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Recreational Marijuana Legalization, Local Retail Availability, and Alcohol and Marijuana Use and Co-Use Among California High School Students

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ABSTRACT. Objective: This study examined whether recreational marijuana legalization (RML) and local retail availability were associated with marijuana and alcohol use and co-use among adolescents. **Method:** We investigated associations between RML and past-30-day marijuana and alcohol use and co-use, and moderating effects of retail availability of marijuana and alcohol, using data from the 2010–2011 to 2018–2019 California Healthy Kids Surveys (CHKS) of 9th and 11th grade students in 38 California cities. Multilevel mixed-effects logistic regression analyses were conducted, controlling for secular trends and student and city demographics. Additional analyses examined associations of RML and retail availability with co-use among subgroups of drinkers and marijuana users. **Results:** For the full sample, RML was inversely associated with alcohol use but was not significantly associated with marijuana use or co-use with alcohol. However, significant interactions between RML and marijuana outlet density showed that there were increases in marijuana and alcohol co-use and alcohol following legalization in cities with higher densities of marijuana outlets. RML was positively associated with co-use among non–heavy and heavy drinkers, but inversely related to co-use among occasional and frequent marijuana users. A significant positive interaction between RML and marijuana outlet density indicated that RML was associated with increases in co-use for occasional marijuana users in cities with higher densities of marijuana outlets. **Conclusions:** RML was associated with increases in marijuana and alcohol co-use and alcohol use among California high school students, particularly those in cities with higher densities of retail cannabis stores, although this varied across alcohol and marijuana use subgroups. (*J. Stud. Alcohol Drugs, 84,* 734–743, 2023)

AS OF APRIL 2023, 27 states and the District of Columbia had decriminalized cannabis possession and use; 37 states and D.C. allowed medical marijuana use among adults at least 18 years old with a medical referral; and 19 states, two territories, and D.C. had legalized recreational marijuana use among adults at least 21 years old (National Conference of State Legislatures, 2022). The liberalization of marijuana laws raises concerns about possible effects on marijuana use and co-use with other substances among underage youth.

Co-use of alcohol and marijuana includes concurrent use and simultaneous use. Concurrent use refers to using both alcohol and marijuana, but not necessarily at the same time, whereas simultaneous use refers to using the two substances close in time such that the effects overlap (Sokolovsky et al., 2020). Marijuana use and co-use with alcohol have been associated with negative consequences among youth, including impaired driving, poor academic performance, aggression, sexual assault, externalizing problems, and risk of substance use disorder later in life (Miech et al., 2021; Volkow et al., 2014, 2016). Moreover, co-use of alcohol and marijuana may increase the risk for adverse outcomes beyond using either substance alone (e.g., Brière et al., 2011; Egan et al., 2019; Yurasek et al., 2017).

Few studies have investigated whether recreational marijuana legalization (RML) is associated with increases in alcohol and marijuana co-use among adolescents. A recent review of national studies indicated that research on the effects of marijuana law liberalization on alcohol and marijuana use and co-use among youth is mixed and inconclusive (Pacula, 2022). This article examines associations of RML and retail availability of marijuana and alcohol in California cities with marijuana and alcohol use and co-use among high school students. California legalized adult recreational marijuana use in 2016, and retail sales began in 2018 (California Bureau of Cannabis Control, 2022). Recent studies indicate that statewide RML in California is associated with increased marijuana use and co-use with alcohol (Paschall et al., 2021, 2022). However, little is known about whether these relationships vary by retail availability of marijuana and alcohol in California cities, as local jurisdictions can ban or restrict retail marijuana sales (California Bureau of Cannabis Control, 2022).

Although studies suggest that underage youth are rarely able to purchase marijuana from retail outlets (Buller et al., 2019, 2016; Fell et al., 2022), local retail availability of

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marijuana may affect marijuana use among underage youth indirectly through diversion (i.e., provision of marijuana to youth by adults who purchase it), by normalizing marijuana use, or by reducing the perceived risk of marijuana use. A recent study in Oregon, for example, found significant post-RML increases in perceived parental approval of marijuana use and perceived availability of marijuana and a decrease in perceived risk of marijuana use (Paschall & Grube, 2020). Additional analyses with post-RML data indicated a positive association between retail marijuana availability (outlet density) in Oregon counties and past-30-day marijuana use among adolescents; this relationship was accounted for by perceived approval, availability, and risk. A more recent study using statewide samples of adolescents in Oregon from 2010 to 2018 found a significant post-RML increase in past-30-day alcohol and marijuana co-use, particularly among adolescents living in counties with higher retail marijuana and alcohol outlet density (García-Ramírez et al., 2021). This study also found that relationships between retail marijuana and alcohol availability and co-use were explained by beliefs favorable to using these substances (e.g., perceived parental approval). However, both studies were limited by the lack of school identifiers that would locate the cities within Oregon counties where adolescents lived and thereby allow more proximal measures of exposure to retail outlets. Recent statewide studies in California showing post-RML increases in marijuana use (Paschall et al., 2021) and co-use with alcohol (Paschall et al., 2022) did not examine whether RML associations with these behaviors varied by local retail availability of marijuana and alcohol.

