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Age, period and cohort effects in frequent cannabis use among US students: 1991–2018

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ABSTRACT

Background and Aims As the legal status of cannabis changes across the United States and modes of administration expand, it is important to examine the potential impact on adolescent cannabis use. This study aimed to assess changes in prevalence of frequent cannabis use in adolescents in the United States and how far this varies by age and cohort. **Design** Analysis of Monitoring the Future, a nationally representative annual survey of 8th-, 10th- and 12th-grade students in the United States conducted from 1991 to 2018. **Setting** In-school surveys completed by US adolescents. **Participants** A total of 1 236 159 8th-, 10th- and 12th-graders; 51.5% female, 59.6% non-Hispanic white, 12.3% non-Hispanic black, 13.4% Hispanic and 14.7% other race/ethnicity. **Measurements** Frequent cannabis use (FCU), defined as six or more occasions in the past 30 days, stratified by sex, race/ethnicity and parental education. **Findings** FCU among US adolescents increased over the study period; the peak in 2010–18 was 11.4% among 18-year-old students. This increase was best explained by both period and cohort effects. Compared with respondents in 2005, adolescents surveyed in 2018 had period effects in FCU that were 1.6 times greater. Adolescents in younger birth cohorts (those born $>$ 1988) had a lower increase in FCU than those born prior to 1988. Results were consistent across sex, parent education and race/ethnicity, with period effects indicating increasing FCU after 2005 and cohort effects indicating a lower magnitude of increase in more recent birth cohorts. Age and parental education disparities in FCU have increased over time, whereas race/ethnicity differences have converged over time; black students were 0.67 [95% confidence interval (CI) = 0.64–0.70] times as likely to use cannabis frequently as white students from 1991 to 2000, and 1.03 (95% CI = 0.98–1.09) times as likely from 2011 to 2018 (*P*-value for time interaction $<$ 0.001). **Conclusions** The prevalence of frequent cannabis use (FCU) increased from 1991 to 2018 among older adolescents in the United States. Racial/ethnic differences in FCU converged, whereas parental education differences have diverged.

Keywords Adolescent cannabis use, age–period–cohort, frequent cannabis use, parental education, race/ethnicity, time trends.

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INTRODUCTION

Cannabis is one of the most commonly used psychoactive substances in the United States [1,2]. Past-year cannabis use among 12th-grade students has decreased since the peak of use in the late 1970s (50.8% in 1979), although data from the past dozen years suggest that cannabis use is again rising (increasing from 31.5% in 2006 to 35.9% in 2018 among 12th-grade students) [3]. There is a concern that those who use cannabis may be using at higher frequency, as we have seen an increase in adult cannabis use frequency [4–6]. Changes in high-frequency use are especially concerning in the context of the major policy changes surrounding cannabis legalization, where recreational use of cannabis is legalized in 10 states and Washington, DC as of February, 2019 [7,8]. Heavy and frequent cannabis use in adolescence is associated with consequences ranging from failing to complete school to cognitive deficits [9–13]. As drug use often begins in adolescence, understanding the pattern of high frequency cannabis use may foreshadow future consequences.

A thorough evaluation of historical trends in frequency of adolescent cannabis use requires assessment of the extent to which these trends reflect age, period or cohort (APC) effects [14]. Differentiating between APC effects disentangles developmental trends from historical time trends and illuminates whether changes across time are consistent across developmental age or influencing particular birth cohorts more than others. Cannabis use generally increases throughout adolescence (an age effect) [15], and declines during the transition to adulthood [16]. However, given changes in population trends in cannabis use, historical changes in developmental course could also occur, including changes in average age of onset [17,18]. Period effects describe the trends over time across all examined ages, which may be coincident with broader socio-environmental changes that affect all age groups simultaneously (e.g. availability and access due to legal changes). Lastly, cohort effects in cannabis use refer to the variance of use by the birth year or adjacent years. For example, some cohorts of youth may have particularly high levels of cannabis use because of high initiation rates during early adolescence that are maintained as they age.

