

Cannabis Concentrate Use in Adolescents

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abstract

BACKGROUND: Cannabis concentrates, which are cannabis plant extracts that contain high concentrations of Δ -9-tetrahydrocannabinol (THC), have become increasingly popular among adults in the United States. However, no studies have reported on the prevalence or correlates of cannabis concentrate use in adolescents, who, as a group, are thought to be particularly vulnerable to the harms of THC.

METHODS: Participants are a racially and ethnically diverse group of 47 142 8th-, 10th-, and 12th-grade students recruited from 245 schools across Arizona in 2018. Participants reported on their lifetime and past-month marijuana and cannabis concentrate use, other substance use, and risk and protective factors for substance use problems spanning multiple life domains (ie, individual, peer, family, school, and community).

RESULTS: Thirty-three percent of all 8th-, 10th-, and 12th-graders reported lifetime cannabis use, and 24% reported lifetime concentrate use. Seventy-two percent of all lifetime cannabis users had used concentrates. Relative to adolescent cannabis users who had not used concentrates, adolescent concentrate users were more likely to use other substances and to experience more risk factors, and fewer protective factors, for substance use problems across numerous life domains.

CONCLUSIONS: Most adolescent cannabis users have used concentrates. Based on their risk and protective factor profile, adolescent concentrate users are at higher risk for substance use problems than adolescent cannabis users who do not use concentrates. Findings raise concerns about high-risk adolescents' exposure to high-THC cannabis.



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WHAT'S KNOWN ON THIS SUBJECT: Cannabis concentrates have high Δ -9-tetrahydrocannabinol (THC) content, and adolescents are thought to be especially vulnerable to the harms of THC. However, little is known about the prevalence or correlates of concentrate use in adolescents.

WHAT THIS STUDY ADDS: Cannabis concentrate use was common in adolescents (prevalence = 24%). Concentrate users were worse off than nonconcentrate cannabis users on every risk and protective factor for substance use problems, raising concerns about high-risk adolescents' exposure to high-THC cannabis.

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At a time when cannabis use is increasing and perceived risk of cannabis use is declining,^{1,2} there is growing concern that the health risks of cannabis use might be underestimated. This is because the concentration of Δ -9-tetrahydrocannabinol (THC) in cannabis has risen dramatically in recent years.³⁻⁵ THC is the main psychoactive constituent of cannabis and has dose effects on drug reinforcement, cognitive impairment, and psychotic-like experiences.⁶⁻¹⁰ Thus, there is speculation, as well as emerging evidence, that use of cannabis with higher THC content might increase risk for cannabis use disorder, cognitive impairment, psychosis, and other adverse consequences.^{7,11-21}

Concerns about rising THC concentrations have come to the forefront recently, in part because cannabis legalization in the United States has led to the marketing and promotion of cannabis concentrates: cannabis plant extracts with unprecedentedly high THC content.^{11,22} Compared with marijuana (the dried buds of the cannabis plant), which has average THC content ranging from 12% to 20% in the United States,^{3,23,24} the estimated average THC content of concentrates is much higher, ranging from ~39% to 69%, depending on how the concentrate is produced.^{3,22,24} Concentrates are produced either by using solvents, such as butane or supercritical carbon dioxide, or nonsolvent-based methods, such as a sieve, ice water, or heat and pressure, to extract THC from cannabis plant material.²² Solvent-based extraction methods produce concentrates (eg, wax, dab, shatter, and butane hash oil [BHO]) with average THC content of ~54% to 69%,^{3,22,24,25} but THC content of these concentrates can exceed 80%. Nonsolvent-based extraction methods produce concentrates (eg, kief, hash

or hashish, and rosin) with THC content of ~39% to 60%.^{3,22}

Evidence suggests that cannabis concentrates are increasingly popular in the United States. Google search data from 2004 to 2016 show that cannabis concentrate-related searches increased dramatically in the United States from ~2012 to 2016.²⁶ Moreover, data from Washington state, where recreational and medical cannabis use are legal, show that growth in concentrate sales outpaced growth in marijuana sales from 2014 to 2016, with concentrates accounting for 21% of all cannabis expenditures in 2016, a 146% increase from 2014.²⁴ However, epidemiological data on the prevalence of concentrate use are lacking. Nationally representative surveys have not yet asked specifically about concentrate use.²⁷ Moreover, although a number of studies have reported on the prevalence of concentrate use in adult cannabis users and have generally found that rates of concentrate use among adult cannabis users are high (Supplemental Table 6),^{21,28-36} these studies are based on unrepresentative samples of adults recruited, for the most part, online. No studies have reported on the prevalence of concentrate use in a representative sample, and no studies have reported on the prevalence of concentrate use in adolescents.

Understanding the prevalence of cannabis concentrate use in adolescents is important because cannabis use is typically initiated in adolescence, and adolescence is a developmental period characterized by heightened risk for cannabis use disorder and other cannabis-related consequences.³⁷⁻³⁹ Adolescent cannabis users' use of concentrates, specifically, might further amplify their risk for cannabis use disorder and adverse cannabis-related consequences; studies of adult cannabis users have suggested that

use of concentrates and use of marijuana with higher versus lower THC content are associated with more severe cannabis dependence,^{7,13,19,21,35} greater risk of psychosis,^{17,18,40} and greater cannabis-related differences in brain structure.²⁰ Moreover, use of cannabis with higher THC content may cause more severe acute effects, such as altered reality and loss of consciousness,^{15,28,32,41-43} and the production and use of solvent-based concentrates are associated with increased risk of explosions and burns.^{27,44} These severe acute consequences might be especially likely among inexperienced cannabis users,¹⁶ who comprise the majority of adolescents who use cannabis.