One issue is whether marijuana serves as a substitute or a complement to alcohol use for adolescents. That is, with greater marijuana availability and normalization of marijuana use, does marijuana use replace alcohol use, or is marijuana used in addition to alcohol? Although the evidence is mixed (Gunn, 2022), some research suggests that marijuana and alcohol are used as complements among some adolescents, particularly those who are regular or heavy drinkers (Pape et al., 2009). Similarly, a recent statewide study of adolescents in California from the 2010–2011 to 2018–2019 school years found an increase in the likelihood of past-30-day alcohol and marijuana co-use after RML in 2016, and this association was stronger among adolescents who engaged in past-30-day alcohol use or heavy drinking (Paschall et al., 2022). These results suggest that RML may increase complementary use of alcohol and marijuana among these youth. In contrast, this study also found a post-RML decrease in co-use among adolescents who reported at least monthly marijuana use, suggesting greater substitution of marijuana for alcohol among youth in this subgroup. This study did not examine whether RML effects on co-use varied by levels of local retail availability of marijuana and alcohol, nor did it compare occasional versus frequent marijuana users.

The present study uses data from the California Healthy Kids Survey (CHKS) for high school students living in 38 cities to examine whether the association of RML with alcohol and marijuana use and co-use is stronger in cities with greater retail availability of marijuana and alcohol. Although the primary focus of this study is co-use of alcohol and marijuana, we also examine possible effects of RML and retail availability on marijuana use and alcohol use separately to gain a better understanding of the nature of the associations of RML and retail availability with co-use of these substances. We also examined possible interactive effects of RML and marijuana and alcohol retail availability on co-use among adolescents who were non–heavy drinkers, heavy drinkers, occasional marijuana users, and frequent marijuana users. We hypothesized that RML would be associated with increases in marijuana and alcohol co-use and that this association would be stronger in cities with higher marijuana and alcohol outlet densities. Based on previous research, we expected RML to have a stronger association with increases in co-use among regular and heavy drinkers and frequent marijuana users.

Method

Study sample

Cities. This study used a purposive sample of geographically and demographically diverse cities in California. To ensure sufficient data for the analyses and reflect the diversity of the California population, the pool of eligible cities was restricted to those with populations of at least 75,000 persons and a minimum of 15% Latino/a. Eligible cities were stratified by region within California (northern, central, southern), and a city was selected within each stratum. To avoid spatial contamination, all cities contiguous to those sampled were eliminated from the sample frame. The sampling process was repeated until 40 cities were selected, with approximately one third from each region and representing a broad range of retail marijuana availability. Of these, two cities were dropped because they did not have CHKS data for at least one of the study years before and one after RML, resulting in a final sample of 38 cities. In the final sample, city population size ranged from 83,700 to 1,021,800 (*M* [*SD*] = 210,300 [181,500]) and varied in racial/ethnic diversity and socioeconomic conditions (e.g., percent Latino/a: *M* [*SD*] = 44.1 [16.1], range: 16.5–79.3; percent Black: *M* [*SD*] = 8.7 [8.7], range: 1.3–40.9; percent below poverty line: *M* [*SD*] = 13.7 [5.2], range: 4.5–29.3). In addition, the cities varied in retail availability of marijuana and alcohol, based on the number of licensed retail outlets per square mile (marijuana outlet density: *M* [*SD*] = 0.08 [0.11], range: 0.0–0.49; alcohol outlet density: *M* [*SD*] = 9.3 [4.7], range: 2.0–24.8). Eight of the 38 cities prohibited retail sales of recreational marijuana, and others restricted the numbers or locations of retail outlets.

California Healthy Kids Survey. We used annual cross-sectional data from 518,207 9th- and 11th-grade students in 554 public high schools within the 38 cities that participated in the CHKS from 2010–2011 to 2018–2019. In high schools, the CHKS focuses on 9th- and 11th-grade students, and data collection is staggered such that it occurs in approximately half of participating schools each school year and in any given school in alternate years (California Department of Education, 2022). CHKS is administered in either the fall or spring at the discretion of the participating schools. The substance use items on the CHKS are modeled on those in national surveys (e.g., Monitoring the Future, Youth Risk Behavior Survey). CHKS requirements include a targeted minimum response rate of 60% using passive or active parental consent. The CHKS is anonymous and confidential; student participation is voluntary, but written assent is not required. About 75% of all California school districts participate in CHKS. Based on a random sample of high schools that participated in CHKS, survey response rates were 73% among 9th graders and 68% among 11th graders.

Based on California Department of Education statistics for 9th and 11th graders from the 2010–2011 to 2018–2019 school years (DataQuest, 2022), we created sample weights for the 38 cities. Sample weights were calculated as the ratio of the proportion of students in each grade, gender, ethnic and racial subgroup for the state to the proportion in each corresponding subgroup in the 38-city sample.

Student-level measures

Recreational marijuana legalization. RML was coded 0 for the school years up to and including the year when RML went into effect on November 9, 2016 (2010–2011 to 2016–2017) and coded 1 for the school years after RML (2017–2018 and 2018–2019). It was not possible to disaggregate survey data for fall 2016 and spring 2017.