Recent APC analyses of cannabis use have mainly been conducted among adults aged 18 and older, among whom cannabis use is increasing [19–21]. Available evidence among adults indicates that increases in adult cannabis use are predominantly explained by period effects [16]. In contrast, Miech & Koester [22] examined time trends and APC effects including both adolescent and adult cannabis use in national data from 1985 to 2009 [22], documented increases in cannabis use among youth and young adults, and found significant positive cohort effects, indicating higher risk of cannabis use overall among those born after World War II. However, those data are now more than a decade old, and the past decade in the United States has also ushered in substantial changes in adolescent cannabis use and environmental changes in availability of and legality around cannabis [23]. Further, APC analyses to date have not examined frequent cannabis use as a unique outcome from any cannabis use, which is critical to study given that trends in frequent use may be distinct from trends in experimental or infrequent use. Studies of adolescence have generally found that more recently born cohorts, those born between 1992 and 2004, are less likely to use cannabis throughout early adulthood [24], indicative of a cohort effect, but that these same cohorts may have a more rapid increase in cannabis use during the transition to adulthood [24]. Updated APC models incorporating younger generations are needed.

Changes over time in cannabis use may vary by demographic characteristics. Although black youth have historically had lower prevalence of cannabis use compared with white youth, cannabis use among black students has increased during the past 10 years and converged with that of white students [15,25]. Similarly, the prevalence of use by boys and girls has converged [3,26]; while prevalence has decreased among boys, there have been some recent increases among girls' use. However, the extent to which these convergences of cannabis use by race/ethnicity and sex extend to high-frequency cannabis use—which is of greatest consequence for public health—remains unknown. Further, family socioeconomic status has an inverse relationship with cannabis use and disorder [27,28], and this association begins as early as adolescence [29–31].

The present study consists of a systematic analysis of APC effects in adolescent frequent cannabis use using nationally representative samples of 1 236 159 8th-, 10th- and 12th-grade students in the United States from 1991 to 2018. We also tested whether trends were consistent across demographic groups as defined by parental education, race/ethnicity, and sex.

METHODS

Sample

Monitoring the Future has conducted nationally representative annual cross-sectional surveys of 8th-, 10th- and 12th-graders since 1991, with approximately 45 000 adolescents included per year [15]. Approximately 420 public and private schools are sampled each year in a multistage random sampling design with replacement, with a maximum of 350 students from each school; schools typically participate for 2 years. Schools that decline participation are replaced with schools that are similar on geographic location, size and urbanicity. Student response rates ranged from 79% (12th grade, 2008) to 91% (8th grade, 1996, 2002, 2006, 2007, 2011, 2012). Almost all non-response is due to absenteeism; fewer than 1% of students refused to participate. Self-administered questionnaires were given to students, typically in classroom settings with a teacher present. Teachers were instructed to avoid close proximity to the students during administration to ensure that students could respond confidentially. Detailed description of design and procedures are provided elsewhere [15].

The present study includes all adolescents with valid responses for cannabis use items (97.8% of the total sample) from 1991 to 2018. Due to unreliable estimates, adolescents aged <13 and $>=19$ were excluded (1.8%), as were those who did not respond to cannabis use questions. The final analytical sample included 1 236 159 adolescents (448 874 8th-graders, 419 127 10th-graders and 368 158 12th-graders).

Overall, 4.0% of data were excluded: 2.2% due to missing on past month cannabis use and 1.8% due to age restrictions.

Measures

Cannabis use

Past 30-day cannabis use was queried of all adolescents, worded as: 'On how many occasions (if any) have you used marijuana (grass, pot) or hashish (hash, hash oil) during the last 30 days?', where 'grass' was replaced with 'weed' between 1998 and 1999. Responses were dichotomized into: frequent use (defined as six times or more in the past month) versus all other students (other cannabis users and non-users). Six times or more was chosen as the cut-off for frequent use as it represents use on average more than once per week. Because there is no accepted standard for frequent cannabis use, we conducted sensitivity analysis at two cut-points: (a) three times or more in the past month versus all others and (b) 10 times or more in the past month versus all others.

