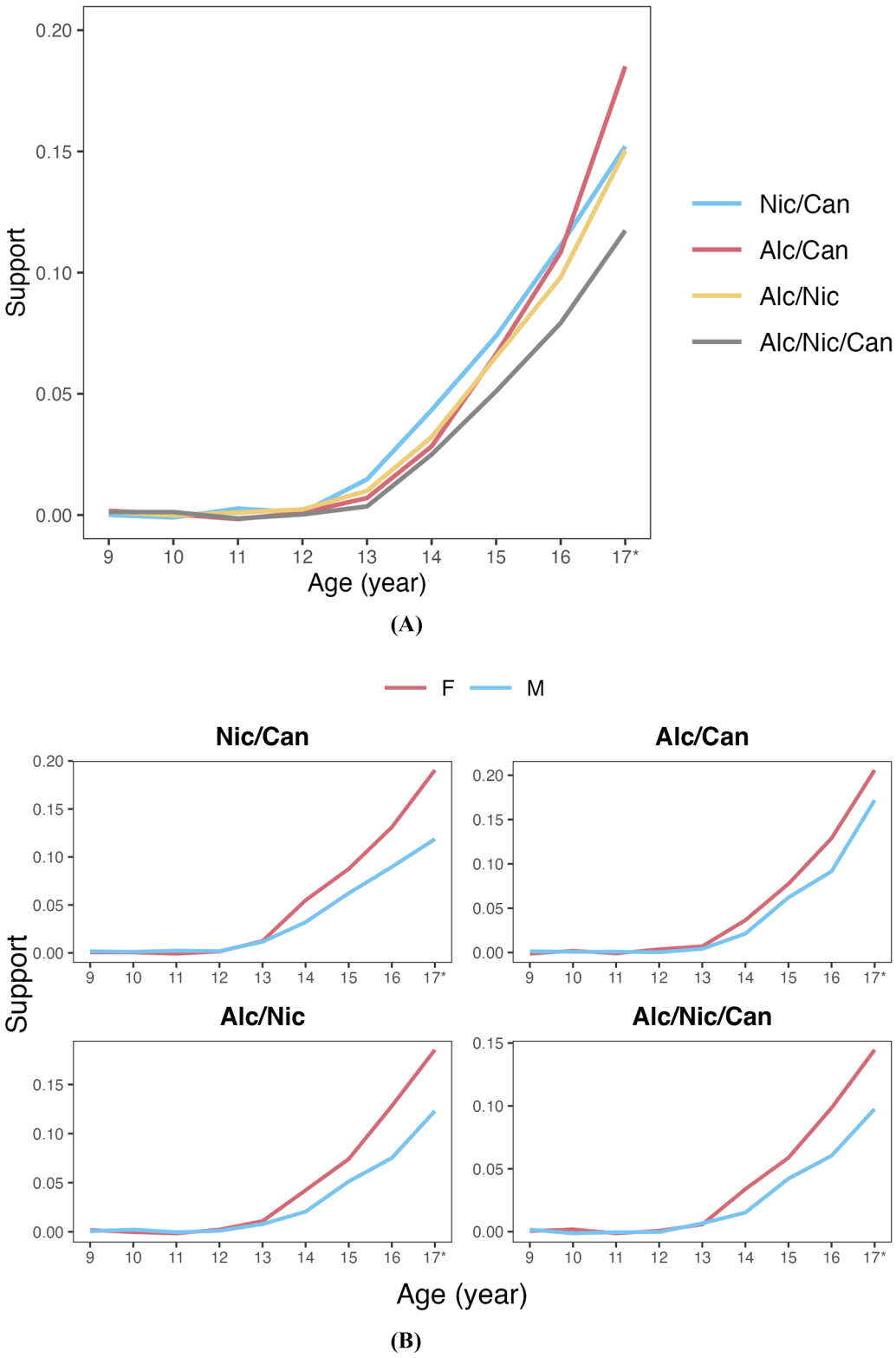


**Fig. 2.** (A) Association Analyses, Support metric (i.e., prevalence of polysubstance use within the sample) for annual self-reported use of all substances within each ruleset, with an overall Support ≥ 0.05 (i.e., ≥5% of the sample), plotted by chronological age and (B) split by sex. *Note: Age 17 has a smaller cell size (n = 375).

stronger for girls (Whole-sample, Female Kulczynski=0.71) than boys (Whole-sample, Male Kulczynski=0.65), and shows stepwise increases with age across the sexes: 9 = 0.0 (i.e., no nicotine/cannabis use), 10 = 0.1, 11 = 0.2, 12 = 0.4, 13 = 0.5, 14 = 0.6, 15 = 0.7, 16 = 0.7, 17 = 0.7 (Table S72-S77 & Figures S29-S37).