The purpose of this study was to report on the prevalence of cannabis concentrate use in a large sample of 8th-, 10th-, and 12th-graders from the state of Arizona, a medical cannabis state. Another aim of the study was to test whether adolescent cannabis users who had versus had not used concentrates were distinguishable in terms of other substance use and multiple risk and protective factors that have been shown to robustly predict substance use problems in longitudinal studies, including individual, peer, family, school, and community factors.^{45,46} Understanding which risk and protective factors distinguish adolescent concentrate users will have important implications for prevention and intervention.

METHODS

Participants

Participants were 8th-, 10th-, and 12th-grade students who participated in the statewide 2018 Arizona Youth Survey (AYS) (for details, see <http://azcjc.gov/content/arizona-youth-survey>). The AYS is conducted every 2 years by the Arizona Criminal Justice Commission to assess substance use and risky behavior as

well as known risk and protective factors for these problem behaviors. All Arizona schools that serve 8th-, 10th-, and 12th-grade students (traditional public, private, or charter school) are invited to participate via mailings and e-mails. The 2018 survey was administered to 52 336 students attending 245 schools from all 15 Arizona counties.

Of the 52 336 adolescents who participated in the survey, 824 were excluded from analyses because they reported use of “phenoxydine,” a fake drug. An additional 4370 adolescents were excluded because of missing cannabis data. This left a total analytic sample of 47 142 adolescents. To ascertain sample representativeness, participants were compared with all students enrolled in the same grades across the state of Arizona in terms of sex and race and/or ethnicity by using the most recent National Center for Education Statistics (NCES) Common Core of Data (2015–2016).⁴⁷ The 2 samples were nearly identical in terms of sex and race and/or ethnicity

(Supplemental Table 7). Table 1 shows sociodemographic information for AYS participants included in analyses. Effect sizes for differences between included and excluded participants on sociodemographic factors were generally small (Supplemental Table 8).

Procedure

Schools received either an online or a paper-and-pencil survey. Most schools ($N = 135$ schools; 25 909 students) participated in the online survey. The remaining schools ($N = 110$; 21 233 students) administered the paper-and-pencil survey. The online and paper-and-pencil surveys were nearly identical except the online version contained additional questions. Most schools used passive parental consent ($N = 236$), whereby parents returned signed consent if they did not want their children to participate. Nine schools used active parental consent, whereby parents returned signed consent for their children to participate in the survey. On the day of survey administration, students were informed of the nature of the study and told they could

decline participation without consequence. Students placed completed paper-and-pencil surveys in an envelope that was sealed and mailed to the research team. For online surveys, students entered responses on a computer via a Web-based survey platform (Qualtrics).

Cannabis Use

Participants answered 4 questions about how often they used marijuana and cannabis concentrates in their lifetime and in the past 30 days (Table 2). If a participant reported use of either marijuana or concentrate, they were considered a cannabis user. For some analyses, cannabis users were subdivided into 2 groups based on whether they had used concentrates.

Other Substance Use

Participants answered questions about their lifetime use of tobacco cigarettes, electronic cigarettes (e-cigarettes), alcohol, and other drugs besides cannabis as well as their age of onset of substance use (Table 2).

Risk and Protective Factors for Substance Use Problems

Participants were administered questions developed as part of the Communities That Care Survey (CTCS).⁴⁶ The CTCS was designed to assess substance use and problem behavior among adolescents as well as risk and protective factors shown to predict these problems in longitudinal studies. The CTCS risk and protective factor subscales show good internal consistency and predictive validity⁴⁶ (for details, see <https://www.communitiesthatcare.net/research-results>). Table 2 shows descriptions of risk and protective factors spanning multiple domains: individual, peer, family, school, and community.

TABLE 1 Sample Sociodemographic Information

Sociodemographic Characteristic	% (SE)	<i>N</i>
Age, y		46 986
11–14	33.1 (3.8)	
15–16	36.8 (2.1)	
17–19	30.1 (1.8)	
Sex		46 749
Male	49.6 (0.4)	
Female	50.4 (0.4)	
Race and/or ethnicity		46 818
White	38.0 (2.4)	
Hispanic	46.4 (2.4)	
African American	4.6 (0.4)	
American Indian	3.3 (0.5)	
Asian American	2.5 (0.2)	
Pacific Islander	0.6 (0.0)	
Multiracial	4.6 (0.2)	
Free or reduced lunch status		46 498
Yes	47.7 (2.6)	
No	52.3 (2.6)	
Caregiver high school completion		46 631
No high school completion	15.7 (1.2)	
High school completion	84.3 (1.2)	

Percentages are raw percentages. SEs are adjusted for clustering (students within schools). Sample sizes for each sociodemographic characteristic ranged from 46 498 to 46 986 because of missing data.