Demographics

Age was measured in calendar years based on self-reported birth year; period was measured as the year of data collection and birth cohort was the year of data collection minus age.

We categorized respondents into: non-Hispanic white (59.6%), non-Hispanic black (12.3%), Hispanic (13.4%) and other race/ethnicity (14.7%). Those who reported more than one category were included in other race/ethnicity. Respondents reported the highest level of education for each parent. We categorized parental education based on the highest level achieved by either parent in the following: high school or less, some college or more. Respondents self-reported sex, 51.5% female.

Statistical analysis

APC effects models were estimated using the Clayton & Schifflers approach [32,33], as we have performed numerous times using MTF and other data sources [34–38]. Modeling strategies are complicated by the fact that APC are linearly dependent variables (cohort = period–age), thus their linear effects together are over-identified. The model-building and assessment begins by estimating a categorical age predictor, given that most health outcomes (including cannabis use) vary by age. Then, a parameter termed 'drift' is introduced, which is the sum of the linear effects over time of period and cohort effects. Finally, first- and second-derivatives of the drift are estimated and regressed on period and cohort, such that we estimate the extent to which the overall acceleration or deceleration of trends in the outcome are greater or less for certain periods (independent of age and cohort) and for certain cohorts (independent of age and period). Period and cohort relative risks are then estimated, with a specified reference period and reference cohort for comparison. Model fit is assessed at each stage including age + drift compared to age alone, and then iteratively adding in cohort and period effects to determine if the model fit statistically significantly improves with more parameters. Then, model fit is assessed as each parameter is iteratively removed, testing whether model fit statistically significantly deteriorates without the parameter in the model. We chose 1988 as the reference cohort because it was in the mid-point of the cohort distributions, and 2005 was chosen as the reference period for the analyses based on distributions in the data. The APC modeling was conducted using '*apc.fit*' in the '*Epi*' package in the R software [39] .

APC effects of cannabis were modeled by comparing frequent cannabis users versus all others. After estimating APC models, we then examined trends in the association between demographics and frequent cannabis use across time, categorizing time into three periods: 1991–2000, 2001–10 and 2011–18. These time-periods were chosen to represent each decade of the past 30 years. Logistic regression models were used to estimate odds ratios (ORs). Multiplicative interactions between year and demographic variables were tested to determine whether there were significant trends over time in associations with demographics, where statistical significance was set at $P < 0.05$. To conduct sensitivity analyses, all analyses were repeated with variation in the cut-off for frequent cannabis use.

RESULTS

Figure 1 shows descriptive statistics regarding the percentage of students who were frequent cannabis users, by age, across three decades: 1991–2000, 2001–10 and 2011–18. Frequent cannabis use increased by age in all time-periods; for older students (17–18-year-olds), it increased by decade group. Among those observed in 1991–2000, 8.9% of 17-year-olds and 9.2% of 18-year-olds reported frequent cannabis use. By 2011–18, 10.4% of 17-year-olds and 11.4% of 18-year-olds reported frequent cannabis use. Few trends were observed at younger ages. The result of the increase in frequent cannabis use among older adolescents is that the differences between younger and older adolescents are increasing in more recently born cohorts.

APC analysis of frequent cannabis use

A significant improvement in model fit was found with the addition of drift (overall linear trend in frequent cannabis use), period and cohort (overall non-linear trend in frequent cannabis use attributable to period and cohorts)

