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Impact of state-level cannabis legalization on poly use of alcohol and cannabis in the United States, 2004–2017

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ABSTRACT

Background: Cannabis policy has shifted toward legalization in many parts of the United States (US). While attention has been focused on whether legalization will lead to changes in cannabis use, it is conceivable that legalization will also affect use of substances that individuals frequently use with cannabis. This study assessed whether cannabis legalization impacted the prevalence of poly use of cannabis and alcohol from 2004 to 2017 and estimated the prevalence of cannabis and alcohol poly use in 2017.

Methods: Public and restricted-use data from the US 2004–2017 National Survey on Drug Use and Health were analyzed. Data on past-month cannabis and alcohol use were assessed each year. Cannabis legalization was determined by the presence or absence of medical marijuana laws (MML) and recreational marijuana laws (RML) in each state. Difference-in-difference approach was used to estimate the association of MML and RML on cannabis and alcohol use overall and by sociodemographic subgroups (e.g., age, income, education).

Results: Between 2004 and 2017, poly use of cannabis and alcohol increased while alcohol-only use decreased. MML were associated with increases in poly use only among adults over age 50 and among those with higher annual incomes and higher education, while RML were associated with increases in poly use broadly among adults across sociodemographic groups.

Conclusions: Legalization of cannabis was associated with increases in cannabis-alcohol poly use in the US. RML were associated with increases across demographics, while the impact of MML was more limited to certain sociodemographic groups.

1. Introduction

In the past two decades, cannabis policy in the United States (US) and other countries has shifted greatly toward legalization. While cannabis remains a federally illicit substance in the US, many states have legalized cannabis use for medicinal and/or recreational purposes. Simultaneously, cannabis use has been increasing (Cerda et al., 2020; Pacek et al., 2020; Smart and Pacula, 2019), at least among adults (Sarvet et al., 2018). This increase may be related to decreasing perceptions of risks related to cannabis use (Pacek et al., 2015, 2020; Wen et al., 2019), changes in societal-level attitudes (Keyes et al., 2011), as well as reduced price and increased availability (Hall and Lynskey, 2016).

Societal shifts in cannabis use may impact use of other substances that are commonly used with cannabis. In fact, a substantial proportion of US adolescents use both cannabis and alcohol (Assanangkornchai et al., 2018; Weinberger et al., 2020; Schlienz and Lee, 2018). Among adolescents and young adults, over half of cannabis users report simultaneous use of alcohol and cannabis (i.e., use of both occurs in the same sitting; Haas et al., 2015; Subbaraman, 2016). In observational studies, adults who use versus do not use cannabis tend to consume more alcohol (Reiman, 2009) and cannabis may be purposefully used to enhance alcohol's effects (Lukas et al., 1992; Lukas and Orozco, 2001; Patrick et al.,

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2017).

When cannabis and alcohol are used together, the adverse effects of use of each substance are amplified and poly use can have deleterious consequences (Kelly et al., 2004; Patrick et al., 2017; Schlienz and Lee, 2018; Terry-McElrath et al., 2013, 2014; Yurasek et al., 2017). These consequences include engaging in risky behaviors such as driving while impaired (Asbridge et al., 2012; Briere et al., 2011; Sewell et al., 2009), increased odds of negative social consequences (Subbaraman and Kerr, 2015), and increased mental health problems and worse mental health treatment outcomes (Briere et al., 2011; Harrington et al., 2012; Shillington and Clapp, 2001).

As cannabis policy in the US and other countries continues to evolve, assessing population trends in the poly use of cannabis and alcohol is imperative to inform policy makers (Guttmannova et al., 2016). For example, a scenario in which cannabis use increases alongside decreases in alcohol use and poly use (i.e., substitution of alcohol with cannabis) would have very different implications regarding polysubstance toxicity, traffic safety, injury prevention, and even cannabis or alcohol tax revenue, compared with a scenario in which the poly use of these substances increases (i.e., complementary use). A review of research on cannabis policies (eight studies on laws related to the decriminalization of cannabis, six studies on medical marijuana laws (MML), and one study on recreational marijuana laws (RML)) and alcohol use through 2015 suggested evidence for both substitution and complementarity (Guttmannova et al., 2016). For example, MML in 15 US states were associated with decreases in alcohol consumption (Anderson et al., 2013), suggesting substitution, while MML in 18 states were associated with increases in cannabis use, binge drinking and simultaneous use of cannabis and alcohol (Wen et al., 2015), suggesting complementarity. While there is less research on RML, Veligati et al. (2020) found no changes in alcohol sales from 1990 to 2016 with either MML or RML. Alcohol consumption or alcohol-cannabis poly consumption were not examined in this study. To our knowledge, no studies to date have examined the impact of both MML and RML on poly consumption of alcohol and cannabis (i.e., use of both by the same person), which is a different question than whether use of alcohol, per se, has increased or decreased. In addition, there is little information on how these trends differ by sociodemographic groups, which would aid in identifying the most vulnerable groups who may warrant focused attention through future research and policy.