TABLE 2 Description of Substance Use Measures and Risk and Protective Factors for Substance Use Problems

Variable	Description
Substance use	
Cannabis	Participants were asked, "On how many occasions (if any) have you used marijuana [in your lifetime, during the past 30 days]," and "On how many occasions (if any) have you smoked or vaped marijuana concentrates (eg, hash oil, wax, crumble, shatter) [in your lifetime, during the past 30 days]." Responses options were "0," "1–2," "3–5," "6–9," "10–19," and "20+."
Tobacco cigarettes	Participants were asked, "Have you ever smoked cigarettes (not including electronic cigarettes)?"
E-cigarettes	Participants were asked, "Have you ever used electronic cigarettes (e-cigs, vapes)?"
Alcohol	Participants were asked, "On how many occasions (if any) have you drunk alcoholic beverages—more than just a few sips—in your lifetime?" This variable was coded as never versus ever.
Other drugs	Participants were asked about lifetime use of other drugs in a similar way to how they were asked about lifetime alcohol use. If a participant reported use of any of the following drugs, they were considered a lifetime drug user: cocaine or crack, LSD or other hallucinogens, inhalants, methamphetamines, heroin, ecstasy, prescription pain relievers or prescription sedatives without a prescription, synthetic drugs, or over-the-counter drugs for the purposes of getting high.
Age of onset of cigarette, alcohol, and marijuana use	Participants were asked, "How old were you when you first...[smoked a cigarette, even a puff; had more than a sip or 2 of alcohol; smoked marijuana]?" Response options were never, 1–10, 11, 12, 13, 14, 15, 16, and 17–21. This variable was coded as onset before age 17 vs never or onset age 17+.
Risk and protective factors for substance use problems	
Individual	
Perceived risk of harm of marijuana	Participants were asked, "How much do you think people risk harming themselves (physically or in other ways) if they...[try marijuana once or twice or smoke marijuana regularly (once or twice a week)]?" Response options ranged from 1 (no risk) to 4 (great risk). Responses to each item were averaged. $\alpha = .90$
Rebelliousness	Participants were asked to respond to the following statements: "I like to see how much I can get away with," "I ignore rules that get in my way," and "I do the opposite of what people tell me just to get them mad." Response options ranged from 1 (very false) to 4 (very true). Responses to each item were averaged. $\alpha = .77$
Attitudes toward antisocial behavior	Participants were asked, "How wrong do you think it is for someone your age to...[take a handgun to school, steal something worth more than \$5, attack someone with the idea of seriously hurting them, pick a fight with someone, or stay away from school all day when their parents think they are at school]?" Response options ranged from 1 (very wrong) to 4 (not wrong at all). Responses to each item were averaged. $\alpha = .80$
Peer	
Peer substance use	Participants were asked, "Think of the 4 friends you feel closest to. In the past 12 months, how many of them have...[smoked cigarettes, tried alcohol when their parents did not know about it, used marijuana, or used illegal drugs besides marijuana]." Response options ranged from 0 to 4. Responses to each item were averaged. $\alpha = .79$
Peer attitudes toward drug use	Participants were asked, "How wrong do your friends feel it would be for you to...[smoke tobacco, have 1 or 2 drinks of an alcoholic beverage nearly every day, use prescription drugs not prescribed to you, smoke marijuana, or use illegal drugs besides marijuana]?" Response options ranged from 1 (very wrong) to 4 (not wrong at all). Responses to the 4 items were averaged. $\alpha = .87$
Perceived as cool for using marijuana	Participants were asked, "What are the chances that you would be seen as cool if you smoked marijuana?" Response options ranged from 1 (no or very little) to 5 (very good).
Antisocial peers	Participants were asked, "Think of the 4 friends you feel closest to. In the past 12 months, how many of them have...[sold illegal drugs; been suspended from school; dropped out of school; carried a handgun; stolen or tried to steal a motor vehicle, such as a car or motorcycle; or been arrested]?" Response options ranged from 0 to 4. Responses to each item were averaged. $\alpha = .80$
Family	
Family history of alcohol or drug use	Participants were asked, "Has anyone in your family ever had a severe alcohol or drug problem?" "Have any of your brothers and sisters ever...[smoked cigarettes; drunk beer, wine, or hard liquor; used prescription drugs without a doctor telling them to take them; smoked marijuana; or used illegal drugs besides marijuana]?" If a participant answered "yes" to any question, they were considered to have a family history of alcohol or drug use. $\alpha = .78$
Family conflict	Participants were asked to respond to the following statements: "People in my family often insult or yell at each other," "We argue about the same things in my family over and over," and "People in my family have serious arguments." Response options ranged from 1 to 4 (NO!, no, yes, or YES!). Responses to the 3 items were averaged. $\alpha = .78$
Poor family management	Participants were asked to respond to the following statements and questions: "The rules in my family are clear," "When I am not at home, 1 of my parents knows where I am and who I am with," "My family has clear rules about alcohol and drug use," "If you drank some alcohol without your parents' permission, would you be caught by your parents?," "If you carried a handgun without your parents' permission, would you be caught by your parents?" "If you skipped school, would you be caught by your parents?" "My parents ask if I've gotten my