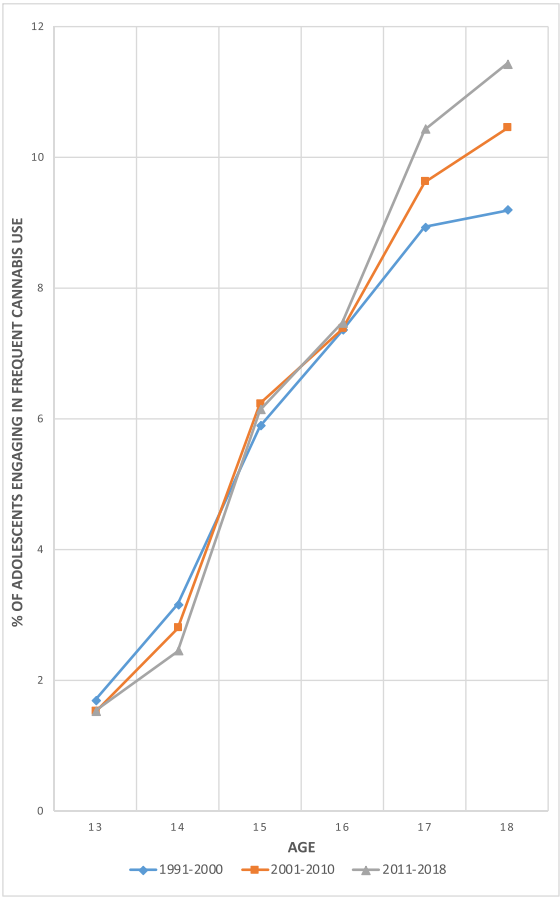

Figure 1 Percentage of adolescents engaging in frequent cannabis use by age and time-period. Frequent cannabis use defined as six or more occasions of use in the past 30 days

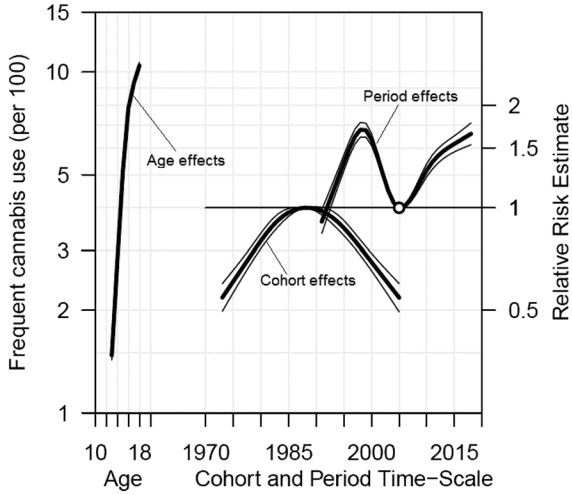

Figure 2 Age, period and cohort effects on frequent cannabis use from 1991 to 2018 (n = 1 236 159). Frequent cannabis use defined as six or more occasions of use in the past 30 days. The cohort and period time-scale contains relative risk estimates for the effect of cohort (left line) and period (right line). Thin lines indicate 95% confidence intervals. The cohort estimates are compared to a referent cohort, 1988, thus the lines can be interpreted as the average proportion of US students' frequent cannabis use, regardless of time-period, compared to the average proportion in 1988. The period estimates are compared to a referent period of 2005, thus the lines can be interpreted as the average proportion of US students' frequent cannabis use in that year, regardless of cohort, compared to the average proportion in 2005

(Supporting information, Table S1), both overall and by gender, parental education and race/ethnicity.

As shown in Fig. 2, frequent cannabis use increased with age; 18-year-olds were approximately five times more likely to be frequent cannabis users than 13-year-olds. The period effect in frequent cannabis use was higher in the time-period both before and after the reference period of 2005. In particular, the period effect of frequent cannabis use was 1.60 times higher in 2018 compared to 2005. Further, the period effect was also higher than the reference period for the years 1994–2005.

Adolescents in the 1988 birth cohort had the highest cohort effect of frequent cannabis use compared with those in preceding and following birth cohorts, with a steady decline in the cohort effect for those born after 1988. Thus, there are two countervailing forces: a positive period effect, driving up prevalence after 2005, and a negative cohort effect, with the amount of the increase by period having less of an effect among younger cohorts. These effects together produce the trends observed where frequent cannabis use is increasing, but more so for older cohorts compared with younger cohorts.