The current study aims to begin to fill this knowledge gap. First, we investigated the prevalence of cannabis and alcohol poly use by cannabis legalization status from 2004–2017. Second, we investigated whether legalization of cannabis for recreational or medical use was associated with changes in the prevalence of cannabis and alcohol poly use among persons ages 12 and older in the US from 2004 to 2017, overall and across sociodemographic subgroups.

2. Material and methods

2.1. Data source and study population

The National Survey on Drug Use and Health (NSDUH) is an annual cross-sectional survey based on a multistage probability sample of the US non-institutionalized population. Public and restricted-use data from the 2004–2017 NSDUH were combined providing an analytic sample ages 12 and older of $n = 56{,}276$ for 2017 and a total combined sample from 2004 to 2017 of $n = 783{,}663$. Sampling weights for the NSDUH were computed to control for unit-level and individual-level nonresponse and adjusted to ensure consistency with population estimates obtained from the U.S. Census Bureau. To use 14 years of combined data, a new weight was created upon aggregating the 14 data sets by dividing the original weight by the total number of data sets. Additional information regarding the complex sampling weight methodology for the NSDUH can be found elsewhere (Center for Behavioral Health Statistics and Quality, 2018). State of residence was used to determine the effects of state-level cannabis laws. Individual state of residence information is a restricted-use variable and was accessed through the National Center for Health Statistics (NCHS) Research Data Center. Analysis of de-identified data from the survey is exempt from federal regulations for the protection of human research participants. Analysis of restricted data through the Research Data Center is approved by the NCHS Ethics Review Board.

2.2. Measures

2.2.1. Cannabis legalization

MML/RML were operationalized using two different approaches. In the first approach, to examine the prevalence of poly use over time (Aim 1), MML/RML were defined as fixed categories over time: 1) states that ever passed RML (AK, CA, CO, DC, MA, ME, MI, NV, OR, VT, and WA); 2) states that passed MML prior to 2011 (AZ, DE, HI, MT, NJ, NM, and RI); 3) states that passed MML after 2011 (AR, CT, FL, IL, LA, MD, MN, MO, ND, NH, NY, OH, OK, PA, UT, and WV); and 4) states that have yet to pass MML or RML (AL, GA, IA, ID, IN, KS, KY, MS, NC, NE, SC, SD, TN, TX, VA, WI, and WY). A distinction was made between states that had passed MML before versus after 2011 due to observed heterogeneity in MML based on duration of passage (Williams et al., 2016). In the second approach, to examine whether MML and RML were associated with changes in the prevalence of cannabis and alcohol poly use from pre- to post-enactment (Aim 2), MML and RML were measured with two time-varying categorical variables, respectively, that were coded as "0" for years with no enacted law and coded as "1″ for years after enactment for each state. If a law was passed in the first half of a year, it was classified as "after enactment" for that year. If a law was passed in the latter half of a year, it was classified as "before enactment" for that year and "after enactment" for the next year consistent with other studies (e.g., Kim et al., 2016; Wen et al., 2015). While no states enacted RML prior to MML, all nine states with RML also had MML that were enacted in earlier years. For these nine states, MML were enacted an average of 14.56 years before RML (range 4–20; all but one state enacted MML 12 or more years prior to RML).

2.2.2. Cannabis and alcohol use categories

Respondents reported how long it had been since their last cannabis use and their last alcohol use. Individuals who reported using cannabis "within the past 30 days" were classified as past-month cannabis users. Similarly, individuals who reported using alcohol "within the past 30 days" were classified as past-month alcohol users. From these two items, four mutually-exclusive use categories were created: 1) past-month non-use of cannabis or alcohol, 2) past-month alcohol-only use (i.e., no past-month cannabis use), 3) past-month cannabis-only use (i.e., no past-month alcohol use), and 4) past-month poly use of cannabis and alcohol.

2.2.3. Sociodemographic variables

Sociodemographic variables for this study included age (12–17, 18−25, 26−34, 35−49, 50+), gender (male, female), marital status (married, widowed/divorced/separated, never married), total annual household income (<$20,000, $20,000–$74,999, ≥$75,000), race/ethnicity (non-Hispanic (NH) White, NH Black, Hispanic, NH Other [i.e., Native American/Alaska Native, Native Hawaiian/Other Pacific Islander, Asian, more than one race]), and education (less than high school, high school graduate, some college, college graduate or higher).

2.3. Statistical analysis

First, to examine the prevalences of alcohol and cannabis poly use between 2004–2017, prevalence of use was determined by fixed cannabis legalization groups (as described above). For each group, separate logistic regression models were fit using a continuous term for calendar year and all individual sociodemographic covariates. Differences in trends across each fixed cannabis legalization category were

examined by including an interaction term between calendar year and RML/MML status.