Marijuana use. From 2010–2011 to 2016–2017 students were asked, "During the past 30 days, on how many days did you use marijuana (pot, weed, grass, hash, bud)?" (*0 days, 1 day, 2 days, 3 to 9 days, 10 to 19 days,* and *20 to 30 days*). The same question was asked in later years but with the addition of "smoke, vape, eat, or drink" to reflect the increasing variety of marijuana products. Because this variable was highly skewed, it was dichotomized to represent any past-30-day marijuana use. Two marijuana use subgroups were created. Students who reported using marijuana from *1 day* to *10 to 19 days* in the past month were classified as "occasional marijuana users," whereas those who reported marijuana use from *20 to 30 days* in the past month were classified as "frequent marijuana users."

Alcohol use and heavy episodic drinking. Students were asked, "During the past 30 days, on how many days did you have at least one drink of alcohol?" (*0 days, 1 day, 2 days, 3 to 9 days, 10 to 19 days,* and *20 to 30 days*). They were also asked about heavy episodic drinking ("On how many days did you have five or more drinks of alcohol in a row, that is, within a couple of hours?") with the same response options. Because both of these measures were highly skewed, dichotomous variables were created to represent any past-30-day alcohol use and any heavy episodic drinking. Two alcohol use subgroups were created from these variables. Students who reported any alcohol use in the past 30 days, but not heavy episodic drinking, were classified as "non–heavy drinkers," whereas students who reported any heavy episodic drinking in the past month were classified as "heavy drinkers."

Alcohol and marijuana co-use. Based on responses to the questions about past-30-day alcohol and marijuana use, a dichotomous variable was created to represent any past-30-day alcohol and marijuana co-use.

Demographics. Students were asked to report their sex, grade, race, and ethnicity. Sex was coded as a dummy variable (1 = *female*). Because the CHKS does not ask students' age, grade level was used as a surrogate measure. Grade level was coded as a dummy variable, with 9th grade as the reference group. Race/ethnicity was coded as a series of dummy variables, with non-Latino/a White as the reference group.

School year. This variable is coded 1–9 for the 2010–2011 to 2018–2019 school years.

City-level measures

Cannabis retail availability. Retail cannabis sales in California became legal in January 2018. We obtained lists of retail cannabis storefronts licensed by the California Bureau of Cannabis Control in each of the 38 cities in 2018 and 2019 (California Bureau of Cannabis Control, 2022). We calculated cannabis outlet density as the number of retail cannabis outlets per square mile within city limits. We considered other measures (outlets per population, per roadway mile) and found these highly correlated with the number of outlets per square mile (*r*s ranging from .80 to .98). Outlet density was coded the same across all survey years, allowing us to address whether communities with higher outlet densities had higher overall rates of use and co-use before and after RML. An RML × Outlet Density interaction term was also calculated as the product of RML (0,1) × outlet density and thus is 0 before RML, allowing us to test whether greater cannabis outlet density was associated with an increase in use and co-use after RML.

Alcohol retail availability. We obtained lists of on- and off-premises alcohol outlets in the 38 cities from the California Department of Alcoholic Beverage Control website in 2018 (California Department of Alcoholic Beverage Control, 2022) and calculated alcohol outlet density as the number of outlets per square mile. We note that local alcohol outlet density changes very little from year to year in California.

We considered other measures (outlets per population, per roadway mile) and found that these highly correlated with the number of outlets per square mile (*r*s ranging from .76 to .93).

Demographics. We used U.S. 2016–2020 Census data to obtain the total population size of each city. For analyses, we divided the total city population by 10,000 to obtain more interpretable parameter estimates. We used 2010 U.S. Census data to obtain the percentage of the population of each city living in poverty based on (a) individual or family income and (b) whether the family's total annual income is below its assigned poverty threshold, determined by size of the family and age of its members. We also used 2016–2020 U.S. Census data to estimate the percentage of the population of each city that identified as Latino/a, Black, and White (U.S. Census Bureau QuickFacts, 2022).

Analyses

Descriptive statistics. We obtained descriptive statistics for the total sample and for the four subgroups of students who engaged in any alcohol use, heavy episodic drinking, occasional marijuana use, and frequent marijuana use in the past 30 days.

Multilevel regression analyses. The primary analyses comprised mixed-effects multilevel logistic regression models to assess the separate and interactive associations of RML and local cannabis and alcohol outlet density with past-30-day alcohol and marijuana use and co-use, controlling for student demographics, school year, and city characteristics. Controlling for the secular trend (school year) allowed us to determine whether post-RML levels of alcohol and marijuana use and co-use were higher than would be expected given the overall declines in these substance use behaviors from 2010–2011 to 2018–2019 and to account for possible confounding effects of the secular trend (Lopez Bernal et al., 2017). This modeling approach is commonly used in interrupted time series studies to evaluate the effects of policies or public health interventions on health outcomes of interest (Hudson et al., 2019; Lopez Bernal et al., 2017).

