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Medical marijuana laws and driving under the influence of marijuana and alcohol

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ABSTRACT

Aims Medical marijuana law (MML) enactment in the United States has been associated with increased cannabis use but lower traffic fatality rates. We assessed the possible association of MML and individual-level driving under the influence of cannabis (DUIC) and also under the influence of alcohol (DUIA). **Design and setting** Three cross-sectional U.S. adult surveys: The National Longitudinal Alcohol Epidemiologic Survey (NLAES; 1991–1992), the National Epidemiologic Survey on Alcohol and Related Conditions (NESARC; 2001–2002), and the NESARC-III (2012–2013). **Participants** The total *n* was 118 497: 41 764, 41 184, and 35 549 from NLAES, NESARC, and NESARC-III, respectively. **Measurements** Across the three surveys, similar questions in the Alcohol Use Disorder and Associated Disabilities Interview Schedule assessed DUIC and DUIA. Ever-MML states enacted MML between 1991–1992 and 2012–2013 (overall period). Early-MML states enacted MML between 1991–1992 and 2001–2002 (early period). Late-MML states enacted MML between 2001–2002 and 2012–2013 (late period). MML effects on change in DUIC and DUIA prevalence were estimated using a difference-in-differences specification to compare changes in MML and other states. **Findings** From 1991–1992 to 2012–2013, DUIC prevalence nearly doubled (from 1.02% to 1.92%), increasing more in states that enacted MML than other states (difference-in-differences [DiD] = 0.59%; 95% CI = 0.06%–1.12%). Most change in DUIC prevalence occurred between 2001–2002 and 2012–2013. DUIC prevalence increased more in states that enacted MML 2001–2002 to 2012–2013 than in never-MML states (DiD = 0.77%; 95% CI = −0.05%-1.59%), and in two early-MML states, California (DiD = 0.82; 95% CI = 0.06–1.59) and Colorado (DiD = 1.32; 95% CI = 0.11–2.53). In contrast, DUIA prevalence appeared unrelated to MML enactment. **Conclusions** Medical marijuana law enactment in US states appears to have been associated with increased prevalence of driving under the influence of cannabis, but not alcohol.

Keywords Driving under the influence, drug policy, legal epidemiology, marijuana, marijuana law, medical cannabis.

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INTRODUCTION

Attitudes and laws regarding marijuana have changed substantially in recent years. From 2002 to 2017, the adult prevalence of past-year marijuana use increased from 10.4% to 15.3% [1, 2], whereas the prevalence of adults perceiving great risk of harm from smoking marijuana once or twice a week decreased from 50.4% to 31.4% [1, 2]. Since first legalized by California in 1996, marijuana is now legal for medical purposes in 33 states [3]. State legalization of marijuana for medical use (MML) is associated with increases in adult non-medical cannabis use [4–6] and cannabis use disorder [4, 5]. Such increases in MML states raise concerns about increases in additional consequences (e.g. driving under the influence of cannabis).

The effect of MML on driving safety is an important public health issue. Motor vehicle crashes are a leading cause of U.S. injury-related mortality, with 29% of these deaths attributable to alcohol-impaired driving [7]. Although the prevalence of alcohol detected in fatally injured U.S. drivers has remained stable, the prevalence of detected cannabis has tripled, from 4.2% of fatally injured drivers in 1999 to 12.2% in 2010 [8]. Further, the prevalence of weekend nighttime drivers testing positive for

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tetrahydrocannabinol (THC) increased from 8.6% in 1999 to 12.6% in 2013–2014 [9]. Despite evidence that cannabis impairs driver reaction time, spatial perceptions, and decision-making [10–13], cannabis users [14–17] and non-users [18] perceive driving under the influence of cannabis (DUIC) to be without risk, or less risky than driving under the influence of alcohol (DUIA). Given that cannabis policy liberalization is likely to further increase the availability of medical cannabis, researchers and policymakers have raised concerns about MML effects on DUIC rates [19–22].