Second, we assessed the impact of MML and RML on the prevalence of past-month poly use of cannabis and alcohol using difference-in-difference (DiD) models. The DiD method estimated the effect of legalization by comparing changes in the outcome (i.e., poly use of alcohol and cannabis) before and after the enactment of a law in states passing laws contrasted with the same difference in states whose legalization status did not change. DiD estimates are only reflective of states that have changed status within the study period. Thus, only states that have a status change for MML (from "0" to "1") were included among the MML "exposed" group (AZ, AK, CT, DC, DE, FL, IL, LA, MA, MD, MI, MN, MO, NH, ND, NJ, NM, NY, OH, PA, RI, VT, WV). Similarly, only states that have a status change for RML (from "0" to "1") were included among the RML "exposed" group (AK, CA, CO, DC, MA, ME, NV, OR, WA). All other states contributed as "unexposed" and were used to estimate the "counterfactual" trend that treatment states would have demonstrated had they not been exposed. Two-way fixed effects models that included fixed effects for calendar year and state of residence, as well as time-varying indicators for MML and RML, were estimated to get crude DiD estimates. Adjusted models included all individual covariates. DiD estimates across sociodemographic strata were also explored by including interaction terms between the sociodemographic factor of interest and both time-varying indicators for MML and RML. Stratum-specific DiD estimates were obtained using the "effects" command. All analyses were done on complete-case basis, conducted using SAS-callable SUDAAN, and incorporated survey weights for all analyses.

3. Results

3.1. Trends in poly use patterns by fixed cannabis legalization groups (Table 1)

The prevalence of past-month cannabis and alcohol poly use increased from 2004 to 2017 across states with all types of cannabis legalization, with the most rapid increase in states with RML (6.06% in 2004 to 10.71% in 2017). The prevalence of past-month cannabis-only use increased between 2004 and 2017 across states with all types of cannabis legalization, with the most rapid increase in states with MML passed before 2011 (0.96% in 2004 to 2.42% in 2017), followed by states with RML (1.08% in 2004 to 2.75% in 2017). The prevalence of past-month alcohol-only use declined from 2004 to 2017 across states with all types of cannabis legalization, with the most rapid decline in states with RML (46.72% in 2004 to 44.27% in 2017).

3.2. Difference-in-difference (DiD) estimates for MML and past-month cannabis and alcohol use

3.2.1. MML and past-month poly use of cannabis and alcohol (Table 2)

Overall, MML were associated with increased past-month cannabis-alcohol poly use (adjusted odds ratio (aOR) = 1.064, 95% confidence interval (CI): 1.009–1.122). Overall, MML enactment and subsequent cannabis-alcohol poly use varied by age, marital status, income, race/ethnicity, and education (all $ps < 0.001$) but not by gender ($p = 0.08$). Regarding age, MML enactment was associated with an increase in poly use among those ages 50+ years (aOR = 1.417, 95% CI: 1.256–1.599) and a decrease in poly use among adolescents (aOR = 0.914, 95% CI: 0.851−0.982). No other age group showed any significant association between MML and poly use. Regarding marital status, MML enactment was not associated with changes in poly use among never married respondents but was associated with increased poly use among those married and widowed/separated/divorced. Regarding income, MML enactment was associated with an increase in poly use only among respondents in the highest income group (aOR = 1.140, 95% CI: 1.072–1.212). Regarding race/ethnicity, MML enactment led to an increase in poly use among NH White and Black individuals, but not among other racial groups. Regarding education, MML led to an increase in poly use among respondents with a college degree or above (aOR = 1.219, 95% CI: 1.123–1.323) and a decrease in poly use among those with less than a high school education (aOR = 0.837, 95% CI: 0.763−0.917).

3.2.2. MML and past-month use of cannabis only (no alcohol) (Table 3)

Overall, MML enactment was associated with an increase in past-month use of cannabis only (aOR = 1.119, 95% CI: 1.011–1.238). The association between MML enactment and past-month cannabis-only use significantly varied by age, such that the greatest increases were reported among those ages 50+ years (aOR = 1.763, 95% CI: 1.455–2.136). The ages 35−49 group was the only other group with a significant positive association, and a significant negative association was observed for adolescents (aOR = 0.878, 95% CI: 0.783−0.985). The association between MML enactment and past-month cannabis-only use also significantly varied by marital status, such that the only significant increase was reported among those widowed/divorced/separated (aOR = 1.532, 95% CI: 1.262–1.860). The MML association with cannabis-only use varied by education, such that the greatest increase was reported among those with a college degree or above (aOR = 1.446, 95% CI: 1.107–1.890).

3.2.3. MML and past-month use of alcohol only (no cannabis) (Table 4)

Overall, MML enactment was associated with a decrease in past-month use of alcohol only (aOR = 0.951, 95% CI: 0.919−0.984). The association between MML enactment and past-month use of alcohol significantly varied by age, gender, marital status, income, and race/ethnicity. Men, all age groups except those over 50, never married or windowed/divorced/separated respondents, respondents reporting the lowest two incomes level, and individuals in all racial/ethnic groups except NH White reported decreases in past-month use of alcohol-only.

3.3. DiD estimates for RML and past-month cannabis and alcohol use

3.3.1. RML and past-month poly use of cannabis and alcohol (Table 2)

Overall, RML enactment was associated with increased past-month cannabis-alcohol poly use (aOR = 1.246, 95% CI: 1.140–1.362). RML enactment and subsequent changes in cannabis-alcohol poly use varied by age, gender, and marital status ($ps < 0.01$) but did not significantly differ by income, race/ethnicity, or education. Regarding age, the impact of RML enactment was greatest among respondents ages 35−49 years old (aOR = 1.506, 95% CI: 1.316–1.723). While poly use increased among respondents ages 25 and older, no change was observed among respondents ages 18−25 and a decline was observed among adolescents. Regarding gender, RML enactment was associated with increased cannabis and alcohol poly use among both men and women with significantly greater odds of increase among women (aOR = 1.388, 95% CI: 1.231–1.564) relative to men (aOR = 1.154, 95% CI: 1.043–1.277). Finally, regarding marital status, RML enactment was associated with increased poly use for those who were married and widowed/divorced/separated, with no significant change for those who were never married.

