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Age, period, and cohort effects in synthetic cannabinoid use among US adolescents, 2011–2015

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Abstract

Background—Synthetic cannabinoids use has been a public health concern given association with hospitalization and death among users. While national reports estimate that reported use is declining among adolescents, differences by birth cohort may indicate subgroups who remain at higher risk, both in the overall adolescent population and among demographic subgroups.

Methods—We estimated age, period, and cohort models of self-reported past-year synthetic cannabinoid use (queried as "synthetic marijuana" ["K2," "Spice"]) among 54,865 adolescents aged 13–19 attending high school from 2011–2015.

Results—Past-year use decreased from 11.86% in 2011 to 4.75% in 2015. This decrease was best represented as a linear downward trend. When stratified by key covariates, however, results indicated evidence of a positive cohort effect for students of higher socioeconomic status (SES). For those students, use did not decrease at the same rate as the overall population; younger cohorts of high SES students remain at higher risk for synthetic cannabinoid use than older cohorts as well as lower SES peers. A similar and stronger association was found for frequent marijuana users (≥ 20 occasions of past-year use). Multi-level models indicated that groups at highest risk included

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Contributors

Dr. Katherine Keyes drafted the paper, Ms. Caroline Rutherford and Ms. Ava Hamilton performed analyses and provided critical revisions to the paper, and Dr. Joseph Palamar drafted sections of the paper. All authors have approved the final paper.

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Conflict of Interest

No conflict declared.

older adolescents, Hispanics and other/mixed race students, cigarette users, and frequent marijuana users.

Conclusion—Synthetic cannabinoid use is associated with morbidity as well as mortality; continued attention to reducing synthetic cannabinoid use remains an important public health priority to maximizing student health.

Keywords

synthetic cannabinoids; adolescents; marijuana

1. INTRODUCTION

Synthetic cannabinoid use is among the newest drug-related public health threats in the United States (US). Synthetic cannabinoids are research chemicals that are intended to mimic tetrahydrocannabinol (THC)—the main psychoactive component in naturally occurring cannabis (marijuana; Zawilska and Andrzejczak, 2015). These chemicals are typically sprayed onto herbal mixtures and commonly sold under names such as “K2” and “Spice” and marketed as “legal” replacements for natural marijuana. Use of synthetic cannabinoids is linked to numerous adverse effects, including anxiety and delusions as well as tachycardia, vomiting, and as described below, seizure and poisoning among some users (Cooper, 2016). While numerous synthetic cannabinoid compounds have been banned or controlled in the US (at the federal and/or state-level) and throughout Europe, new compounds continue to emerge at a rapid pace. By 2014 in Europe alone, at least 134 compounds had been discovered (with 30 new compounds discovered in 2014; European Monitoring Centre for Drugs and Drug Addiction, 2015).

Seizures and poisonings secondary to synthetic cannabinoid use have generally increased in recent years. For example, synthetic cannabinoids were identified in 37,500 seizures in the US in 2014 while 2,892 were identified in 2010 and 22,087 in 2011. There were also more reported poisonings related to synthetic cannabinoid use in 2015 (7,779) than in any previous year (i.e., 6,968 in 2011, 5,230 in 2012, 2,668 in 2013, and 3,682 in 2014), with spikes in some areas such as New York City (Law et al., 2015; Palamar et al., 2016). Despite increases in seizures and poisonings in recent years, prevalence of self-reported use actually appears to have decreased, at least among youth. Monitoring the Future (MTF) is the only nationally representative survey in the US that queries use of synthetic cannabinoids, and among high school seniors in the MTF sample, in years 2011–2013, one out of ten seniors self-reported use, but self-reported use has decreased to about five percent 2015 (Johnston et al., 2015; Palamar and Acosta, 2015). Previous studies focusing on MTF samples have found demographic and other differences in reported use such as lower risk among girls compared with boys, and marijuana and other substance users are at particularly high risk for reporting use (Palamar and Acosta, 2015; Patrick et al., 2015).