In an initial model, co-use was predicted from RML, marijuana and alcohol outlet densities, school year, student demographics, and city covariates for the full sample of students. Next, we added RML × Marijuana Outlet Density and RML × Alcohol Outlet Density terms to the regression model. To avoid confounding the main effects, nonsignificant interaction terms were dropped from analyses. We then conducted separate analyses of the associations of RML and retail outlet density with past-30-day marijuana use and alcohol use with the full sample. Supplemental regression analyses were conducted to investigate the nature of significant RML × Marijuana Outlet Density interaction effects on alcohol and marijuana use and co-use. A parallel set of multilevel logistic regression analyses were conducted to examine the associations of RML and marijuana and alcohol outlet density with co-use among the four subgroups of 9th and 11th graders: non–heavy drinkers, heavy drinkers, occasional marijuana users, and frequent marijuana users. We conducted the multilevel regression analyses in Stata (StataCorp LP, College Station, TX) to adjust standard errors for clustering of student observations within schools and cities. Sample weights were applied in all analyses.

Results

Sample characteristics. Characteristics of the total sample and the subgroups of non–heavy alcohol users, heavy alcohol users, occasional marijuana users, and frequent marijuana users are shown in Table 1 as weighted percentages. Of the full study sample, approximately half were male, more than half were Latino/a, and slightly more than half were in 9th grade. Over the 9 school years, 16.2% of students reported any past-30-day marijuana use, 20.3% reported any past-30-day alcohol use, and 10.8% reported any past-30-day co-use of alcohol and marijuana. Among non–heavy drinkers, heavy drinkers, occasional marijuana users, and frequent marijuana users, the percentages of students reporting any past-30-day co-use were 36.3%, 69.1%, 63.2%, and 76%, respectively. Supplemental Table A compares the sample characteristics in school years before and after RML. (Supplemental material appears as an online-only addendum to this article on the journal's website.)

Multilevel regression analyses predicting alcohol and marijuana use and co-use in the full sample

Results for the regression analyses for the total sample are shown in Table 2. Overall, RML was associated with an increase in marijuana use, although this effect did not reach conventional statistical significance ($p < .061$), and inversely related to past-30-day alcohol use. There was a significant interaction between RML and marijuana outlet density, indicating a greater increase in the likelihood of alcohol use and co-use of alcohol and marijuana after RML in cities with higher retail availability of cannabis, but not for marijuana use. The RML × Alcohol Outlet Density interaction term was statistically significant, although substantively small for marijuana use. This interaction was not statistically significant for alcohol use or co-use and was therefore dropped from those models. The pre-/post-RML trends in marijuana and alcohol use and co-use by local marijuana outlet density level are illustrated in Figure 1. Additional regression analyses were conducted to assess the nature of RML × Marijuana Outlet Density interaction effects on alcohol and marijuana use and co-use with the full sample (Supplemental Table B). These results indicate a positive association between RML and marijuana use in cities at all marijuana outlet density levels. In contrast, there were significant inverse relation-

TABLE 1. Sample characteristics, percent

Student characteristics	Total sample (N = 518,207)	Non–heavy drinkers (n = 48,765)	Heavy drinkers (n = 58,277)	Occasional marijuana users (n = 62,527)	Frequent marijuana users (n = 23,494)
Past-30-day marijuana use	16.2	36.3	69.1	–	–
Past-30-day alcohol use	20.3	–	–	64.7	76.9
Past 30-day alcohol and marijuana co-use	10.8	36.3	69.1	64.7	76.9
Grade 9	52.8	46.1	38.7	44.2	38.7
Grade 11	47.2	53.9	61.3	55.8	61.3
Female	48.3	57.3	46.7	49.4	33.6
Male	51.7	42.7	53.3	50.6	66.4
Hispanic (Latino/a)	52.4	58.5	58.2	58.4	56.3
American Indian/ Alaska Native	0.6	0.6	0.8	0.7	1.0
Asian	11.8	6.8	5.4	5.1	3.7
Black	6.3	5.5	4.6	7.5	8.8
Native Hawaiian/ Pacific Islander	0.5	0.4	0.5	0.5	0.4
White	25.2	24.8	27.1	24.0	25.9
Multiracial	2.5	2.5	2.4	2.9	2.9
Unknown race	0.7	0.8	1.0	0.9	0.9

Note: Sample (N) and subsample (n) sizes are unweighted, whereas percentages are weighted.

ships between RML and alcohol use at all marijuana outlet density levels. None of the associations between RML and co-use were statistically significant at different outlet density levels. Nonsignificant terms were dropped from the analyses. Summary results for nonsignificant RML × Outlet Density interaction terms in regression models for the full sample can be found in Supplemental Table C.

Multilevel regression analyses predicting co-use by subgroups. We conducted separate analyses for the subgroups of past-30-day non–heavy drinkers, heavy drinkers, occasional marijuana users, and frequent marijuana users (Table 3). There was a significant positive interaction between RML and marijuana outlet density only for the occasional marijuana users. The RML and alcohol outlet density interaction terms were not significant for any of the subgroups. Significant positive associations between RML and co-use were found for past-30-day non–heavy and heavy drinkers. Significant inverse associations were found between RML and co-use among past-30-day occasional and frequent marijuana users. Trends in co-use among the four subgroups before and after RML are illustrated in Figure 2. Nonsignificant interaction terms were dropped from the analyses. Summary results for nonsignificant interaction terms in the regression models for the four subgroups can be found in Supplemental Table D.