3.3.2. RML and past-month use of cannabis-only (no alcohol) (Table 3)

The association between RML enactment and past-month use of cannabis only was not significant overall (aOR = 1.131, 95% CI: 0.968–1.320), but it did significantly vary by age, such that the only significant increases associated with RML enactment were found among those ages 25–34 (aOR = 1.340, 95% CI: 1.021–1.758) and those ages 50+ (aOR = 1.623, 95% CI: 1.192–2.208).

3.3.3. RML and past-month use of alcohol-only (no cannabis) (Table 4)

Similar to MML enactment, RML enactment was associated with a decrease in past-month use of alcohol only (aOR = 0.933, 95% CI: 0.878−0.992). For RML enactment, the association with past-month

Table 1
Prevalence of alcohol and cannabis use by state-level cannabis legalization status from 2004 to 2017 (NSDUH, ages 12 and older, total combined sample from 2004 to 2017, $n = 783{,}663$).

No past-month alcohol or cannabis use															
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	aOR (95% CI)
RML	46.14	44.99	45.66	45.36	44.41	43.84	43.82	44.88	44.58	44.61	42.99	43.41	44.65	42.27	0.994 (0.990, 0.998)
MML 2004–2011	46.91	43.42	46.29	45.70	46.52	46.51	44.95	44.82	45.43	44.74	42.63	45.95	45.56	46.25	1.000 (0.991, 1.009)
MML post 2011	47.93	46.64	47.00	46.13	46.60	46.34	47.28	46.09	45.51	44.73	44.52	45.06	45.88	45.44	0.997 (0.994, 1.000)
No MML	52.57	50.66	51.87	52.64	51.15	50.48	49.55	49.75	49.58	50.30	49.74	50.73	51.09	50.26	1.001 (0.997, 1.005)
Differential time trend: year as continuous vs. RML/MML status (4 categories)															$F(3) = 1.046$ ($p = 0.371$)
Differential time trend: RML vs. no MML															$F(1) = 1.582$ ($p = 0.114$)
Differential time trend: MML 2004–2011 vs. no MML															$F(1) = 0.198$ ($p = 0.843$)
Differential time trend: MML post-2011 vs. no MML															$F(1) = 1.069$ ($p = 0.285$)
Differential time trend: RML vs. MML post-2011															$F(1) = 0.693$ ($p = 0.488$)
Differential time trend: MML 2004–2011 vs. MML post-2011															$F(1) = 0.778$ ($p = 0.437$)
Differential time trend: RML vs. MML 2004–2011															$F(1) = 1.119$ ($p = 0.263$)

Past-month alcohol use, no past-month cannabis use															
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	aOR (95% CI)
RML	46.72	47.87	46.78	47.53	47.95	47.41	46.91	45.79	45.55	45.01	46.04	45.62	42.69	44.27	0.981 (0.977, 0.985)
MML 2004–2011	47.54	50.55	48.43	48.55	47.34	47.29	47.79	47.83	47.45	47.79	48.69	46.24	46.10	44.25	0.985 (0.977, 0.994)
MML post 2011	46.01	47.16	47.16	48.18	47.66	47.10	46.57	47.29	47.53	48.29	47.50	46.84	45.85	45.51	0.990 (0.987, 0.993)
No MML	42.12	44.46	42.88	42.51	43.49	44.21	44.70	44.65	44.83	43.66	43.52	42.69	42.08	42.62	0.990 (0.987, 0.994)
Differential time trend: year as continuous vs. RML/MML status (4 categories)															$F(3) = 5.957$ ($p < 0.001$)
Differential time trend: RML vs. no MML															$F(1) = 3.679$ ($p < 0.001$)
Differential time trend: MML 2004–2011 vs. no MML															$F(1) = 1.373$ ($p = 0.170$)
Differential time trend: MML post-2011 vs. no MML															$F(1) = 0.284$ ($p = 0.777$)
Differential time trend: RML vs. MML post-2011															$F(1) = 3.722$ ($p < 0.001$)
Differential time trend: MML 2004–2011 vs. MML post-2011															$F(1) = 1.266$ ($p = 0.206$)
Differential time trend: RML vs. MML 2004–2011															$F(1) = 0.836$ ($p = 0.403$)