TABLE 2 Continued

Variable	Description
Parental attitudes favorable toward drug use	homework done,” and “Would your parents know if you did not come home on time?” Response options ranged from 1 to 4 (NO!, no, yes, or YES!). Responses to each item were reverse coded and then averaged. $\alpha = .82$
Family attachment	Participants were asked, “How wrong do your parents feel it would be for you to...[smoke cigarettes, have 1 or 2 alcoholic drinks nearly every day, or smoke marijuana].” Response options ranged from 1 (very wrong) to 4 (not wrong at all). Responses to the 3 items were averaged. $\alpha = .68$
Opportunities for prosocial involvement	Participants were asked, “Do you feel very close to your [mother or father]?” and “Do you share your thoughts and feeling with your [mother or father]?” Response options ranged from 1 to 4 (NO!, no, yes, or YES!). Responses to the 4 items were averaged. $\alpha = .77$
School	Participants responded to the following statements: “My parents ask me what I think before most family decisions affecting me are made,” “If I had a personal problem, I could ask my mom or dad for help,” and “My parents give me lots of chances to do fun things with them.” Response options ranged from 1 to 4 (NO!, no, yes, or YES!). Responses to the 3 items were averaged. $\alpha = 0.76$
Academic failure	Participants were asked, “Putting them all together, what were your grades like last year?” Response options ranged from 1 (mostly As) to 5 (mostly Fs), but values were recoded according to CTCS guidelines to be on the same scale as the next item. Participants were asked, “Are your school grades better than the grades of most students in your class?” Response options ranged from 1 to 4 (YES!, yes, no, or NO!). Responses to the 2 items were averaged. $\alpha = .70$
Low commitment to school	Participants were asked, “How interesting are most of your courses to you?” and “How important do you think the things you are learning in school are going to be for your later life?” Response options for these 2 questions ranged from 1 (very interesting or very important) to 5 (not at all interesting or not at all important). Participants were also asked, “Now thinking back over the past year in school, how often did you...[enjoy being in school, hate being in school, try to do your best work, or feel that the schoolwork you were assigned was meaningful and important]?” Response options ranged from 1 (almost always) to 5 (never). Finally, participants were asked, “During the last 4 weeks, how many whole days of school have you missed because you skipped or cut?” Response options ranged from 0 (0 d) to 7 (11 or more d), but values were recoded to according to CTCS guidelines to be on the same scale as the other items. Responses to the 7 items were averaged. $\alpha = .74$
Community	
Laws and norms favorable to drug use	Participants were asked, “Would a kid in your neighborhood get caught by police if they...[drank alcohol, smoked marijuana, or carried a handgun]?” Response options ranged from 1 to 4 (NO!, no, yes, or YES!), and items were reverse coded. Participants were also asked, “How wrong would most adults (over 21) in your neighborhood think it is for kids your age to...[smoke cigarettes, drink alcohol, or use marijuana]?” Response options ranged from 1 (very wrong) to 4 (not wrong at all). Responses to the 6 items were averaged. $\alpha = .78$
Perceived availability of drugs	Participants were asked, “How easy would it be for you to get the following things if you wanted them...[some cigarettes, some alcohol, some marijuana, or an illegal drug besides marijuana]?” Response options ranged from 1 (very hard) to 4 (very easy). Responses to the 4 items were averaged. $\alpha = .88$

Sample sizes for each variable ranged from 41 503 to 47 119 because of missing data. LSD, lysergic acid diethylamide.

Statistical Analyses

Before analyses, we tested for survey mode effects (paper and pencil versus online). There was no evidence that the prevalence of cannabis use or cannabis concentrate use differed as a function of survey mode (Supplemental Table 9). To ascertain whether concentrate users, cannabis users who had not used cannabis concentrates, and cannabis nonusers could be distinguished in terms of sociodemographic factors, other substance use, and risk and protective factors for substance use problems, we compared the 3 groups using mixed-effects linear regression (for continuous

variables) or logistic regression (for categorical variables). Analyses of sociodemographic factors were bivariate. Analyses of other substance use and risk and protective factors for substance use problems included sociodemographic factors as covariates (linear and quadratic age, grade, sex, race and/or ethnicity, parent education, and free or reduced lunch status). To account for clustering (students clustered within schools), we included a random intercept for school. To control for any differences between schools, we held school constant by including 2 independent variables: 1 that was school-mean centered and 1 that was the school mean.⁴⁸ The estimate for the school-

mean-centered independent variable yields the person-level association of interest net of any school effects.⁴⁸ Statistical tests were 2 tailed. To gauge the magnitude of effects, we reported effect sizes: mean differences in SD units for continuous variables and odds ratios for categorical variables. Analyses were conducted in Stata version 15.1 (Stata Corp, College Station, TX).