An overall decrease in prevalence, however, may mask variation specific to particular subgroups of adolescents. Given that use of these compounds is often associated with deleterious outcomes (Law et al., 2015) and seizures and poisonings continue to increase, a focus on estimating the potential for cohort effects is warranted. Cohort effects occur when

particular age groups evidence particular health patterns that differ from other individuals observed at the same time period (Keyes et al., 2010). The emergence of cohort effects has two central implications for etiology and intervention. First, if there are particular groups that are not experiencing the same decrease in self-reported synthetic cannabinoid prevalence compared with other groups, then the risk factors particular to those groups should be scrutinized for potential etiological relevance. For example, given that frequent marijuana use is associated with use of synthetic cannabinoids (Caviness et al., 2015; Palamar and Acosta, 2015; Winstock and Barratt, 2013), we might expect frequent marijuana users to have a slower decline in synthetic cannabinoid use compared with other adolescents. If this protracted decline is also particular to younger age groups among whom neurological development may be more fragile, adverse consequences may be heightened. Second, health patterns that are aggregated by cohort suggest that need for target efforts at prevention and treatment, as well as allocation services and planning that attend to the particular groups at highest risk for the outcomes of interest.

MTF includes an annually conducted cross-sectional survey of US high-school attending adolescents, querying use of multiple drugs including synthetic cannabinoids since 2011. As such, these data present an opportunity to estimate age, period, and cohort effects in self-reported synthetic cannabinoid use. Therefore, the present study formally decomposes variance in synthetic cannabinoid use into age, period, and cohort effects, and further, we estimate whether there is variation in age, period, and cohort effects by subgroups defined by sex, parental education (an indicator of socioeconomic status [SES]), race/ethnicity, and frequent marijuana use. Finally, we estimate multi-level models of synthetic cannabinoid use with random period and cohort effects to assess the stability of risk factors for use over time.

2. METHODS

2.1 Sample

MTF has sampled 8th, 10th, and 12th grade students in ~130 U.S. public and private high schools in the US annually since 1991. Included measurement years were 2011 through 2015, representing birth cohorts 1992–2002. High schools are selected under a multi-stage random sampling design with replacement. Schools are invited to participate for two years. Schools that decline participation are replaced with schools that are similar on geographic location, size, and urbanicity. The overall school participation rates (including replacements) range from 92% to 97% for all study years. Student response rates have averaged 87%. Almost all non-response is due to absenteeism; less than 1% of students refuse to participate. Self-administered questionnaires are given to students. Detailed description of design and procedures are provided elsewhere (Miech et al., 2015). The present study focuses on students who were randomized to questionnaires that included questions regarding synthetic cannabinoid use (8th and 10th grade: Forms 1 and 6 in 2011, and Form 1 from 2012–2015; 12th grade: Forms 3 and 6 in 2011–2015). The total eligible sample size was 54,865 (17,237 8th graders, 17,753 10th graders, 19,875 12th graders). Respondents with missing data regarding age or synthetic cannabinoid use were not analyzed. Due to few respondents at extreme ages, we restricted analysis to those aged 13–19 for graphical presentations. We conducted preliminary analyses of synthetic cannabinoid prevalence separately by form

(Supplementary Figure 1¹); while there were some differences in prevalence across years, notably in 2011 when only 12th grade students received synthetic cannabinoid questions, no substantial differences in prevalence emerged from 2012–2015, thus we analyzed data all data together.

2.2 Measures

The MTF questionnaire is administered via paper and pencil within schools. Self-administered questionnaires are given to students, typically in classroom settings with a teacher present. Teachers are instructed to avoid close proximity to the students during administration to ensure student confidentiality. Detailed description of design and procedures are provided elsewhere (Miech et al., 2015). All question wording and placement in the questionnaires has remained unchanged throughout the study period of 2011 to 2015.

2.2.1 Age, period, and birth cohort—Age was estimated based on respondent reported birth date and the date of the survey. Year of survey administration was recorded in each respondent record. Birth cohort was then estimated as the difference between survey year and current age (e.g. a respondent aged 15 at the 2012 survey was born in 1997).

2.2.2 Synthetic cannabinoid use—Respondents were asked “During the last 12 months, on how many occasions (if any) have you taken “synthetic marijuana” (“K2”, “Spice”) to get high?”. Respondents could select from seven response options ranging from 0 occasions to 40 or more. We dichotomized the measure into 0 versus 1 or more occasions due to low variation in the occasions of use.