PAST-month cannabis use, no past-month alcohol use															
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	aOR (95% CI)
RML	1.08	1.08	1.21	1.10	1.35	1.35	1.60	1.92	1.94	1.90	2.27	2.69	3.12	2.75	1.106 (1.091, 1.120)
MML 2004–2011	0.96	0.69	0.87	0.70	0.60	1.03	1.14	1.73	0.98	2.36	1.80	1.57	1.88	2.42	1.112 (1.090, 1.135)
MML post 2011	0.84	0.98	0.81	0.95	0.79	1.09	1.04	1.08	1.13	1.16	1.51	1.47	1.74	1.91	1.082 (1.071, 1.094)
No MML	0.75	0.83	0.82	0.85	0.84	0.89	1.14	1.18	1.19	1.01	1.30	1.59	1.59	1.69	1.080 (1.068, 1.094)
Differential time trend: year as continuous vs. RML/MML status (4 categories)															$F(3) = 4.549$ ($p = 0.003$)
Differential time trend: RML vs. no MML															$F(1) = 2.735$ ($p = 0.006$)
Differential time trend: MML 2004–2011 vs. no MML															$F(1) = 2.414$ ($p = 0.016$)
Differential time trend: MML post-2011 vs. no MML															$F(1) = 0.102$ ($p = 0.919$)
Differential time trend: RML vs. MML post-2011															$F(1) = 2.887$ ($p = 0.004$)
Differential time trend: MML 2004–2011 vs. MML post-2011															$F(1) = 2.430$ ($p = 0.015$)
Differential time trend: RML vs. MML 2004–2011															$F(1) = 0.304$ ($p = 0.761$)

Past-month alcohol and cannabis use															
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	aOR (95% CI)
RML	6.06	6.05	6.35	6.01	6.29	7.40	7.67	7.40	7.93	8.48	8.70	8.28	9.54	10.71	1.055 (1.048, 1.062)
MML 2004–2011	4.59	5.33	4.41	5.05	5.55	5.17	6.12	5.62	6.14	5.12	6.88	6.24	6.46	7.07	1.037 (1.025, 1.049)
MML post 2011	5.22	5.22	5.02	4.74	4.94	5.47	5.10	5.55	5.83	5.82	6.46	6.62	6.54	7.14	1.035 (1.030, 1.040)
No MML	4.57	4.05	4.42	4.17	4.52	4.42	4.60	4.42	4.40	5.03	5.44	4.99	5.24	5.43	1.025 (1.018, 1.031)
Differential time trend: year as continuous vs. RML/MML status (4 categories)															$F(3) = 12.926$ ($p < 0.001$)
Differential time trend: RML vs. no MML															$F(1) = 6.114$ ($p < 0.001$)
Differential time trend: MML 2004–2011 vs. no MML															$F(1) = 1.539$ ($p = 0.124$)
Differential time trend: MML post-2011 vs. no MML															$F(1) = 2.509$ ($p = 0.012$)
Differential time trend: RML vs. MML post-2011															$F(1) = 4.470$ ($p < 0.001$)
Differential time trend: MML 2004–2011 vs. MML post-2011															$F(1) = 0.018$ ($p = 0.986$)
Differential time trend: RML vs. MML 2004–2011															$F(1) = 2.772$ ($p = 0.006$)

Abbreviations: aOR adjusted odds ratio; CI confidence interval; MML medical marijuana laws; NSDUH, National ; Survey on Drug Use and Health; RML recreational marijuana laws.

Note: States are defined by cannabis legalization groups fixed over time: RML: ever passed RML (AK, CA, CO, DC, MA, ME, MI, NV, OR, VT, and WA); MML 2004−2011: passed MML prior to 2011 (AZ, DE, HI, MT, NJ, NM, and RI); MML post-2011: passed MML after 2011 (AR, CT, FL, IL, LA, MD, MN, MO, ND, NH, NY, OH, OK, PA, UT, and WV); No MML: yet to pass MML or RML (AL, GA, IA, ID, IN, KS, KY, MS, NE, NC, SC, SD, TN, TX, VA, WI, and WY).

Table 2
DiD estimates for changes in past-month poly use of cannabis and alcohol after passage of MML and RML (NSDUH, ages 12 and older, total combined sample from 2004 to 2017 $n = 783{,}663$).