RESULTS

Prevalence of Cannabis Use and Cannabis Concentrate Use

Table 3 shows the lifetime and past-month prevalence of cannabis use

TABLE 3 Prevalence of Cannabis Use and Cannabis Concentrate Use by Sociodemographic Characteristics

Sociodemographic Characteristic	Lifetime Cannabis Use		Lifetime Concentrate Use		Past-Month Cannabis Use		Past-Month Concentrate Use	
	% (SE)	N	% (SE)	N	% (SE)	N	% (SE)	N
Total	33.3 (1.0)	47 142	24.0 (0.9)	47 142	18.3 (0.7)	46 733	12.7 (0.7)	46 592
Grade		46 373		46 373		45 985		45 842
8th	19.9 (0.9)		14.7 (0.7)		10.4 (0.6)		6.9 (0.4)	
10th	35.0 (0.8)		25.3 (0.9)		19.5 (0.7)		13.8 (0.8)	
12th	46.4 (1.1)		32.9 (1.1)		25.7 (0.9)		18.0 (0.9)	
Sex		46 749		46 749		46 347		46 211
Male	31.6 (1.0)		22.9 (0.9)		17.4 (0.7)		12.5 (0.7)	
Female	34.9 (1.1)		25.0 (0.9)		19.1 (0.7)		13.0 (0.7)	
Race and/or ethnicity		46 818		46 818		46 417		46 276
White	31.1 (1.6)		23.1 (1.4)		17.5 (1.1)		12.8 (0.9)	
Hispanic	35.1 (1.0)		25.0 (0.8)		18.7 (0.7)		12.9 (0.6)	
African American	33.0 (1.3)		22.6 (1.3)		18.7 (1.2)		11.5 (1.0)	
American Indian	41.0 (2.5)		26.5 (1.5)		24.4 (1.9)		14.5 (1.2)	
Asian American	18.4 (1.4)		13.5 (1.2)		8.6 (0.8)		6.6 (0.8)	
Pacific Islander	33.9 (2.9)		30.0 (2.7)		20.9 (2.6)		18.7 (2.5)	
Multiracial	37.1 (1.6)		26.1 (1.4)		20.9 (1.3)		13.8 (1.2)	
Free or reduced lunch status		46 498		46 498		46 110		45 974
No	32.8 (1.4)		24.4 (1.3)		18.4 (1.0)		13.5 (0.9)	
Yes	34.0 (0.9)		23.7 (0.7)		18.3 (0.7)		12.0 (0.5)	
Caregiver high school completion		46 631		46 631		46 232		46 096
No high school completion	37.2 (1.0)		26.6 (0.8)		20.3 (0.8)		13.7 (0.7)	
High school completion	32.6 (1.1)		23.6 (1.0)		18.0 (0.8)		12.6 (0.7)	

Percentages are raw percentages. SEs are adjusted for clustering (students within schools). Lifetime cannabis use = lifetime use of either marijuana or concentrate. Past-month cannabis use = past-month use of either marijuana or concentrate. Percentages are interpreted as the percentage of those within a specific sociodemographic category who had used cannabis in their lifetime, used concentrates in their lifetime, used cannabis in the past month, and used concentrates in the past month. Sample sizes for each analysis ranged from 45 842 to 47 142 due to missing sociodemographic data.

and cannabis concentrate use for the total sample and sociodemographic subgroups. Thirty-three percent of the sample reported lifetime cannabis use (ie, lifetime use of either marijuana or concentrate), and 24% reported lifetime concentrate use. As expected, the prevalence of cannabis use and concentrate use increased across grade in school. For example, 19.9%, 35.0%, and 46.4% of 8th-, 10th-, and 12th-graders, respectively, had used cannabis in their lifetime, and 14.7%, 25.3%, and 32.9% of 8th-, 10th-, and 12th-graders, respectively, had used concentrates in their lifetime. Cannabis use and cannabis concentrate use were slightly more prevalent in girls than boys and in youth whose caregivers did not complete high school. Cannabis use and cannabis concentrate use were less common among Asian American youth compared with youth of other races and/or ethnicities.

Comparison of Cannabis Groups on Sociodemographic Factors, Other Substance Use, and Risk and Protective Factors for Substance Use Problems

We compared the following cannabis groups on sociodemographic factors, use of other substances besides cannabis, and risk and protective factors for substance use problems: cannabis nonusers ($N = 31\,463$; 66.7% of the sample), cannabis users who had not used concentrates ($N = 4379$; 9.3% of the sample and 27.9% of cannabis users), and cannabis users who had used concentrates ($N = 11\,300$; 24.0% of the sample and 72.1% of cannabis users). The 3 groups differed somewhat in terms of sociodemographic characteristics (Table 4). Therefore, we adjusted for sociodemographic characteristics when comparing the groups in terms of other substance use and risk and protective factors for substance use problems (Table 5). Table 5

shows that concentrate users had the highest lifetime rates of other substance use, particularly e-cigarette use (81.7%). For example, the odds of using e-cigarettes were 3.24 times higher ($P < .001$) for concentrate users than for cannabis users who had not used concentrates and were 24.50 times higher ($P < .001$) for concentrate users than for cannabis nonusers. Concentrate users were also more likely to have initiated substance use before age 17. For example, the odds of using alcohol before age 17 were 1.75 times higher ($P < .001$) for concentrate users than for cannabis users who had not used concentrates and were 13.86 times higher ($P < .001$) for concentrate users than for cannabis nonusers. In terms of risk and protective factors for substance use problems, concentrate users showed the highest levels of risk and the lowest levels of protection on every factor, including perceived risk of harm from marijuana,

TABLE 4 Comparison of Lifetime Cannabis Nonusers, Lifetime Cannabis Users Who Had Never Used Concentrates, and Lifetime Concentrate Users on Sociodemographic Factors