2.2.3 Regular marijuana use—Respondents were first given a stem: “The next questions are about marijuana and hashish. Marijuana is sometimes called: Weed, Pot, Dope. Hashish is sometimes called: Hash, Hash oil.” Respondents were then asked about hashish and marijuana separately, including the number of occasions of marijuana use in the past 12 months, with response options ranging from 0 to 40+. We considered individuals to be regular marijuana users if they reported 20 or more occasions of marijuana use in the past year. While there is no precedent in the literature for a definition of regular marijuana use, 20 or more occasions indicates use almost twice a month, on average, and suggests a patterns of regular use in keeping with the construct of regular marijuana use.

2.2.4 Cigarette use—Respondents were asked “Have you ever smoked cigarettes?”. Response options included: Never, once or twice, occasionally, regularly in the past, or regularly now.

2.2.5 Demographics and urbanicity—Respondents reported on their self-described gender, race/ethnicity, and both of their parents’ highest levels of education. To measure race/ethnicity, respondents self-identified their racial category and were allowed to select more than one category. Those who selected more than one category were categorized as “Mixed”. Respondents who selected one category were categorized as White, Black, Asian,

¹Supplementary material can be found by accessing the online version of this paper at <http://dx.doi.org> and by entering doi:...

or Other. Respondents reported their parents' levels of education; we categorized the highest of the two (or level for one parent if the student only reported on one parent) as the parents' highest level of education. The survey also captures whether the school is in a Metropolitan Statistical Area as a measure of urbanicity.

2.3 Statistical analysis

We began by graphing the prevalence of self-reported synthetic cannabinoid use by age and period using basic cross-tabulation. We then proceeded to age-period-cohort modeling. It is well known that linear effects of age, period, and cohort cannot be simultaneously considered due to dependency (Cohort=Period-Age; Keyes et al., 2010). We estimated age-period-cohort models with the Clayton and Schifflers approach (Clayton and Schifflers, 1987a, b), as we have done in other investigations in these and other data (Ananth et al., 2015, 2013; Keyes et al., 2015). In this approach we iteratively estimated parameters for age, period, and cohort effects and selected among them using model fit statistics including the AIC and BIC, likelihood-based deviance statistics, and penalizing additional degrees of freedom. We began by estimating a parameter for the linear effect of age, given that age is strongly related to synthetic cannabinoid use (Palamar and Acosta, 2015). We then estimated the overall linear change across time (termed "drift") that is a sum of both period and cohort effects, but because of linear dependency, not able to be uniquely attributed to either period or cohort. Finally, we estimate the first derivatives of the linear drift, which can be attributable to period and cohort. These effects are termed "curvatures". We chose birth year 1996 as the cohort referent group as it was in the midpoint of the cohort distributions; we chose 2013 as the period referent group as it contained data on a high number of birth cohorts. We estimated age-period-cohort models by sex, race, parental education, and heavy marijuana use status. Modeling was conducted using the "*apc.fit*" function in the "*Epi*" package in R software (R Core Team, 2015).

Finally, we estimated multi-level models with period and cohort as random effects (Yang and Land, 2013) and age as a fixed effect. We estimated these models for two reasons. First, we estimated coefficients for period and cohort effects as a robustness check on the results from the Clayton and Schifflers models to ensure that results were not driven by a particular modeling choice. Second, we estimated covariates of synthetic cannabinoid use prevalence allowing the prevalence to vary across period and cohort, in order to assess the stability of risk factors for use taken into account the variation in prevalence over time. These models were fit using PROC GLIMMIX in SAS version 9.4.

3. RESULTS

Past year synthetic cannabinoid use increased across age, in all study years (see Figure 1). In the figure, we removed 12- and 20-year-old students due to low sample size (12: N=5; 20: N=273). Concomitantly, past year use decreased among US adolescents across the study period. For example, past year use among 12th grade students decreased from 11.86% in 2011 to 4.75% in 2015.

Age-period-cohort modeling fitting is shown in Table 1. In the total sample, and by sex, the linear term for the overall trend (drift) significantly improved model fit, with no remaining variance uniquely attributable to period or cohort.

By education, we observed both a linear overall trend as well as evidence of a cohort effect for those with a parent with greater than high school ($p=0.07$). Specifically, among those with a parent with greater than high school education, we observed a cohort effect that trended towards statistical significance. This indicates that for those students, use did not decrease at the same rate as the overall population, such that younger cohorts of high SES students remained at higher risk for synthetic cannabinoid use than older cohorts as well as similarly aged peers with lower SES. Among those reporting 20 occasions of marijuana use in the past 12 months, we observed a significant cohort effect, including both an increase in model fit when cohort was included in the model ($p=0.03$), and a decrease in model fit when cohort was removed from the model ($p=0.03$). This indicates that there is a positive cohort effect for younger cohorts, indicating that use was not declining at the same rate as older peers and peers who are not frequent marijuana users.