Discussion

This study is one of the first to investigate whether statewide legalization of adult recreational marijuana use and local retail availability of marijuana and alcohol are associated with marijuana and alcohol use and co-use among adolescents. Our hypothesis that the association between RML and alcohol and marijuana co-use would be stronger in cities with greater retail availability of marijuana was supported with the full sample of adolescents, whereas local retail availability of alcohol did not have a significant moderating effect on this relationship. Similarly, the association between RML and alcohol use was significantly stronger in cities with greater retail availability of marijuana, but this was not true for marijuana use. Overall, the findings suggest that local retail availability of marijuana may play a role in increasing opportunities for and acceptability of alcohol and marijuana use and co-use, even though underage youth may not be able to obtain marijuana directly from retail outlets. Of note, RML was positively related to marijuana use but inversely associated with alcohol use, which may explain the lack of an association between RML and co-use independent of local retail marijuana availability. Moreover, this finding may indicate that marijuana use is increasing after RML in the general population of California adolescents, whereas alcohol use continues to decrease.

Neither marijuana nor alcohol outlet density had a significant moderating effect on the relationship between RML and co-use among subgroups of past-30-day drinkers and frequent marijuana users. However, among occasional marijuana users, the positive association between RML and co-use was significantly stronger in cities with a higher density of cannabis retail outlets. Among these subgroups, RML was positively related to co-use among non–heavy and heavy drinkers but was inversely related to co-use among marijuana users. The increase in alcohol and marijuana co-

TABLE 2. Results of multilevel logistic regression analysis predicting alcohol use, marijuana use, and co-use with full sample (N = 518,207), odds ratio [95% confidence interval]

Variable	Past-30-day co-use	Past-30-day alcohol use	Past-30-day marijuana use
Student level			
Pre-post RML	0.97 [0.91, 1.04]	0.77 [0.73, 0.81]**	1.09 [1.00, 1.19]
Female	0.94 [0.92, 0.97]**	1.19 [1.17, 1.22]**	0.90 [0.87, 0.92]**
Grade 11	1.59 [1.51, 1.67]**	1.68 [1.61, 1.75]**	1.53 [1.46, 1.61]**
Hispanic (Latino/a)	1.11 [1.06, 1.18]**	1.10 [1.05, 1.15]**	1.17 [1.11, 1.22]**
American Indian/Alaska Native	1.24 [1.11, 1.39]**	1.03 [0.93, 1.13]	1.26 [1.14, 1.38]**
Asian	0.36 [0.34, 0.39]**	0.44 [0.41, 0.46]**	0.37 [0.34, 0.40]**
Black	0.93 [0.86, 1.00]	0.68 [0.64, 0.72]**	1.23 [1.16, 1.30]**
Native Hawaiian/Pacific Islander	0.78 [0.71, 0.85]**	0.74 [0.69, 0.79]**	0.82 [0.76, 0.89]**
Multiracial	1.07 [1.02, 1.13]**	0.94 [0.90, 0.98]**	1.22 [1.17, 1.28]**
Unknown race	0.97 [0.88, 1.06]	0.99 [0.91, 1.07]	1.04 [0.97, 1.12]
School year	0.89 [0.88, 0.90]**	0.89 [0.88, 0.90]**	0.90 [0.89, 0.91]**
City level			
Population (10,000)	1.00 [1.00,1.00]	1.00 [1.00, 1.00]	1.00 [1.00, 1.00]
% Latino/a	1.00 [0.99, 1.01]	1.00 [1.00, 1.01]	1.00 [0.99, 1.00]
% Black	0.99 [0.98, 1.00]*	0.99 [0.99, 1.00]	0.99 [0.99, 1.00]
Poverty	1.00 [0.98, 1.01]	0.99 [0.98, 1.00]	1.00 [0.98, 1.02]
Alcohol outlet density	1.01 [1.00, 1.03]	1.01 [1.00 1.02]	1.01 [0.99, 1.03]
Marijuana outlet density	1.06 [0.57, 1.98]	1.03 [0.65, 1.63]	1.19 [0.64, 2.24]
Pre-post RML × Alcohol Outlet Density	–	–	1.01 [1.00, 1.02]*
Pre-post RML × Marijuana Outlet Density	1.71 (1.02, 2.86)*	1.87 (1.22, 2.85)**	–

Notes: Demographic reference groups are 9th graders, males, and non-Hispanic (Latino/a) White students. RML = recreational marijuana legalization. Pre-post RML is a dummy variable coded 0 for pre-RML years (2010–2011 to 2016–2017) and 1 for post-RML years (2017–2018 to 2018–2019). All regressions are weighted.
*p < .05; **p < .01.