Sociodemographic Factors	Group 1: Cannabis Nonusers (N = 31 463)		Group 2: Nonconcentrate Cannabis Users (N = 4379)		Group 3: Concentrate Users (N = 11 300)		Group 2 vs 1		Group 3 vs 1		Group 3 vs 2	
	Mean, %	SE	Mean, %	SE	Mean, %	SE	Effect Size ^a	95% CI	Effect Size ^a	95% CI	Effect Size ^a	95% CI
Age	14.94	0.07	15.17	0.07	15.15	0.07	0.14*	0.12 to 0.16	0.15*	0.12 to 0.14	-0.01	-0.03 to 0.01
Sex (male)	50.8	0.4	47.0	0.7	48.0	0.5	0.84*	0.78 to 0.90	0.88*	0.84 to 0.92	1.05	0.97 to 1.12
Race and/or ethnicity												
White	35.2	1.6	32.1	1.6	31.8	1.5	0.82*	0.76 to 0.89	0.80*	0.76 to 0.85	0.98	0.90 to 1.07
Hispanic	47.9	1.5	49.9	1.7	52.1	1.6	1.12*	1.04 to 1.21	1.26*	1.20 to 1.33	1.13*	1.04 to 1.23
African American	4.5	0.4	5.2	0.5	4.1	0.4	1.17*	1.01 to 1.36	0.92	0.82 to 1.03	0.79*	0.67 to 0.94
American Indian	4.0	0.5	5.4	0.7	4.9	0.6	1.38*	1.15 to 1.67	1.24*	1.08 to 1.43	0.90	0.73 to 1.10
Asian American	2.3	0.2	0.8	0.2	0.7	0.1	0.43*	0.32 to 0.57	0.41*	0.34 to 0.49	0.95	0.69 to 1.31
Pacific Islander	0.3	0.0	0.0	0.0	0.4	0.1	0.39*	0.20 to 0.76	1.29	0.98 to 1.70	3.34*	1.67 to 6.68
Multiracial	4.2	0.2	6.2	0.5	5.3	0.3	1.43*	1.24 to 1.67	1.25*	1.11 to 1.37	0.86	0.73 to 1.01
Caregiver HS completion	82.9	0.9	81.6	1.1	80.3	1.0	0.91*	0.83 to 0.99	0.82*	0.77 to 0.87	0.90*	0.82 to 0.99
Free or reduced lunch	56.1	1.8	58.8	1.8	58.7	1.8	1.19*	1.10 to 1.28	1.18*	1.12 to 1.25	1.00	0.92 to 1.08

Means are estimated marginal means for each cannabis group (nonuser, nonconcentrate cannabis user, and concentrate user). Percentages are estimated marginal probabilities and therefore sum to close to 100% for race and/or ethnicity. All analyses are bivariate. N = 44 847 for all analyses (n = 29 833 cannabis nonusers; n = 4207 nonconcentrate cannabis users; and n = 10 807 concentrate users) because individuals with missing data on any sociodemographic factor were excluded from analyses. HS, high school.

^a Effect sizes are either mean differences in SD units (for continuous correlates) or odds ratios (for categorical correlates). * P < .05.

peer substance use, parental attitudes toward drug use, commitment to school, and perceived availability of drugs in the community. Findings were similar when we reanalyzed the data with cannabis groups defined on the basis of past-month use (Supplemental Tables 10 and 11).

DISCUSSION

The lifetime prevalence of cannabis concentrate use in this sample of ~50 000 8th-, 10th-, and 12th-graders from the state of Arizona was high, ranging from 15% in 8th-graders to 33% in 12th-graders. The majority (72%) of adolescents who had used cannabis had used concentrates. Overall, the high rates of concentrate use in adolescents are concerning because some evidence in adults suggests that exposure to cannabis with higher THC content could increase a person's risk for cannabis use disorder, cognitive impairment, and psychosis.^{7,13,14,17-19,21,35,42,43} Moreover, adolescent cannabis users may be more vulnerable to these effects than adult cannabis users.³⁷⁻³⁹ Finally, adverse acute consequences of concentrate use, such as loss of consciousness and burn injuries,^{15,27,28,41,44} might be more likely among infrequent users, who comprise the majority of adolescent users.

Our prevalence estimates of lifetime cannabis use are comparable to estimates obtained in the nationally representative 2017 Monitoring the Future survey.⁴⁹ Specifically, we found that 19.9%, 35.0%, and 46.4% of 8th-, 10th-, and 12th-graders had used cannabis in their lifetime, respectively, and corresponding estimates in the Monitoring the Future survey were 13.5%, 30.7%, and 45.0%, respectively.⁴⁹ Our slightly but consistently higher estimates might be explained, in part, by regional differences because Monitoring the Future data

TABLE 5 Comparison of Lifetime Cannabis Nonusers, Lifetime Cannabis Users Who Had Never Used Concentrates, and Lifetime Concentrate Users on Other Substance Use and Risk and Protective Factors for Substance Use Problems, Adjusted for Sociodemographic Factors