## 4. Discussion

Adolescent SU remains a prevalent and burdensome public health concern,(Miech et al., 2025; SAMHSA, 2025) particularly in the U.S.(Yu and Chen, 2025) SU initiation in late-childhood/early-adolescence can contribute to high-risk neurodevelopmental trajectories(Conrod and

Nikolaou, 2016). Understanding SU prevalences, particularly in large-scale prospective cohort studies, is important for investigations on antecedents and sequelae of SU(Lisdahl et al., 2021; Sullivan et al., 2022). This report detailed that both lifetime and annual reporting of SU within the ABCD cohort is steadily increasing across age, with the highest prevalence observed for alcohol, cannabis, and nicotine, respectively. Unique sex differences emerged where, generally, boys reported more SU before age 12, but from age 13 onward girls reported significantly more SU with the largest disparity observed in nicotine use. Examining modality-specific use, ENDS remain the highest used nicotine modality in the cohort, whereas cannabis modality usage were more diverse with smoked cannabis flower as the most prevalent. Age of onset values were calculated and are expected to evolve in future data releases. Unweighted SU prevalence were non-significantly different compared to census-weighted prevalences, indicating the ABCD cohort SU prevalence can be representative of broader sociodemographic-adjusted SU prevalence in the U.S. Finally, association analyses demonstrate that polysubstance use is fairly common (15% of cohort) with the highest prevalence seen between rulesets that include alcohol, cannabis, or nicotine. Nicotine/cannabis use demonstrated the highest occurrence, with girls displaying larger prevalence rates of polysubstance use during mid-adolescence.

Narratively comparing the prevalence rates of SU in ABCD to recent (2025) national survey data(Miech et al., 2025; SAMHSA, 2025), prevalence prior to age 13 were generally lower in ABCD as reported previously(Sullivan et al., 2022); however, NDSUH prevalence at ages 14–15 appear to closely align for alcohol [NSDUH: lifetime 18%, annual 13%; ABCD: lifetime 16%, annual 12% (Table 2)], nicotine [NSDUH: lifetime 18%, annual 12%; ABCD: lifetime 16%, annual 12% (Table 2)], and are slightly lower for cannabis [NSDUH: lifetime 11%, annual 8%; ABCD: lifetime 15%, annual 13% (Table 2)](SAMHSA, 2025). Whereas, MTF prevalence among 10th graders (15–16-years-old) are generally higher relative to ABCD for alcohol [MTF: lifetime 32%, annual 26%; ABCD: lifetime 17%, annual 14% (Table S11,S31)], cannabis [MTF: lifetime 21%, annual 16%; ABCD: lifetime 16%, annual 13% (Table S15, S35)], cigarettes [MTF: lifetime 8%, annual 4%; ABCD: lifetime 3%, annual 2% (Table S51,S55)], and vaping nicotine [MTF: lifetime 23%, annual 15%; ABCD: lifetime 14%, annual 11% (Table S51,S55)](Miech et al., 2025). Therefore, ABCD SU data is generally lower when contrasted against MTF 2025, likely due to MTF's combination of low-level use (e.g., alcohol sip) and full unit of SU (e.g., full drink) but is on par with NSDUH 2025 prevalence rates—mirroring a national survey on U.S. youth. Further, the ABCD protocol is also distinct from national survey-based studies in that SU assessments are multi-modal, participants are in private/confidential spaces away from caregivers and peers, include a trained interviewer-led protocol with queries and picture aids, and utilize well-validated instruments (e.g., TLFB)(Lisdahl et al., 2021, 2018; Sullivan et al., 2022). Thus, these data are not only accessible to researchers(Volkow et al., 2017) but is one of a few studies to contain extremely detailed phenotyping of SU in a large cohort (i.e., *within-individual*).

Association analyses revealed unique polysubstance use patterns in the ABCD cohort. These prevalence rates align with a prior publication from the Add Health Survey showing 34% of youth prior to age 16 reported polysubstance use of alcohol, cannabis, and nicotine(Moss et al., 2014); yet, while prior studies (Moss et al., 2014) have used latent analyses to classify polysubstance use, the present association analyses add unique and distinct description of polysubstance use prevalence among an adolescent sample. Notable for interpretation of the current prevalence rates are that association rulesets are not mutually exclusive (e.g., those with use of alcohol/cannabis/nicotine are also counted in each respective two-substance relationship), they are constrained to annual reporting (i.e., to not overinflate with any lifetime use), and *Confidence* and *Kulczynski* values can be inflated by small cell sizes, evidenced at ages 9–10 (Figure S34). Future analyses using ABCD can continue to examine these trends, given that polysubstance use is associated with poorer SU and psychological outcomes(Carbonneau et al., 2023). Further, these trends remain important to continue documenting due to the prevailing gateway hypotheses linking alcohol and nicotine use to cannabis and other substance use(Reed et al., 2022; Wang et al., 2025).