	Adjusted DiD estimate[a]	
	MML aOR (95% CI)	RML[b] aOR (95% CI)
Overall	1.064 (1.009, 1.122)	1.246 (1.140, 1.362)
Age		
12−17	0.914 (0.851, 0.982)	0.714 (0.596, 0.854)
18−25	0.975 (0.922, 1.031)	0.998 (0.896, 1.112)
26−34	1.048 (0.972, 1.131)	1.303 (1.131, 1.502)
35−49	1.044 (0.967, 1.127)	1.506 (1.316, 1.723)
50+	1.417 (1.256, 1.599)	1.403 (1.135, 1.734)
	$F(4) = 14.002$	$F(4) = 15.604$
	($p < 0.001$)	($p < 0.001$)
Gender		
Male	1.044 (0.984, 1.107)	1.154 (1.043, 1.277)
Female	1.097 1.031, 1.167)	1.388 (1.231, 1.564)
	$F(1) = 2.983$	$F(1) = 7.730$
	($p = 0.084$)	($p = 0.005$)
Marital status		
Married	1.227 (1.127, 1.336)	1.449 (1.258, 1.668)
Widowed/divorced/ separated	1.133 (1.017, 1.261)	1.543 (1.275, 1.867)
Never married	0.988 (0.933, 1.047)	1.063 (0.955, 1.184)
	$F(2) = 16.964$	$F(2) = 10.488$
	($p < 0.001$)	($p < 0.001$)
Income		
<$20,000	1.014 (0.945, 1.087)	1.209 (1.022, 1.430)
$20,000-$74,000	0.984 (0.919, 1.054)	1.279 (1.123, 1.457)
≥$75,000	1.140 (1.072, 1.212)	1.227 (1.096, 1.374)
	$F(2) = 11.004$	$F(2) = 0.216$
	($p < 0.001$)	($p = 0.805$)
Race/ethnicity		
Non-Hispanic White	1.093 (1.033, 1.158)	1.243 (1.122, 1.377)
Non-Hispanic Black	1.122 (1.022, 1.233)	1.032 (0.792, 1.344)
Hispanic	0.902 (0.817, 0.995)	1.286 (1.086, 1.522)
Other	0.877 (0.776, 0.990)	1.423 (1.166, 1.738)
	$F(3) = 9.440$	$F(3) = 1.430$
	($p < 0.001$)	($p = 0.232$)
Education		
Less than high school	0.837 (0.763, 0.917)	1.246 (1.001, 1.551)
High school or equivalent	1.046 (0.971, 1.127)	1.106 (0.948, 1.289)
Some college	1.060 (0.989, 1.136)	1.194 (1.049, 1.359)
College graduate or above	1.219 (1.123, 1.323)	1.401 (1.200, 1.635)
	$F(3) = 16.454$	$F(3) = 1.753$
	($p < 0.001$)	($p = 0.154$)

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval; DiD, difference-in-difference; MML, medical marijuana laws; NSDUH, National Survey on Drug Use and Health; RML, recreational marijuana laws.

[a] Analyses were adjusted for all other sociodemographic factors listed in the table.

[b] All states with RML had MML that were passed prior to the RML.

Table 3
DiD estimates for changes in past-month use of cannabis only (no alcohol) after passage of MML and RML (NSDUH, ages 12 and older, total combined sample from 2004 to 2017 $n = 783{,}663$).

	Adjusted DiD estimate[a]	
	MML aOR (95% CI)	RML[b] aOR (95% CI)
Overall	1.119 (1.011, 1.238)	1.131 (0.968, 1.320)
Age		
12−17	0.878 (0.783, 0.985)	0.752 (0.608, 0.930)
18−25	0.942 (0.836, 1.063)	0.785 (0.639, 0.964)
26−34	0.951 (0.811, 1.114)	1.340 (1.021, 1.758)
35−49	1.215 (1.047, 1.411)	1.024 (0.794, 1.320)
50+	1.763 (1.455, 2.136)	1.623 (1.192, 2.208)
	$F(4) = 15.528$	$F(4) = 8.947$
	($p < 0.001$)	($p < 0.001$)
Gender		
Male	1.103 (0.986, 1.233)	1.055 (0.881, 1.263)
Female	1.144 (1.013, 1.293)	1.258 (1.013, 1.562)
	$F(1) = 0.386$ ($p = 0.534$)	$F(1) = 1.990$
		($p = 0.158$)
Marital Status		
Married	1.157 (0.978, 1.370)	1.490 (1.079, 2.059)
Widowed/divorced/ separated	1.532 (1.262, 1.860)	0.831 (0.580, 1.190)
Never married	1.011 (0.887, 1.152)	1.084 (0.881, 1.334)
	$F(2) = 9.765$ ($p < 0.001$)	$F(2) = 2.637$
		($p = 0.072$)
Income		
<$20,000	1.144 (1.006, 1.301)	1.095 (0.856, 1.401)
$20,000–$74,000	1.120 (0.984, 1.276)	1.103 (0.891, 1.366)
≥$75,000	1.097 (0.966, 1.245)	1.183 (0.915, 1.530)
	$F(2) = 0.182$ ($p = 0.834$)	$F(2) = 0.123$
		($p = 0.885$)
Race/ethnicity		
Non-Hispanic White	1.180 (1.057, 1.316)	1.122 (0.942, 1.337)
Non-Hispanic Black	1.064 (0.899, 1.259)	1.308 (0.848, 2.018)
Hispanic	0.964 (0.810, 1.148)	1.227 (0.821, 1.834)
Other	0.973 (0.772, 1.226)	0.933 (0.639, 1.361)
	$F(3) = 2.340$ ($p = 0.072$)	$F(3) = 0.688$
		($p = 0.559$)
Education		
Less than high school	0.947 (0.801, 1.121)	0.965 (0.682, 1.365)
High school or equivalent	1.212 (1.046, 1.405)	1.077 (0.779, 1.489)
Some college	1.123 (0.960, 1.313)	1.167 (0.913, 1.490)
College graduate or above	1.446 (1.107, 1.890)	1.363 (0.907, 2.049)
	$F(3) = 4.222$ ($p = 0.005$)	$F(3) = 0.589$
		($p = 0.622$)

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval; DiD, difference-in-difference; MML, medical marijuana laws; NSDUH, National Survey on Drug Use and Health; RML, recreational marijuana laws.

[a] Analyses were adjusted for all other sociodemographic factors listed in the table.

[b] All states with RML had MML that were passed prior to the RML.

alcohol-only use significantly varied by age, gender and marital status, such that men, all age groups except those over 50, and never married respondents reported decreases in past-month use. RML was not associated with any changes in past-month alcohol-only use among women and those over 50 years old.