TABLE 3. Results of multilevel logistic regression analyses predicting alcohol and marijuana co-use in subgroups, odds ratio [95% confidence interval]

Variable	Non–heavy drinkers (n = 48,765)	Heavy drinkers (n = 58,277)	Occasional marijuana users (n = 62,527)	Frequent marijuana users (n = 23,494)
Student level				
Pre-post RML	1.67 [1.53, 1.83]**	1.25 [1.16, 1.35]**	0.66 [0.60, 0.71]**	0.80 [0.71, 0.90]**
Female	0.77 [0.73, 0.81]**	0.70 [0.68, 0.73]**	1.33 [1.27, 1.39]**	1.10 [1.02, 1.18]*
Grade 11	1.08 [1.02, 1.13]**	0.87 [0.82, 0.91]**	1.25 [1.20, 1.30]**	0.97 [0.91, 1.04]
Hispanic (Latino/a)	1.11 [1.03, 1.19]**	1.04 [0.97, 1.12]	0.90 [0.83, 0.96]**	0.94 [0.84, 1.04]
American Indian/Alaska Native	1.62 [1.23, 2.12]**	1.21 [0.99,1.46]	0.97 [0.78, 1.21]	0.88 [0.65, 1.18]
Asian	0.60 [0.54, 0.66]**	0.68 [0.60, 0.78]**	0.84 [0.76, 0.94]**	0.93 [0.75, 1.16]
Black	2.39 [2.17, 2.64]**	1.57 [1.39, 1.78]**	0.50 [0.45, 0.55]**	0.54 [0.47, 0.63]**
Native Hawaiian/Pacific Islander	1.05 [0.89, 1.24]	0.99 [0.84, 1.16]	0.78 [0.67, 0.91]**	0.87 [0.68, 1.11]
Multiracial	1.44 [1.32, 1.59]**	1.24 [1.15, 1.34]**	0.70 [0.65, 0.76]**	0.79 [0.69, 0.90]**
Unknown race	1.03 [0.88, 1.20]	0.92 [0.80, 1.07]	0.77 [0.66, 0.90]**	0.82 [0.62, 1.09]
School year	0.98 [0.96, 0.99]**	1.03 [1.02, 1.04]**	0.93 [0.92, 0.94]**	0.93 [0.91, 0.95]**
City level				
Population (10,000)	1.00 [1.00, 1.00]	1.00 [1.00, 1.00]	1.00 [1.00, 1.00]**	1.00 [1.00, 1.00]
% Latino/a	1.00 [0.99, 1.00]	0.99 [0.99, 0.99]*	1.00 [1.00, 1.00]	1.00 [1.00, 1.01]
% Black	1.00 [0.99, 1.00]	0.99 [0.98, 0.99]*	1.00 [0.99, 1.00]	0.98 [0.97, 0.99]**
Poverty	1.00 [0.99, 1.02]	1.00 [0.99, 1.01]	1.00 [0.99, 1.00]	1.00 [0.99, 1.01]
Alcohol outlet density	1.02 [1.00, 1.03]*	1.01 [1.00, 1.02]*	1.00 [1.00, 1.02]	1.01 [1.00, 1.02]
Marijuana outlet density	1.04 [0.60, 1.80]	1.14 [0.75, 1.75]	0.73 [0.53, 1.00]	0.72 [0.46, 1.12]
Pre-post RML × Marijuana Outlet Density	–	–	1.71 [1.08, 2.72]*	–

Notes: Demographic reference groups are 9th graders, males, and non-Hispanic (Latino/a) White students. RML = Recreational Marijuana Legalization. Pre-post RML is a dummy variable coded 0 for pre-RML years (2010–2011 to 2016–2017) and 1 for post-RML years (2017–2018 to 2018–2019). All regressions are weighted.
*p < .05; **p < .01.