Knowledge about MML and driving safety is limited. Using data on fatal car crashes from the Fatality Analysis Reporting System (FARS), three studies of MML effects on overall rates of traffic fatalities found ~10% decreases in overall traffic fatalities [23–25]. State-specific results revealed that only Western states experienced post-MML reductions in traffic fatalities, with post-MML increases observed in Eastern states [23]. However, <0.5% of crashes result in fatality [26]. Self-reported DUIC or DUIA potentially taps a much broader domain of driving safety. To our knowledge, no study has investigated change in DUIC following MML, and knowledge is limited regarding MML effects on alcohol-related outcomes, including DUIA. How policies targeting marijuana affect consumption and behaviors associated with alcohol is critical to formulating policies that limit unintended consequences. In a previous study of MML effect on cannabis- and alcohol-related outcomes, MML enactment was followed by an 11.0% decrease in fatalities involving drivers with alcohol detectable [24] and post-MML decrease in adult binge drinking was suggested [24]. However, adult binge drinking increased after MML enactment in a different study [5], leaving MML effects on alcohol-related outcomes unclear. No national study has examined MML effects on both cannabis- and alcohol-related driving outcomes.

In addition, to our knowledge, no study has examined differences in driving behaviors before and after MML using adult national data predating all MML, differentiating between earlier and more recent periods, or separately examined particular states. Although federal law has prohibited cannabis for medical or other use since 1971, federal enforcement efforts in states enacting an MML changed over time. During the 1990s and early 2000s, federal enforcement was common (e.g. seizures of medical marijuana facility assets) [27–30]. Then, with a 2009 Department of Justice (DOJ) memo instructing U.S. attorneys not to focus federal resources on medical marijuana patients and programs whose actions were compliant with state laws [31], federal enforcement scaled back, and medical marijuana dispensaries were documented to proliferate in two early-MML states, California (MML enacted in 1996) [32] and Colorado (MML enacted in 2000) [33]. These changes indicate the need to examine MML effects across different time periods, and to examine California and Colorado separately during years encompassing the effects of the DOJ changes.

We therefore examined MML, DUIC and DUIA in the only national data known to us that include the pre-MML period. This consisted of three cross-sectional adult surveys: National Longitudinal Alcohol Epidemiological Survey (NLAES; 1991–1992) [34, 35], National Epidemiologic Survey on Alcohol and Related Conditions (NESARC; 2001–2002), [36–38] and National Epidemiologic Survey on Alcohol and Related Conditions-III (NESARC-III; 2012–2013) [39, 40]. During the time between NLAES and NESARC-III, the national policy environment around MML changed dramatically, with no American living in MML states in 1991–1992 to more than one-third (34.3%) in MML states in 2012 [4]. Our main question was the relationship of MML to DUIC. However, given the substantial impact of alcohol-impaired driving on population health [24], we also explored the relationship of MML to DUIA. We examined these questions across all years (1991–1992 to 2012–2013), and stratified into an earlier period (1991–1992 to 2001–2002) and a later period (2001–2002 to 2012–2013) to examine differences over time in MML effects on DUIC and DUIA. Finally, given previous findings that MML effects on non-medical cannabis use differed in California compared to other states during the earlier period [4] and that MML effects on non-medical use differed in Colorado and California during the later period consistent with DOJ policy changes [4], we examined California and Colorado separately when examining the earlier and later periods.

METHODS

Study design and participants

The 1991–1992 NLAES [34, 35], 2001–2002 NESARC [36–38], and 2012–2013 NESARC-III [39, 40] are nationally representative samples of American adults. Similar methods were used across the three surveys, including a multi-stage sampling design, inclusion of adults ≥18 years in households and group quarters, sampling weights to adjust for selection probabilities and non-response, and interviewer-administered measures. All surveys used similar assessment procedures, allowing examination of trends over time in multiple studies [4, 41–46]. Additional details about interview procedures and sample demographic characteristics are provided elsewhere [40–43, 47]. Overall response rates were 60% to 84% [34, 38, 40], similar to contemporaneous response rates in other national surveys [48, 49].