APC analyses by demographics

APC analyses were consistent across gender, parental education and racial/ethnic categories, with the best-fitting models including drift, period and cohort (Supporting information, Tables S1–S3). Supporting information, Figs S1, S2 and S3 graph the APC effects by gender (Supporting information, Fig. S1), parental education (Supporting information, Fig. S2) and race/ethnicity (Supporting information, Fig. S3). Results were consistent across all demographic groups, with period effects indicating increasing frequent cannabis use after 2005, with a lower magnitude of increase for adolescents in more recent birth cohorts.

Demographic associations with cannabis use across time

As adolescent cannabis use has had periods of both increase and decrease between 1991 and 2018 [40], we divided the data into three time-periods, broken up by decade, to analyze demographics of frequent cannabis use (Table 1). Tests of interaction by decade indicated substantial variation in reports of frequent cannabis use. Gender differences remained relatively stable over time, with a

Table 1 Odds ratios for association between demographic variables and frequent cannabis use, by time-period.

		1991–2000	*2001–10*	*2011–18*	*Interactions*		
	n	*472 092*	*439 849*	*324 218*			
					91_00 versus	*00_10 versus*	*91_00 versus*
					01_10	*11_18*	*11_18*
Gender	Male	1	1	1			
	Female	0.57 (0.55–0.58)	0.53 (0.52–0.55)	0.57 (0.55–0.59)	*	**	NS
Race/	White	1	1	1			
ethnicity	Black	0.67 (0.64–0.70)	0.76 (0.73–0.80)	1.03 (0.98–1.09)	***	***	***
	Hispanic	1.02 (0.98–1.07)	0.80 (0.77–0.84)	0.90 (0.86–0.94)	***	***	***
	Others	0.92 (0.88–0.96)	0.87 (0.84–0.91)	1.04 (0.99–1.08)	NS	***	***
Parent educ.	High school or less	1	1	1			
	College or more	0.80 (0.78–0.82)	0.70 (0.68–0.72)	0.66 (0.64–0.68)	***	**	***
Age (years)	13	1	1	1			
	14	1.76 (1.64–1.90)	1.77 (1.63–1.93)	1.51 (1.36–1.66)	NS	*	*
	15	3.54 (3.32–3.79)	4.28 (3.97–4.62)	4.16 (3.80–4.56)	***	NS	**
	16	4.35 (4.07–4.64)	4.91 (4.56–5.30)	5.05 (4.62–5.52)	*	NS	**
	17	5.66 (5.31–6.03)	6.87 (6.38–7.40)	7.44 (6.81–8.13)	***	NS	***
	18	5.57 (5.22–5.94)	7.19 (6.68–7.74)	8.01 (7.34–8.74)	***	NS	***

NS: not significant; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$. 95% confidence intervals are in parentheses.

slight increase in disparity between the 1990s and 2000s and a slight decrease in disparity between the 2000s and 2010s. In the 1990s, black students were less likely to report frequent cannabis use in comparison to white students, in the 2000s the strength of the effect decreased (from OR = 0.67–0.76) and by the 2010s there was no significant difference between white and black student frequent cannabis use; these interactions are significant, as shown in Table 1. Students who had higher parental education were increasingly less likely to report frequent cannabis use compared to students with lower parental education (from OR = 0.80–0.66), showing a diverging difference in use by parental education status ($P < 0.01$ for interactions between decades). Lastly, within each decade each additional year of age was associated with higher odds of frequent cannabis use. In comparison to 13-year-olds, 16–18-year-old students were increasingly more likely to be frequent cannabis users over time (16-year-old OR = 4.35–5.05; 17-year-old OR = 5.66–7.44; 18-year-old OR = 5.57 to 8.01; $P < 0.01$), showing another divergence over time.