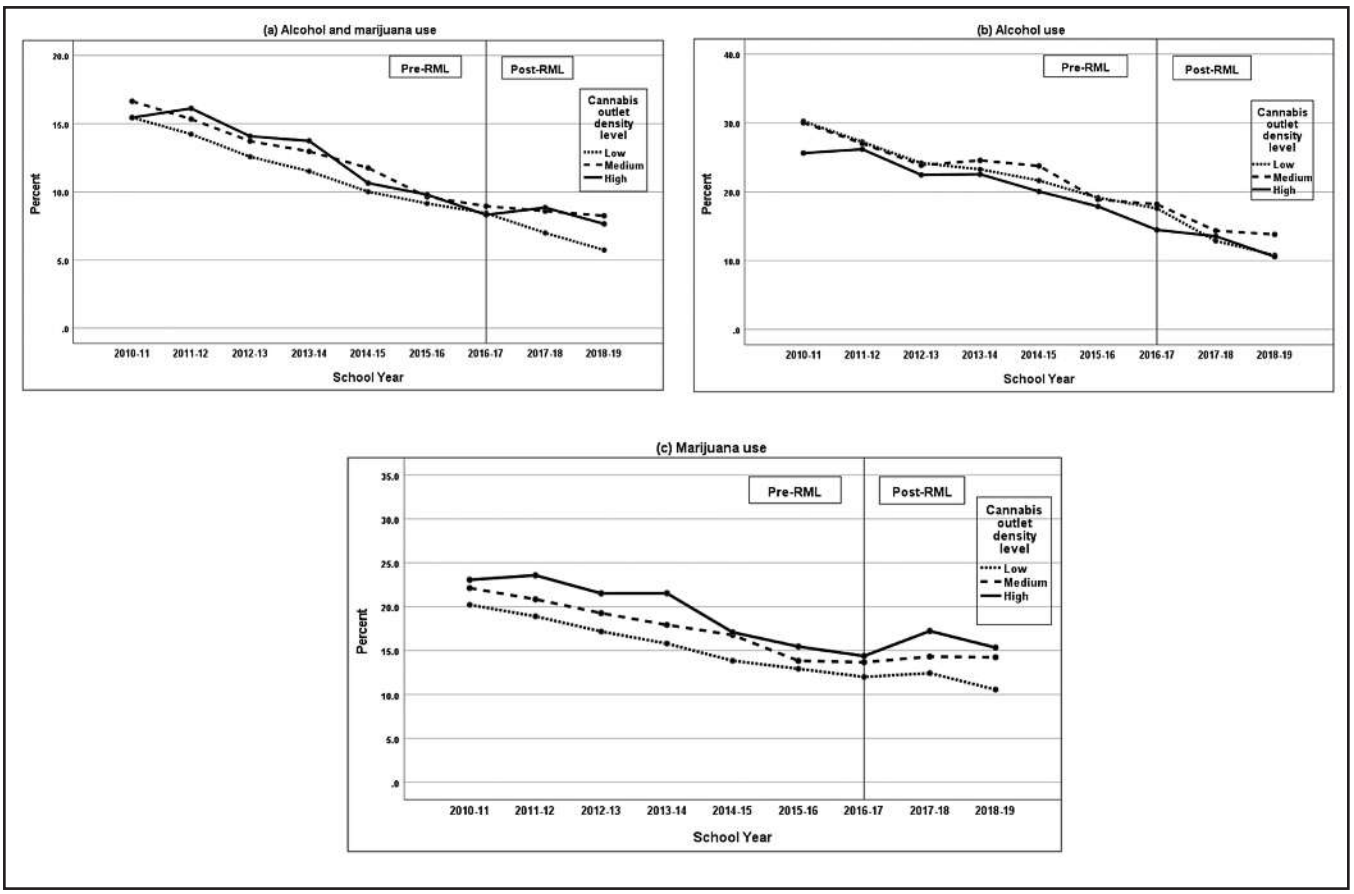

FIGURE 1. Trends in the prevalence of past-30-day (a) co-use of alcohol and marijuana, (b) marijuana use, and (c) alcohol use by marijuana outlet density level (low = 0, medium = 0.02–0.09, high = 0.16– 0.49 outlets per square mile). RML = recreational marijuana legalization.

use after RML among past-30-day drinkers suggests possible complementary use of both substances for these youth. Conversely, among marijuana users, the decrease in co-use prevalence after RML suggests substitution of marijuana for alcohol among these adolescents.

Our findings are consistent with a statewide study in Oregon that found a stronger association between RML and co-use among adolescents living in counties with greater retail availability of marijuana and alcohol (García-Ramírez et al., 2021). This study is also consistent with a statewide study on RML and co-use among California adolescents in terms of the associations between RML and co-use among drinkers and marijuana users, although the statewide study also found a positive association between RML and co-use in the general student population (Paschall et al., 2022). Our finding regarding the positive association between RML and marijuana use is also consistent with previous studies in Oregon (Paschall & Grube, 2020) and California (Paschall et al., 2021) but is not consistent with a national study that found a decrease in marijuana use among adolescents after RML (Anderson et al., 2019) and a study in Washington State that found post-RML decreases in marijuana use among 8th and 10th graders, and no change among 12th graders (Dilley et al., 2019). These differences may reflect state-specific variation in effects of RML on marijuana use among underage youth, differences in how RML was implemented, or possible differences in state-level sample representativeness in studies based on national surveys such as the Youth Risk Behavior Survey versus statewide surveys such as the CHKS. Further research is needed to better understand these discrepancies.

Limitations

The CHKS sample may not be representative of all high school students in the 38 cities or California. Of note, however, the school-level response rates for the CHKS are acceptable, and the overall CHKS sample characteristics align well with California Department of Education enrollment data for the sampled grade levels. The use of sample weights further reduces this concern. Although the sample does not include students who have dropped out of school or those absent on the day of administration, research suggests that these groups, even when they have substantially higher