In NLAES and NESARC, primary sampling units (PSUs) were randomly selected from all 50 states, while in NESARC-III, random selection of PSUs resulted in inclusion of 39 states. The eleven states in which PSUs were not

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selected in NESARC-III were excluded from the main analytical dataset (Supporting information, Table S1), resulting in total analytic sample of 118 497 participants: 41 764 from NLAES, 41 184 from NESARC, and 35 549 from NESARC-III.

Measures

The Alcohol Use Disorder and Associated Disabilities Interview Schedule (AUDADIS), a fully structured diagnostic interview for use by professional non-clinician interviewers was the assessment instrument. Questions about DUIC and DUIA were similar in the three surveys, with respondents in each survey asked if they repeatedly drove a car, motorcycle, truck, boat, or other vehicle while under the influence of cannabis or alcohol, respectively.

Because NLAES only asked about DUIC and DUIA among participants who reported using cannabis or alcohol ≥12 times, we limited NESARC and NESARC-III participants to those who used cannabis or alcohol ≥12 times. To provide a consistent timeframe, we analyzed DUIC and DUIA in the past 12 months. To test robustness of findings, we conducted the following sensitivity analyses: (i) adding participants from all states included in each survey for both outcomes; (ii) adding originally excluded NESARC and NESARC-III participants who used cannabis 1–11 times to the DUIC outcome models and those who used alcohol 1–11 times to the DUIA outcome models; and (iii) investigating a four-level combined DUIC and DUIA measure: neither DUIC nor DUIA in the prior 12 months, DUIC-only, DUIA-only, and DUIC+DUIA.

State-level medical marijuana law variables

Year of MML enactment was determined by a team of legal scholars, policy analysts and economists after reviewing state policies [50, 51]. Three variables were then created. One indicated participants in states enacting MML between 1991 and 2012 (ever-MML states) versus others (never-MML states). A second indicated participants in early-MML states excluding California, in California, and in non-early–MML states (i.e. never-MML and late-MML states). A third variable indicated participants in early-MML states except California and Colorado, late-MML states, never-MML states by 2012, California and Colorado.

Individual and state-level control covariates

Covariates included sex, age, education, race/ethnicity, marital status, urbanicity, and poverty. Following prior MML work [40, 52–54], U.S. Census data were used to define four state-level covariates: percent male; percent white; percent <30 years old; and percent ≥25 years without a high school diploma.

Statistical analyses

The analysis plan for this study was not pre-registered, and the findings should be considered exploratory. Using a difference-in-difference (DiD) approach [55, 56], we examined whether change in state prevalence of DUIC and DUIA differed among survey participants by state MML status. By assuming that trends in non-MML states reflect what would have happened in MML states if they had not enacted MML, DiD estimate the causal effect of MML status on the predicted prevalence of DUIC and DUIA in states or groups of states compared to other groups of states [57]. To display the statistical uncertainty of the MML effect, we calculated 95% CI for the DiD comparisons of rates of change. When interpreting the results, the DiD estimate gives the highest probability value of the MML effect, whereas the 95% CI provide the range of values reasonably compatible with the data.

All models included state fixed effects, individual- and state-covariates, survey (NLAES, NESARC, NESARC-III), MML indicators, and survey × MML interaction terms. Multivariable logistic regression models (SAS-callable SUDAAN 11.0.1 Proc RLOGIST) using sample weights generated weighted predicted marginal prevalence estimates (back-transformed from marginal log-odds) and standard errors of outcomes in each survey within each MML state group. A first set of contrasts estimated between-survey change in predicted prevalence within MML strata. In a second set of contrasts, the DiD tests determined if these between-survey changes differed by MML strata. The code for the DiD models used to calculated predicted marginal prevalence estimates is provided in the Supporting information online material.