Given the evidence for overall linear effects as well as evidence for cohort effects among some subgroups, we estimated the age, period, and cohort parameters for the overall sample presented in Figure 2, as well as across subgroups presented in Figures 3 through 5. Overall results indicated yearly monotonic declines in synthetic cannabinoid risk after 2012 (see Figure 2), as well as emerging evidence for an increased in risk for younger cohorts. Synthetic cannabinoid use increased with age and levels off after age 18. Results were similar when stratified by sex (Figure 3).

By subgroups, a pattern of cohort effects also emerged for those with a parent with greater than high school education (Figure 4). Compared with the referent cohort (1996), there was an increasingly positive cohort effect in younger born cohorts, with a significant cohort effect for those born between 1998 and 2000. This positive cohort effect was even more pronounced among those reporting 20 occasions of marijuana use in the past year. There were significant positive cohort effects for each successively younger cohort compared to the referent cohort of 1996.

Finally, multi-level models with random effects for period and cohort are shown in Table 2. Period and cohort effects showed similar patterns as in the Clayton and Schiffers results, indicating that results were not dependent on particular assumptions of that model. Covariate results indicated that overall, groups at highest risk for synthetic cannabinoid use included older adolescents, Hispanics and other/mixed race students, cigarette users, and frequent marijuana users. Parental education was not predictive of synthetic cannabinoid use in the multi-level model. This indicates that while at the individual level, parental education is not predictive of risk of use, it is predictive of the overall trend in use, such that those with parental education decrease use less during the overall decrease at the population level.

4. DISCUSSION

The present results indicate that while use of synthetic cannabinoids is declining overall among US adolescents, the declines in use are not uniform across demographic groups. Specifically, young adolescents who use marijuana regularly as well as those whose parents have greater than high school education are declining in synthetic cannabinoid use at slower rates than other adolescents. Further, risk factors for use have remained stable across time despite the decreases overall in prevalence, including concurrent other substance use, older age, and Hispanic as well as mixed/other race and ethnicity.

We found that adolescents whose parents have higher than high school education are declining more slowly than other adolescents. Such findings are in line with a broader literature that indicates that some forms of substance use as well as patterns of use are more common among high socioeconomic status students (Ennett et al., 1997; Humensky, 2010; Patrick et al., 2012). Individuals in highly advantaged areas are more likely to engage in high levels of alcohol use (Ennett et al., 1997; Pollack et al., 2005), marijuana use (Humensky, 2010; Patrick et al., 2012), as well as hazardous drinking patterns (Keyes and Hasin, 2008), despite the consistent findings that adolescents and adults living in deprivation are more exposed to alcohol-related violence and alcohol outlets (Pollack et al., 2005). While such socioeconomic patterning is generally not seen for illicit drugs other than marijuana, many synthetic cannabinoid compounds are currently “legal”, and available for purchase in convenient stores and on the internet, providing ease of access for young adults, especially those with economic means to purchase. As such, our results underscore a distribution of synthetic cannabinoids which may increasingly be more common among high socioeconomic groups. However, we note that our multi-level analysis did not identify parental education as a risk factor for use; rather, parental education predicted the overall population-level trend in use. Continued monitoring of these trends is necessary to determine whether the social patterning of population-level trends translates into individual risk patterns.

Further, young adolescents who reported using marijuana at least 20 times in the past year also did not decline in use at the same rate as other adolescents, and risk for use is higher for younger cohorts of frequent marijuana users. This is particularly concerning as a cohort effect, as the positive cohort effect was more pronounced among young adolescents, among whom drug use patterns are still forming, and among whom concern remains focused about potential maturational deficits coinciding with heavy drug use (Volkow et al., 2014). The effects of synthetic cannabinoids on developing neurological processes has not been extensively studied, but the combined effect of synthetic cannabinoid use with regular marijuana exposure is certainly a cause for concern.