Sensitivity analysis

To examine the robustness of our results we repeated the analysis with two alternative frequency cut-points, one with a lower threshold for frequent use (three or more times in the past month) and one with a higher threshold for frequent use (10 or more times in the past month). For both alternate cut-points, results replicated the main results presented (Supporting information, Table S4), with significant change in deviance for age, drift, period and cohort. Supporting information, Fig. S4 illustrates the APC effects at the alternative cut-points, which again are consistent with the main analysis using six or more times in the past month as the cut-point. This indicates that while higher cut-points of cannabis use frequency have lower prevalence, the trends over time are still consistent.

Further, trends in the demographic associations with frequent cannabis use were consistent across cut-points (Supporting information, Table S5). By gender, we see a growth in disparity between the 1990s and 2000s followed by a decrease in disparity between the 2000s and 2010s. The convergence of frequent use between black and white students seen in the main analyses is shown in both the lower and higher cut-points of frequent use, where black students were less likely to report frequent cannabis use compared to white students, where the magnitude of ORs decreased show a growing convergence. Over time, students who had higher parental education were less likely to report frequent cannabis use in comparison to students with lower parental education, where the magnitude of ORs increased, showing a growing difference. Lastly, in comparison to 13-year-olds, 17- and 18-year-olds have increasingly higher odds of being frequent users under these additional cut-points, although not significant in the higher level of frequency cut-point.

DISCUSSION

During the past three decades, the prevalence of frequent cannabis use—using six or more times in the past 30 days—among 16–18-year-old students has increased; APC analyses indicate that the trends in frequent cannabis use are driven by both period and cohort effects. Since 2005 there has been a positive period effect of frequent cannabis use, indicating that there are overall shifts upward in frequent cannabis use for all ages. Simultaneously, there is a negative cohort effect, suggesting that the largest increases in frequent cannabis use are observed among older rather than younger cohorts; that is, frequent cannabis use is increasing more rapidly among those born before 1995 than those born after 1995. Observed trends are consistent across sex, parental education and race/ethnicity and across different cut-points for the definition of 'frequent' cannabis use, a term that is inconsistently defined in the literature [41–44]. While trends are consistent even when stratified by demographic groups, the relationship between demographic groups and frequent cannabis use are themselves shifting across time. The prevalence of frequent cannabis use is converging by race/ethnicity and sex and diverging by parental education and age across time, which is consistent with previous research showing a complete convergence in use between black and white students [25], a shrinking gap in use between boys and girls in the most recent decade [26] and a growing gap in cannabis use across age during the past 3 decades [3]. To our knowledge, ours are the first data to suggest that cannabis use differences by socio-economic status among US adolescents are growing over time, indicative of the potential for an emerging health disparity.

These results have substantial implications for understanding the etiological factors that underlie changes in prevalence over time of cannabis use. The increases in frequent cannabis use during a time-period in which overall cannabis use has also been slightly increasing across the past decade suggests that prevention and intervention regarding cannabis use among youth remains an important public health priority. Adolescents are increasingly less likely to report that cannabis use is a great risk to health [45], suggesting that acceptance of cannabis use and tolerance regarding use may underlie, at least in part, the increases in prevalence and period effects observed, and the cohort effects suggesting that older adolescents are driving much of the increase in frequent use. Repeated heavy exposure to cannabis during adolescence is hypothesized to

alter brain development [46–48], and has been associated with poor educational outcomes [13,49–51] and cognitive impairment [52,53]. Cohort effects observed in the present study suggest that the greatest increases in frequent cannabis use are occurring among older birth cohorts compared with younger birth cohorts. While intervention and prevention should be universally directed at all adolescents, particular attention to adolescents in the later years of high school are warranted.