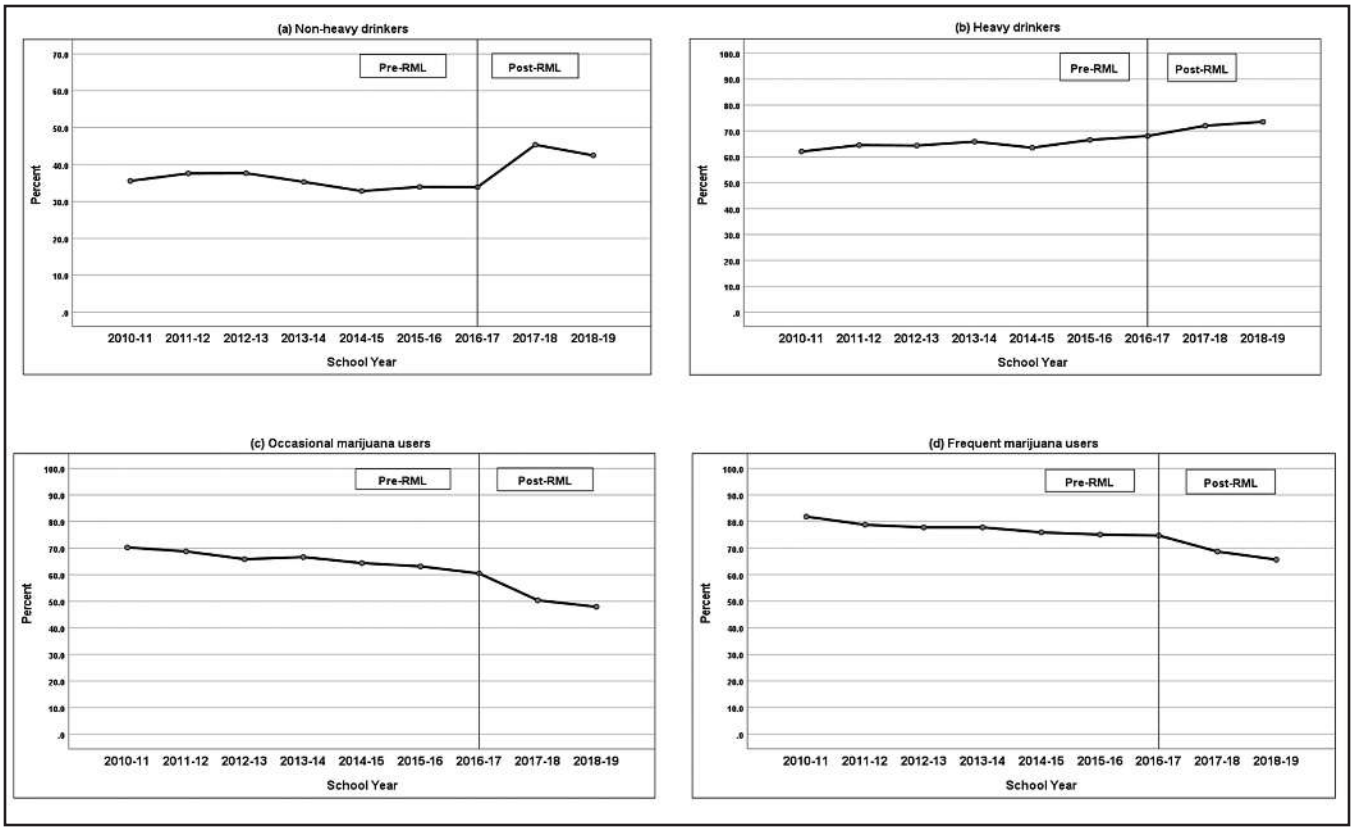

FIGURE 2. Trends in the prevalence of past-30-day alcohol and marijuana co-use among (a) non–heavy drinkers, (b) heavy drinkers, (c) occasional marijuana users, and (d) frequent marijuana users. RML = recreational marijuana legalization.

substance use rates, are likely to have minimal influence on overall prevalence estimates given their relatively small numbers in the population (e.g., Miech et al., 2021, Appendix A). Moreover, any biases in the prevalence estimates introduced by excluding these youth are consistent across the years of the CHKS and should not confound the observed associations of co-use with RML or availability. Bias in responses to alcohol and marijuana use questions may have occurred because of social desirability (e.g., underreporting) and errors in recall. The anonymity of the CHKS and the use of 30-day recall measures help to mitigate these concerns. The data consisted of repeated cross-sections, which limits our ability to assess within-person changes in marijuana and alcohol use and co-use. Our measures of marijuana retail outlet density are incomplete as they only included legally licensed outlets. This is an important consideration given the robust illicit market in California (Firth et al., 2022), which may serve as an important source of marijuana to underage youth. Thus, our counts of cannabis retail outlets are likely underestimates, and we may be underestimating the moderating and independent effects of marijuana availability. However, we expect that cities with more legal marijuana retail outlets would also have more illicit outlets because of consumer demand. Finally, some concerns can be raised about the generalizability of the results to other states and cities. We believe that our findings can help state and local decision-makers in other states by informing them of potentially important issues to consider (e.g., limitations on outlet densities) when developing policies relating to cannabis legalization. Importantly, similar findings emerge across states and countries in other policy areas (e.g., alcohol and tobacco regulation) regarding the associations of increased availability and normalization with use, suggesting that the underlying processes do generalize, even if the contexts are very different. In addition, our findings regarding associations of RML with marijuana use and co-use with alcohol are similar to those observed in a California statewide study (Paschall et al., 2021) and an Oregon statewide study (García-Ramírez et al., 2021), providing evidence for the external validity.

Conclusions

This study improves our understanding of the possible effects of legalizing adult recreational marijuana use and retail marijuana availability on adolescents' co-use of alcohol and marijuana. Although the cannabis environment in California differs from that in other states, findings from this study may nonetheless help inform policy decision-making

in states considering the passage of RML, and among local policymakers tasked with implementing and regulating cannabis legalization. Given that among the full sample of high school students, the effect of RML was strongest in the cities with relatively high marijuana outlet density, attention should be paid to policies that limit retail availability. Regulatory policies should be considered at the state level and in local jurisdictions with zoning authority over retail marijuana businesses. Finally, the findings can help to inform future research on possible effects of RML and marijuana retail outlet density on alcohol and marijuana co-use, and guide research on mechanisms underlying these associations.

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