Age, period, and cohort analyses of drug use among adolescents have illuminated a series of trends that have not been visible using traditional surveillance. Through these studies we have been able to identify particular groups at risk for long terms patterns of substance use, including younger birth cohorts of women who are reporting higher levels of binge drinking (Keyes et al., 2011a), and cohorts of marijuana users who began using in time periods of high overall population rates of use (Kerr et al., 2007; Keyes et al., 2011b), among whom

cohort effects indicate continued high rates of use. Tobacco products have consistently demonstrated strong cohort effects since World War II (Holford et al., 2016). To our knowledge, similar age-period-cohort methodology has not been applied to novel psychoactive substances, and yet as the present results demonstrate, cohort effects are important for these lesser-used but still problematic substances that remain an emerging cause of morbidity and mortality.

Limitations of the study are noted. All measures are based on self-reported of the adolescents, which may be subject to recall bias and error, especially for novel psychoactive substances which are known by a rapidly changing array of street names. However, synthetic cannabinoids are typically well labeled and available for “legal” purchase for adults, thus most users likely understand what they are using, which may not be the case for other novel psychoactive substances purchased illegally. Further, MTF uses procedures that have been shown to enhance valid reporting, that is, school based (rather than in-home), self-completed questionnaires containing only close-ended responses, administered by non-school-associated university personnel, with convincing assurances of confidentiality (Harrison, 1995; Johnston et al., 2011). Synthetic cannabinoids were included in the MTF survey beginning in 2011; thus trends prior to this date could not be assessed, and we have only five years of surveillance information. While this is a limited time horizon, we note that MTF is the only nationally representative survey to query novel psychoactive substances, thus remains the best source of information on trends of use. However, cohort effects may take more time to emerge in the data; thus continued follow-up is necessary. Finally, because MTF is a school-based survey, high school drop-outs are not included in any survey estimates. This is a minor issue for the eighth grade survey; however, by tenth grade approximately 5% of adolescents drop out, and by twelfth grade between 10 to 20% of each cohort is missing due to drop-out (Johnston et al., 2007). However, trends in high school drop-out have remained relatively stable over time overall (U.S. Department of Education, 2015), thus while rates of drug use may be different among high school attenders and non-attenders, the trends over time should be robust to the non-inclusion of dropouts. The conclusions from this study can be generalized only to high-school attending students, which represent the large majority of adolescents in the US. Further, results should not be generalized to adults.

Self-reported synthetic cannabinoid use is decreasing among adolescents, but use is decreasing at a slower rate for some subgroups—primarily those with high SES parents and those who are frequent marijuana users. Across time, risk factors for use include older adolescents, adolescents who identify as Hispanic/Mixed race, and cigarette/other substance users. Thus, additional prevention programming should target those at higher risk for use of these compounds. Further research is needed, however, to further determine not only risk factors for use (e.g., in older populations), but also to determine who is at highest risk for adverse health outcomes related to use. Poisonings related to synthetic cannabinoid use have increased in recent years despite a decrease in prevalence of use; therefore, research is also needed to determine who is at highest risk for experiencing these adverse health outcomes (e.g., poisonings), and whether adverse health outcomes are related to frequency and/or severity of use, or to use of specific compounds. Given that synthetic cannabinoid use is closely associated with frequent marijuana use, more research is needed to determine

temporal associations as well as reasons for individuals using these compounds. Analysis of synthetic cannabinoid use or poisonings might also yield important associations with regard to local marijuana policies as many users may try or resort to synthetic cannabinoids as a “legal” version of marijuana. Given that synthetic cannabinoids arrived and spiked in popularity very quickly, health surveys—both national and local—should monitor self-reported use not only of synthetic cannabinoid products, but also new potentially dangerous drugs that quickly emerge.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Prevalence of past year synthetic cannabinoid use among adolescents in the US aged 13 to 19, 2011 to 2015.

Figure 2.

Age, period, and cohort effects of synthetic cannabinoid use among 8th, 10th, and 12th graders, 2011–2015 (covering cohorts born between 1992 and 2002).

Footnote: The cohort and period time-scale contains risk ratio estimates for the effect of cohort (far left line) and period (far right line). Thin lines indicate 95% confidence intervals. The cohort estimates are compared to a referent cohort of 1996, thus the lines can be interpreted as the average proportion of adolescents using synthetic cannabinoids, regardless of time period, compared to the average proportion among those born in 1996. The period estimates are compared to a referent period of 2013, thus the lines can be interpreted as the average proportion of adolescents using synthetic cannabinoids, regardless of cohort, compared to the average proportion in 2013.

Figure 3.