Our analyses are consistent with and extend previous research; first, with a converging rate of frequent cannabis use among racial/ethnic groups [25,54]. The convergence by racial/ethnic groups may be due to in part to the increased prevalence of blunt smoking, which is more common among black and older youths [55]; this is consistent with the increased rates of cannabis use disorder, which are most common among young black men compared to other racial/ethnic groups [54]. Given that black and other minority youth are increasing overall cannabis use prevalence [25], outpacing other racial/ethnic groups, these results in totality suggest that attention to increasing use among minority youth is increasingly critical to the health of minority adolescents. Secondly, period effects are underlying increases in cannabis use across a variety of previously published analyses throughout recent historical time-periods focused primarily on adults [16,22]. Similar to other APC analyses, we find that cohort effects are additional predictors of cannabis use prevalence throughout time independent of period effects. Miech & Koester [22] suggested that post-World War II cohorts, especially those within the baby boom, have higher rates of cannabis use throughout the life-course compared with other cohorts. We did not examine data among adults, but add to this literature by also documenting cohort effects among current generations of adolescents, especially older adolescents, which may portend higher rates as these students progress into adulthood.

Socio-economic status has varied associations with substance use in adolescence, with several studies suggesting that adolescents from high socio-economic status families are more likely to use [44,56]. Our results suggest that frequent cannabis use is more common among students with low parental education, indicating that while students with high parental education may be more likely to experiment, those in lower economic positions may be more likely to use frequently. Other work suggests that high socio-economic status young adults have heavier patterns of cannabis use during the transition to adulthood [44,56], indicating that associations between socio-economic status and cannabis may shift across the life-course. Further, low socio-economic status is consistently associated with cannabis and other drug use [57], but due to the growth in income inequality in the United States [58] there is a discernible increasing divergence in cannabis use between high and low economic adolescents.

Limitations should be noted. The data are self-reported and adolescents may misreport their frequency of cannabis use; relatedly, there may be changes over time in the willingness of adolescents to report cannabis use. However, the trends in MTF correspond to other large national surveys [1], suggesting that self-report is a reliable proxy for overall patterns of use. The MTF survey is administered in schools and does not include adolescents who have dropped out of high school, who are more likely to be cannabis users [51,59], suggesting that the estimates reported here cannot be generalized for non-school-attending youth. However, we would anticipate that frequent use of cannabis would be greater among those in older age groups if dropouts were observed, which would expand the age differences observed here. School dropouts by 8th and 10th grades are rare in the United States [40,60]. MTF samples three grades and thus age variation is limited, and further, we do not observe adolescents at the same age in different grades, which again limits generalizability. Lastly, the APC models used in the present analysis do not provide the causal predictors of the APC effects, an important direction for future research.

Mitigating these limitations are substantial strengths. Monitoring the Future is nationally representative with large sample sizes, and has been conducted in the 8th, 10th and 12th grades for more than 25 years with time-invariant procedures and measures, which allows for a robust long-term assessment of the trends in frequent cannabis use. Additionally, our sensitivity analyses show that our results are consistent across definitions of frequent use, as well as across sex, parental education and race/ethnicity.

This work has public health relevance to the goal of reducing health disparities in the United States. The protective effect of race/ethnicity is dissipating, and differences between those at lower socio-economic positions compared to high, as well as between younger and older students, are diverging. As income inequality increases in the United States, intervention and prevention for marginalized groups will become increasingly relevant for public health. When this growing income inequality is combined with the continuous decrease in perceived harm of cannabis use [61], the amelioration of health disparities should remain at the forefront of intervention and policy changes.

Declaration of interest

None.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1 Model fit statistics for age-period-cohort model on adolescent frequent cannabis use, by gender
Table S2 Model fit statistics for age-period-cohort model on adolescent frequent cannabis use, by parent education
Table S3 Model fit statistics for age-period-cohort model on adolescent frequent cannabis use, by race/ethnicity
Figure S1 Age, period, and cohort effects on the probability of adolescents reporting frequent cannabis use from 1991 to 2018, by *gender*
Figure S2 Age, period, and cohort effects on frequent cannabis use from 1991 to 2018, by low (both parents less than high school) and high (both parents more than high school) parental education
Figure S3 Age, period, and cohort effects on the probability of adolescents reporting frequent cannabis use from 1991 to 2018, by *race/ethnicity*
Table S4 Model fit statistics for age-period-cohort model with alternative cut points
Figure S4 APC sensitivity analyses on the probability of adolescents reporting frequent cannabis use with alternative cut points.