	Group 1: Cannabis Nonusers (N = 31 463)		Group 2: Nonconcentrate Cannabis Users (N = 4379)		Group 3: Concentrate Users (N = 11 300)		Group 2 vs 1		Group 3 vs 1		Group 3 vs 2		
	Mean, %	SE	Mean, %	SE	Mean, %	SE	Effect Size ^a	95% CI	Effect Size ^a	95% CI	Effect Size ^a	95% CI	N ^b
Other substance use													
Cigarette use (lifetime)	5.8	0.3	34.0	1.0	47.2	0.8	8.53*	7.82 to 9.32	16.10*	15.03 to 17.26	1.89*	1.74 to 2.04	44 639
E-cigarette use (lifetime)	20.2	0.5	60.4	0.9	81.7	0.6	7.55*	7.02 to 8.13	24.50*	23.00 to 26.11	3.24*	2.98 to 3.53	44 751
Alcohol use (lifetime)	29.4	0.4	75.6	0.8	84.6	0.5	9.53*	8.79 to 10.35	17.31*	16.23 to 18.46	1.82*	1.65 to 2.00	44 755
Other drug use (lifetime)	8.8	0.3	26.4	0.8	47.2	0.6	3.76*	3.45 to 4.11	10.54*	9.91 to 11.21	2.80*	2.58 to 3.05	44 702
Age of onset of alcohol (<17)	28.5	0.6	70.8	0.9	80.2	0.6	7.93*	7.34 to 8.57	13.86*	13.04 to 14.72	1.75*	1.60 to 1.91	44 041
Age of onset of cigarette (<17)	5.8	0.3	32.9	1.0	45.6	0.8	8.06*	7.38 to 8.81	14.94*	13.93 to 16.01	1.85*	1.71 to 2.01	44 393
Age of onset of marijuana (<17)	N/A	N/A	82.4	1.1	84.0	1.0	N/A	N/A	N/A	N/A	1.14*	1.02 to 1.26	14 560
Risk and protective factors													
Individual													
Perceived risk of harm from marijuana	2.66	0.01	1.90	0.02	1.70	0.01	-0.68*	-0.71 to -0.65	-0.86*	-0.88 to -0.84	-0.18*	-0.21 to -0.14	42 629
Rebelliousness	1.63	0.01	1.89	0.01	2.03	0.01	0.35*	0.32 to 0.39	0.55*	0.53 to 0.57	0.19*	0.16 to 0.23	42 897
Favorable attitudes: antisocial behavior	1.42	0.00	1.61	0.01	1.75	0.01	0.35*	0.32 to 0.38	0.59*	0.57 to 0.62	0.24*	0.21 to 0.28	42 761
Peer													
Peer use of any substance (past year)	0.48	0.01	1.16	0.01	1.64	0.01	0.69*	0.66 to 0.71	1.17*	1.15 to 1.19	0.48*	0.45 to 0.51	44 457
Peer favorable attitudes: drug use	1.44	0.01	1.95	0.01	2.26	0.01	0.66*	0.63 to 0.69	1.06*	1.04 to 1.08	0.40*	0.37 to 0.44	44 329
Perceived as cool for marijuana use	2.24	0.02	2.84	0.03	3.02	0.02	0.41*	0.38 to 0.44	0.54*	0.52 to 0.56	0.13*	0.09 to 0.16	42 946
Antisocial peers	0.19	0.01	0.33	0.01	0.58	0.01	0.26*	0.23 to 0.29	0.71*	0.69 to 0.74	0.46*	0.42 to 0.49	44 508
Family													
Family history alcohol and/or drug use	58.9	0.4	80.3	0.7	84.6	0.4	3.1*	2.86 to 3.43	4.26*	4.00 to 4.55	1.36*	1.23 to 1.51	41 835
Family conflict	2.24	0.01	2.43	0.01	2.51	0.01	0.25*	0.22 to 0.28	0.35*	0.32 to 0.37	0.10*	0.06 to 0.13	41 987
Poor family management	1.70	0.01	1.94	0.01	2.05	0.01	0.41*	0.37 to 0.44	0.60*	0.57 to 0.62	0.19*	0.15 to 0.22	41 878
Parental favorable attitudes: drug use	1.14	0.00	1.33	0.01	1.46	0.01	0.40*	0.36 to 0.43	0.67*	0.65 to 0.69	0.27*	0.24 to 0.31	42 208
Family attachment	2.88	0.01	2.66	0.01	2.58	0.01	-0.29*	-0.32 to -0.25	-0.39*	-0.41 to -0.36	-0.10*	-0.14 to -0.06	41 355
Prosocial opportunities	2.97	0.01	2.78	0.01	2.68	0.01	-0.26*	-0.29 to -0.23	-0.39*	-0.41 to -0.37	-0.13*	-0.17 to -0.09	41 451
School													
Academic failure	1.96	0.01	2.15	0.01	2.29	0.01	0.27*	0.24 to 0.30	0.47*	0.44 to 0.49	0.20*	0.16 to 0.23	43 836
Low commitment to school	2.62	0.01	2.87	0.01	3.02	0.01	0.36*	0.35 to 0.41	0.60*	0.58 to 0.62	0.22*	0.19 to 0.25	44 703
Community													
Laws and norms favorable to drug use	2.06	0.01	2.30	0.01	2.40	0.01	0.38*	0.35 to 0.41	0.54*	0.52 to 0.56	0.16*	0.13 to 0.20	39 750
Perceived availability of drugs	2.13	0.01	2.68	0.02	2.93	0.01	0.54*	0.51 to 0.57	0.79*	0.77 to 0.81	0.24*	0.21 to 0.28	42 593

Means are estimated marginal means, and percentages are estimated marginal probabilities. Estimates are adjusted for sociodemographic characteristics (linear and quadratic age, grade, sex, race/ethnicity, caregiver education, and free or reduced lunch). N/A, not applicable.