Sex differences emerged across SU prevalences and polysubstance use. Prior epidemiological reports of SU in adolescence indicated males generally report higher prevalence of initiation and larger densities of SU than females(Bhatia et al., 2023; Kloos et al., 2009) yet recent surveys have identified a switch in this pattern such that girls are endorsing more use(Miech et al., 2025). Interestingly, the ABCD Study data also supports higher SU reporting in females relative to males from mid-adolescence onward. Prevalence of polysubstance use indicate a similar divergence with adolescent females reporting use of $>1$ substances, predominantly driven by nicotine use, which contributes to the largely mixed but substance-specific literature on polysubstance use sex differences(Goodwin et al., 2022). Further examination of these findings and their associated outcomes will have important implications for sex-specific trajectories in SU vulnerabilities (i.e., neurobiological sensitivities), progression to problematic use (i.e., rapid escalation in density and problematic use in females; "telescoping"), and differences in treatment outcomes(Bhatia et al., 2023; Chavez et al., 2025; Dir and Hulvershorn, 2019; Hammerslag and Gulley, 2016; Kirsch et al., 2025) requiring continued analysis in the ABCD cohort.

It is important to consider the present findings in the context of their limitations. First, self-reported SU prevalence rates are subject to reporting biases across various instruments and timing—with variability observed between remote versus in-person visits(Wade et al., 2024) and within the COVID−19 pandemic(Pelham et al., 2023). Toxicology data can further confirm and capture non-reporters (Wade et al., 2023). Second, intervals between annual study visits allowed for participants to have $>1$ observation in non-visit bins (e.g., age). Random draws removed these excess observations, yet this may have subtly impacted SU prevalence rates. Third, prior analyses identified sociodemographic-related factors that relate to attrition in ABCD (Feldstein Ewing et al., 2022); however, non-significant differences between raw and census-weighted prevalence rates indicate these factors did not significantly affect the SU prevalences reported herein. It will be important to combine the present findings with attrition analyses to assess SU prevalence rates in the cohort with consideration of attrition (i.e., through inverse probability weighting) in future reports of SU in the ABCD cohort. Lastly, while comparisons between ABCD and other national cohorts were completed narratively here, given the differences between birth cohorts, survey wording, and timing of data collection (e.g., during COVID−19), a more detailed analysis comparing ABCD rates to MTF or NSDUH are warranted as a follow-up.

This study provides the most up-to-date SU information across multiple metrics (age, annual study visit, educational grade, and data collection year) using the ABCD Study(Jernigan and Brown, 2018; Lisdahl et al., 2018; Volkow et al., 2017). These data can assist scientists in calculating SU information for utilization in analyses of adolescent health and further describes the current ABCD SU methodology. Results of association analyses provide an estimate of novel polysubstance use patterns, described by age and sex, from late-childhood to mid-adolescence not previously investigated within national surveys on adolescent SU. Understanding trajectories of use has important implications for substance use progression, and neurodevelopmental and health outcomes.(Dir and Hulvershorn, 2019; Hammerslag and Gulley, 2016; Volkow et al., 2021, 2017; Yu and Chen, 2025).

## Ethical approvals

A centralized Institutional Review Board (IRB), located at University of California, San Diego, approved all study procedures [#160091AW; "The Adolescent Brain Cognitive Development (ABCD) Study: UC San Diego"].

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## Declaration of Generative AI and AI-assisted technologies in the writing process

No generative AI was used in the conceptualization or production of this manuscript.

## 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.

## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.dadr.2026.100463.

## Data Availability

Data used in the preparation of this article were obtained from the Adolescent Brain Cognitive Development™ (ABCD) Study (https://abcdstudy.org/), held in the NIH Brain Development Cohorts Data Sharing Platform (https://www.nbdc-datahub.org/). This is a multisite, longitudinal study designed to recruit more than 10,000 children aged 9–10 and follow them over 10 years into early adulthood. Code to reproduce these results are located in an OSF repository: https://doi.org/10.17605/OSF.IO/DGQC9.

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