4. Discussion

The purpose of this study was to estimate the prevalence of cannabis and alcohol poly use in the US and to investigate whether cannabis legalization for medical and recreational use was associated with changes in the prevalence of cannabis and alcohol poly use over time. Several key findings are notable. First, RML and MML enactment were associated with an overall increase in cannabis and alcohol poly use from pre- to post-enactment. Second, RML enactment had a broad impact and was associated with increases in poly use across most age and other sociodemographic subgroups while enactment of MML was associated with increases in poly use mainly among respondents over 50, with higher incomes and higher levels of formal education. Third, MML enactment was associated with overall increased cannabis-only use while RML enactment was not related to significant changes in cannabis-only use. MML enactment was associated with increases in cannabis-only use predominantly among respondents ages 35 and over and among those with the highest level of formal education. Fourth, MML and RML enactment were related to decreases in alcohol-only use overall and among all age groups except for respondents over 50.

Prior work suggested that MML and RML adoption were associated with increases in cannabis use among adults (Sarvet et al., 2018). Our

Table 4
DiD estimates for changes in past-month use of alcohol only (no cannabis) after passage of MML and RML (NSDUH, ages 12 and older, total combined sample from 2004 to 2017 n = 783,663).

	Adjusted DiD estimate[a]	
	MML aOR (95% CI)	RML[b] aOR (95% CI)
Overall	0.951 (0.919, 0.984)	0.933 (0.878, 0.992)
Age		
12–17	0.837 (0.796, 0.881)	0.658 (0.565, 0.768)
18–25	0.809 (0.778, 0.842)	0.799 (0.736, 0.868)
26–34	0.877 (0.834, 0.922)	0.786 (0.703, 0.879)
35–49	0.948 (0.909, 0.989)	0.882 (0.802, 0.969)
50+	1.041 (0.996, 1.088)	1.097 (0.998, 1.205)
	$F(4) = 37.310$	$F(4) = 11.739$
	($p < 0.001$)	($p < 0.001$)
Gender		
Male	0.899 (0.864, 0.936)	0.867 (0.799, 0.941)
Female	1.001 (0.964, 1.038)	1.001 (0.926, 1.082)
	$F(1) = 32.951$	$F(1) = 7.499$
	($p < 0.001$)	($p = 0.006$)
Marital Status		
Married	1.017 (0.976, 1.060)	1.017 (0.935, 1.106)
Widowed/divorced/ separated	0.944 (0.893, 0.997)	0.941 (0.824, 1.075)
Never married	0.843 (0.810, 0.878)	0.799 (0.737, 0.867)
	$F(2) = 47.684$	$F(2) = 10.448$
	($p < 0.001$)	($p < 0.001$)
Income		
<$20,000	0.867 (0.823, 0.914)	0.889 (0.777, 1.017)
$20,000-$74,000	0.952 (0.912, 0.995)	0.925 (0.837, 1.022)
≥$75,000	0.974 (0.938, 1.012)	0.942 (0.875, 1.013)
	$F(2) = 10.901$	$F(2) = 0.307$
	($p < 0.001$)	($p = 0.736$)
Race/ethnicity		
Non-Hispanic White	0.984 (0.949, 1.020)	0.892 (0.834, 0.955)
Non-Hispanic Black	0.850 (0.797, 0.907)	0.985 (0.759, 1.277)
Hispanic	0.911 (0.860, 0.966)	0.976 (0.858, 1.110)
Other	0.898 (0.828, 0.975)	1.076 (0.929, 1.247)
	$F(3) = 8.887$	$F(3) = 2.291$
	($p < 0.001$)	($p = 0.076$)
Education		
Less than high school	0.911 (0.858, 0.968)	1.030 (0.874, 1.214)
High school or equivalent	0.953 (0.910, 0.998)	0.873 (0.786, 0.971)
Some college	0.936 (0.896, 0.978)	0.913 (0.826, 1.009)
College graduate or above	0.968 (0.922, 1.015)	0.958 (0.872, 1.052)
	$F(3) = 1.278$	$F(3) = 1.195$
	($p = 0.280$)	($p = 0.310$)

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval; DiD, difference-in-difference; MML, medical marijuana laws; NSDUH, National Survey on Drug Use and Health; RML, recreational marijuana laws.

[a] Analyses were adjusted for all other sociodemographic factors listed in the table.

[b] All states with RML had MML that were passed prior to the RML.

findings confirm and extend this work by being the first study to show that cannabis legalization may not only be associated with an increase in cannabis use, but also with increases in cannabis and alcohol poly use, as well as decreases in alcohol-only use. These findings suggest that RML and/or MML enactment may confer unintended consequences such as increased cannabis and alcohol poly use, which is associated with additional increased risks including mental health problems, driving-related injuries, several cancers and premature mortality (Asbridge et al., 2012; Perez-Reyes et al., 1988; Sewell et al., 2009). In general, a full understanding of the consequences of cannabis laws requires looking beyond cannabis use alone to examine cannabis and alcohol poly use and its health and societal consequences.