^a Effect sizes are either mean differences in SD units (for continuous correlates) or odds ratios (for categorical correlates).

^b Sample sizes for each analysis ranged from 39 750 to 44 755 because of missing data.

* $P < .05$.

showed that the prevalence of cannabis use is highest in western states (such as AZ), particularly for 8th-graders.⁴⁹ Another possible explanation for our slightly higher estimates is that we defined cannabis use based on answers to 2 questions (ie, 1 question about marijuana use and 1 question about concentrate use) as opposed to the single question used in the Monitoring the Future survey (ie, 1 question about marijuana or hashish use). When we recalculated the lifetime prevalence of cannabis use based on our single question about marijuana use, our prevalence estimates were nearly identical to Monitoring the Future estimates (Supplemental Table 12). In our sample, cannabis use and concentrate use were both slightly more prevalent among girls than boys. This is not inconsistent with the 2017 Monitoring the Future data, which showed either no sex difference in the prevalence of cannabis use or a slightly higher prevalence in 1 sex or the other depending on grade in school. Overall, the between-study similarities provide an important context for interpreting our estimates of the prevalence of concentrate use. Namely, because our sampling and assessment procedures produced estimates of cannabis use that are in the range of what we expected on the basis of a similar survey, we have increased confidence in our estimates of concentrate use.

Concentrate users were distinguishable from cannabis users who had not used concentrates and from cannabis nonusers in that they had higher rates of other substance use and were worse off on every risk and protective factor for substance use problems. Notably, the substance that best distinguished concentrate users was e-cigarette use. This is consistent with recent studies suggesting that adolescents and young adults are using

e-cigarettes to vaporize cannabis,^{50–53} and it reinforces the recent decision by the Food and Drug Administration to impose new restrictions on e-cigarettes and their constituents as a means of reducing cannabis use.

This study has limitations. First, information about cannabis use was based on self-reports, and evidence suggests that adolescents both under- and overreport cannabis use.⁵⁴ However, adolescents were informed that surveys were voluntary, anonymous, and confidential, mitigating risk of underreporting for fear of getting caught. We also excluded adolescents who reported use of a fake drug, mitigating overreporting. Second, some adolescents might not have understood the difference between concentrates and marijuana. To distinguish concentrates from marijuana, we provided specific examples of concentrates (ie, hash oil, wax, crumble, and shatter). However, it is possible that some adolescents reported that they had used concentrates despite having only used marijuana. Third, although we asked broadly about use of “concentrates,” the specific examples of concentrates we provided are examples of solvent-based concentrates. Therefore, our estimates of concentrate use might not capture use of nonsolvent-based concentrates (eg, kief and hash or hashish). Fourth, findings are limited to adolescents from the state of Arizona, a medical cannabis state. Studies of adult cannabis users have shown that the prevalence of concentrate use is higher in states with recreational or medical cannabis laws than in prohibition states,^{30,55} suggesting that the prevalence of concentrate use in adolescents from Arizona might be higher than in adolescents from prohibition states. Notably, most US states are not prohibition states. The majority of states have legalized

medical cannabis use. Yet, medical cannabis laws differ from state to state,⁵⁶ and some states with medical cannabis laws prohibit cannabis concentrates. In AZ, the courts have reversed decisions on the legality of concentrates numerous times, but concentrates are currently sold in Arizona dispensaries. Research is needed to determine if our findings generalize to adolescents from other states with medical cannabis laws. Fifth, data from this study are cross-sectional. Longitudinal data are needed to determine the temporal associations between cannabis concentrate use, other substance use, and some of the risk and protective factors studied here that could be affected by concentrate use, such as academic failure.

CONCLUSIONS

This study has a number of implications. First, cannabis concentrate use is common in adolescents from a medical cannabis state. Such high rates of concentrate use raise concerns about adolescents' exposure to high-THC cannabis because some research suggests that use of cannabis with higher THC content is associated with increased risk of cannabis use disorder, cognitive impairment, and psychosis.^{7,13,14,17–19,21,35,42,43} Second, the risk and protective factor profile for adolescent concentrate users suggests that concentrate users are at higher risk for substance use problems than cannabis users who do not use concentrates. It will be important to ascertain if adolescent concentrate users have higher rates of substance use problems generally, and cannabis use disorder specifically, and to disentangle effects associated with selection into concentrate use from effects of exposure to higher-THC cannabis. Third, concentrate users' higher levels of risk, and lower levels of protection, across

multiple life domains suggest that broad interventions that target multiple risk factors are needed. Restricting e-cigarette use might not be enough to reduce cannabis use and lower the risk of concentrate use in the highest-risk adolescents. Fourth, monitoring of adolescent concentrate use is needed, as is a standardized and psychometrically sound measure

that accurately distinguishes marijuana and concentrate use. As findings emerge showing high rates of concentrate use in adolescents, and increased cannabis-related risks associated with use of high-THC cannabis, policy makers might consider putting a limit on THC concentration in cannabis.

ABBREVIATIONS

AYS: Arizona Youth Survey
 CTCS: Communities That Care Survey
 e-cigarette: electronic cigarette
 NCES: National Center for Education Statistics
 THC: Δ -9-tetrahydrocannabinol

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