Age, period, and cohort effects of synthetic cannabinoid use among 8th, 10th, and 12th graders, 2011–2015 (covering cohorts born between 1992 and 2002) stratified by sex.

Footnote: The cohort and period time-scale contains risk ratio estimates for the effect of cohort (far left line) and period (far right line). Thin lines indicate 95% confidence intervals. The cohort estimates are compared to a referent cohort of 1996, thus the lines can be interpreted as the average proportion of adolescents using synthetic cannabinoids, regardless of time period, compared to the average proportion among those born in 1996. The period estimates are compared to a referent period of 2013, thus the lines can be interpreted as the average proportion of adolescents using synthetic cannabinoids, regardless of cohort, compared to the average proportion in 2013.

Figure 4.

Age, period, and cohort effects of synthetic cannabinoid use among 8th, 10th, and 12th graders, 2011–201 (covering cohorts born between 1992 and 2002) stratified by parental education.

Footnote: The cohort and period time-scale contains risk ratio estimates for the effect of cohort (far left line) and period (far right line). Thin lines indicate 95% confidence intervals. The cohort estimates are compared to a referent cohort of 1996, thus the lines can be interpreted as the average proportion of adolescents using synthetic cannabinoids, regardless of time period, compared to the average proportion among those born in 1996. The period estimates are compared to a referent period of 2013, thus the lines can be interpreted as the average proportion of adolescents using synthetic cannabinoids, regardless of cohort, compared to the average proportion in 2013.

Figure 5.

Age, period, and cohort effects of synthetic cannabinoid use among 8th, 10th, and 12th graders, 2011–2015 (covering cohorts born between 1992 and 2002) stratified by marijuana use.

Footnote: The cohort and period time-scale contains risk ratio estimates for the effect of cohort (far left line) and period (far right line). Thin lines indicate 95% confidence intervals. The cohort estimates are compared to a referent cohort of 1996, thus the lines can be interpreted as the average proportion of adolescents using synthetic cannabinoids, regardless of time period, compared to the average proportion among those born in 1996. The period estimates are compared to a referent period of 2013, thus the lines can be interpreted as the average proportion of adolescents using synthetic cannabinoids, regardless of cohort, compared to the average proportion in 2013.

Table 1

Model Fit Statistics for Age-Period-Cohort Model of synthetic cannabinoid use among 8th, 10th, and 12th graders, 2011–2015 (covering cohorts born between 1992 and 2002).

Model Parameter	Change in Deviance (Degrees of Freedom)							
	All	Sex		Parental Education			Marijuana Use in Last 12 Months	
		Males	Females	Grade School/Some HS	HS Graduate	> High School	<20 Occasions	20 Occasions
Age	-	-	-	-	-	-	-	-
Age-drift	299.15 (1) **	237.45 (1) **	66.46 (1) **	13.015 (1) **	70.44 (1) **	216.95 (1) **	143.05 (1) *	125.53 (1) **
Age-Cohort	7.22 (4)	6.94 (4)	1.06 (4)	4.997 (4)	3.54 (4)	8.56 (4) †	1.51 (4)	10.49 (4) *
Age-Period-Cohort	4.96 (3)	2.54 (3)	2.63 (3)	3.535 (3)	1.86 (3)	3.71 (3)	0.91 (3)	4.95 (3)
Age-Period	-7.75 (-4)	-4.75 (-4)	-3.06 (-4)	-6.073 (-4)	-2.49 (-4)	-7.31 (-4)	-1.70 (-4)	-10.50 (-4) *
Age-drift	-4.43 (-3)	-4.73 (-3)	-0.63 (-3)	-2.459 (-3)	-2.91 (-3)	-4.95 (-3)	-0.72 (-3)	-4.95 (-3)

<0.01

*
< 0.05

†
<0.1

Footnote: Each model is iteratively fit. The age-drift model is compared to a model with age only, and a statistically significant change in deviance for this model indicates that there is an overall linear trend. The addition of the cohort parameter is the 'curvature', and indicates whether cohort uniquely contributes to the increases or decreases in the overall linear trend. The addition of the period parameter is the 'curvature', and indicates whether period uniquely contributes to the increases or decreases in the overall linear trend and the curvature by cohort. We then begin removing parameters from the model to see whether the model fit significantly decreases when cohort is removed, then finally, when period is removed. A significant negative change in model fit indicates that the model fit significantly decreases when the parameter is removed.