Increases in poly use of cannabis and alcohol were associated with both MML and RML for women, older adults and married adults. While poly use associated with RML increased for both women and men, the increase for women was significantly greater than for men. The results are consistent with studies demonstrating increases in cannabis use among older adults (Han et al., 2017; Han and Palamar, 2020) and narrowing of the difference in cannabis use among genders (i.e., men consistently reporting greater use but with the gap narrowing over time; Chapman et al., 2017). Longitudinal studies will be needed to understand the drivers of these trends, but one possible explanation is that adults, especially women, who use alcohol and live in states with MML/RML now have increased access (including home delivery in several states) to cannabis because it is no longer illegal. Increases in cannabis and cannabis-alcohol poly use are especially concerning for women and older adults due to the specific risks of cannabis use experienced by both groups. For women, compared with men, there is evidence of a shorter time (i.e., telescoping) between cannabis use and the onset of CUD and reports of more intense withdrawal symptoms (Ketcherside et al., 2016; Schlienz et al., 2017). For older adults, consequences of cannabis use include impaired cognitive performance and increased risks of falls, as well as potential interactions with a range of prescription medications (Minerbi et al., 2019; Scott et al., 2019). Obtaining information on both reasons for use (e.g., medical purposes) and potential negative consequences of cannabis and cannabis-alcohol poly use for women and older adults may facilitate conception and implementation of public health initiatives and clinical interventions that are tailored and more effective for these groups versus a “one size fits all” approach.

In contrast to the increase in poly use among older adults, both RML and MML were associated with decreased poly use among adolescents, consistent with past research (Cerda et al., 2018; Johnson et al., 2018). In addition, among young people, cannabis-only use increased and alcohol-only use decreased. This may reflect a trend toward cannabis rather than alcohol as the substance of initiation (i.e., first substance used) among younger individuals. Research should continue to monitor trends in cannabis and alcohol poly use among youth to determine whether decreases in cannabis and alcohol poly use are also associated with decreases in long-term harmful health and psychosocial consequences related to poly use.

Our results provide new information on one potential unanticipated consequence of MML/RML enactment that has not previously been reported: a decrease in alcohol-only use. While two studies reported no change in alcohol use with MML or RML (Subbaraman and Kerr, 2020; Veligati et al., 2020), this was the first study to examine changes from pre- to post- cannabis law enactment and to report overall decreases in alcohol-only use. Regarding alcohol-only use and age, we found that alcohol-only use decreased with MML and RML for all age groups except those 50 years of age and older. Similarly, a study in Washington state (Subbaraman and Kerr, 2020) found decreases in alcohol consumption among the youngest age cohort (ages 18–29) but no changes among older cohorts (ages 30–49, 50+). Other studies using national US data of adolescents only found decreases in alcohol use with MML laws (Cerda et al., 2018; Johnson et al., 2018). Changes in alcohol by cannabis legalization status should continue to be monitored and studies should also examine potential mechanisms that are driving decreases in alcohol-only use such as substitution (i.e., switching from alcohol use to cannabis use).

Our findings should also be considered within the context of several limitations. First, our results may generalize only to persons living in the US. Second, cannabis and alcohol use were measured by self-report, which may lead to an underestimation of undesirable or illicit behaviors or reporting or memory errors. Third, our study focused on the prevalence of cannabis and alcohol use. It is unclear whether the frequency or quantity of cannabis or alcohol use is increasing at a population level, and assessments of these variables can be useful (Zarkin et al., 1994) and should be increasingly utilized as more data become available. Fourth, all states with RML also had MML that were enacted earlier than the RML, with most of these states enacting the MML more than a decade earlier than the RML. We included two separate time-varying indicators for MML and RML in order to adjust for each simultaneously and future research should examine the relationship between different types of cannabis laws and the timing of their enactment in relation to cannabis-alcohol poly use. It is also conceivable that

psychosocial and cultural issues could impact poly use patterns over time. However, as long as any group variant issues are time invariant, and any time variant issues are group invariant, the DiD method is designed to account for many of these potential sources of confounding.

5. Conclusions

These data are suggestive of a link between legalization of cannabis for recreational use and increased poly use of alcohol and cannabis, as well as increased cannabis-only use, broadly in the US population. At the same time, cannabis legalization appears to be associated with declines in alcohol-only use. Stakeholders, policymakers and lawmakers should be aware of the potential impact of cannabis legalization on substance use beyond cannabis only (e.g., cannabis and alcohol poly use, alcohol use) so that they are fully informed in terms of potential unintended consequences of cannabis legalization. It would therefore be prudent to obtain additional information on these critical outcomes before cannabis legalization continues across the country.

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Contributors

Drs. Goodwin and Kim conceived of the study questions and drafted the manuscript. Drs. Wyka and Kim designed the analytic strategy and Dr. Kim and Ms. Zhu conducted the statistical analyses. Drs. Weinberger and Barrington-Trimis provided critical intellectual content feedback and revisions. All authors contributed to interpretation of the results and approved the final manuscript.

Disclaimer

The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the Research Data Center, the National Center for Health Statistics, the Centers for Disease Control and Prevention or the National Institutes of Health/National Institute on Drug Abuse.

Declaration of Competing Interest

No conflict declared.

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