Table 2

Period- and cohort-level fixed and random effects on synthetic cannabinoid use among 8th, 10th, and 12th graders, 2011–2015 (covering cohorts born between 1992 and 2002).

Fixed Effects	Random effect = year, unadjusted		Random effect = year, adjusted		Random effect = cohort, unadjusted		Random effect = cohort, adjusted	
	Estimate (s.e.)	pValue	Estimate (s.e.)	pValue	Estimate (s.e.)	pValue	Estimate (s.e.)	pValue
Intercept	–2.60 (0.18)	<0.001	–3.92 (0.18)	<0.001	–2.51 (0.20)	<0.001	–3.79 (0.18)	<0.001
Age								
13–14	–0.67 (0.05)	<0.001	–0.14 (0.06)	0.019	–0.28 (0.07)	<0.001	–0.14 (0.08)	0.074
15–16	REF*	REF	REF	REF	REF	REF	REF	REF
17–19	0.16 (0.04)	<0.001	–0.25 (0.05)	<0.001	–0.34 (0.06)	<0.001	–0.70 (0.07)	<0.001
Race								
White			REF	REF			REF	REF
Black			–0.07 (0.08)	0.340			–0.08 (0.08)	0.317
Hispanic			0.45 (0.06)	<0.001			0.45 (0.06)	<0.001
Asian			–0.36 (0.14)	0.011			–0.34 (0.14)	0.016
Other/Mixed			0.35 (0.06)	<0.001			0.36 (0.06)	<0.001
Parental Education								
Grade school/some HS			0.11 (0.07)	0.118			0.11 (0.07)	0.133
HS Degree			0.09 (0.05)	0.099			0.09 (0.05)	0.104
>HS			REF	REF			REF	REF
MSA**								
Not MSA			–0.02 (0.05)	0.762			–0.02 (0.05)	0.687
MSA			REF	REF			REF	REF
Cigarettes								
Never			REF	REF			REF	REF
Once/twice			1.57 (0.05)	<0.001			1.57 (0.05)	<0.001
Occasionally			2.14 (0.06)	<0.001			2.14 (0.06)	<0.001
Regularly in past			2.14 (0.08)	<0.001			2.13 (0.08)	<0.001
Regularly now			2.47 (0.07)	<0.001			2.46 (0.07)	<0.001
Marijuana								

		Random effect = year, unadjusted		Random effect = year, adjusted		Random effect = cohort, unadjusted		Random effect = cohort, adjusted	
Fixed Effects		Estimate (s.e.)	p Value	Estimate (s.e.)	p Value	Estimate (s.e.)	p Value	Estimate (s.e.)	p Value
<20 times				REF				REF	
				1.65 (0.05)	<0.001			1.64 (0.05)	<0.001
>=20 times									
Random Effects									
Year									
2011		0.44 (0.18)	0.015	0.48 (0.18)	0.008				
2012		0.30 (0.18)	0.092	0.28 (0.18)	0.120				
2013		0.02 (0.18)	0.902	-0.02 (0.18)	0.898				
2014		-0.26 (0.18)	0.142	-0.27 (0.18)	0.132				
2015		-0.49 (0.18)	0.005	-0.46 (0.18)	0.010				
Cohort									
1992						0.68 (0.25)	0.007	0.71 (0.25)	0.005
1993						0.84 (0.20)	<0.001	0.80 (0.19)	<0.001
1994						0.78 (0.20)	<0.001	0.69 (0.19)	<0.001
1995						0.46 (0.20)	0.023	0.35 (0.19)	0.058
1996						0.18 (0.20)	0.376	0.07 (0.18)	0.696
1997						-0.04 (0.20)	0.831	-0.15 (0.18)	0.417
1998						-0.24 (0.20)	0.238	-0.28 (0.18)	0.133
1999						-0.52 (0.20)	0.009	-0.46 (0.19)	0.013
2000						-0.61 (0.21)	0.004	-0.49 (0.19)	0.011
2001						-0.87 (0.22)	<0.001	-0.75 (0.21)	<0.001
2002						-0.66 (0.28)	0.017	-0.49 (0.28)	0.076
Model Fit									
-2 Res Log-Pseudo-Likelihood		317220 df = 1		317507 df = 1		316528 df = 1		316871 df = 1	

* REF indicates the reference group for comparison

** MSA = Metropolitan Statistical Area, and indicator of school urbanicity