Separate models tested MML effects during the overall period (model 1), the earlier period (model 2), and the later period (model 3). In model 1, the effects of MML were evaluated by testing for differential changes between ever-MML states versus never-MML states. In model 2, the effects of early-MML were evaluated by testing for differential changes in early-MML states excluding California, and in California versus remaining states (i.e., late-MML and non-MML states, which served as the reference group). In model 3, we tested for differential changes between never-MML states (the reference group), late-MML states, the two early-MML states affected by DOJ changes (California, Colorado), and the remaining early-MML states.

RESULTS

Table 1 presents the predicted prevalence of past-year DUIC and DUIA, by survey. Between 1991–1992 and 2001–2002, the predicted prevalence of DUIC changed little, whereas the predicted prevalence of DUIA decreased. In contrast, in 2012–2013, the predicted prevalence of both

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Table 1 Predicted prevalence of driving under the influence of cannabis or alcohol by survey

	% (SE)			*% difference (95% CI)*		
Driving under the influence	*1991–1992 (NLAES)* n = *41 764*	*2001–2002 (NESARC)* n = *41 184*	*2012–2013 (NESARC-III)* n = *35 549*	*1991–1992 vs. 2012–2013*	*1991–1992 vs. 2001–2002*	*2001–2002 vs. 2012–2013*
Cannabis	1.02 (0.14)	1.06 (0.06)	1.92 (0.18)	0.90 (0.31, 1.49)	0.04 (−0.23, 0.31)	0.86 (0.47, 1.25)
Alcohol	3.72 (0.31)	2.76 (0.12)	3.93 (0.26)	0.20 (−0.84, 1.23)	−0.96 (−1.62, −0.30)	1.16 (0.61, 1.71)

NLAES = National Longitudinal Alcohol Epidemiologic Survey; NESARC = National Epidemiologic Survey on Alcohol and Related Conditions; SE = standard error; CI = confidence interval.

DUIC and DUIA increased (Supporting information, Figures S1 and S2).

Model 1: Overall period

Between 1991–1992 and 2012–2013, the predicted prevalence of both DUIC and DUIA increased in both the never- and the ever-MML states (Table 2). DiD results showed that DUIC increased in ever-MML states 0.59% more than in never-MML states (95% CI = 0.06%, 1.12%). In contrast, DiD results indicated that changes in DUIA were similar in ever- versus never-MML states.

Model 2: Early period 1991–1992 to 2001–2002

Between 1991–1992 and 2001–2002, the predicted prevalence of DUIC remained relatively stable in the non-early MML states and in early-MML states excluding California and declined slightly in California (Supporting information, Table S2). DiD results showed that the predicted prevalence of DUIA declined and did so similarly across states regardless of MML status.

Model 3: Late period 2001–2002 to 2012–2013

Between 2001–2002 to 2012–2013, the predicted prevalence of DUIC increased by the following percentage points: 0.79% in the never-MML states; 0.30% in early-MML states except California and Colorado; 1.56% in late-MML states; 1.61% in California; and 2.11% in Colorado (Supporting information, Table S3). DiD results showed that DUIC increased 0.77% more (95% CI = −0.05%,

Table 2 Difference in predicted prevalence of driving under the influence of cannabis or alcohol, 1991–1992 to 2012–2013: never- versus ever-MML states (model 1)

	Prevalence[b] (SE)	
	Never-MML states[a] (24 states)	*Ever-MML states[a] (15 states)*
Outcome	*No MML before 2012*	*Passed MML 1991–2012*
Driving under the influence of cannabis		
1991–1992	1.02 (0.16)	1.02 (0.14)
2012–2013	1.72 (0.18)	2.31 (0.28)
Difference in prevalence	0.70 (0.11, 1.29)	1.29 (0.55, 2.03)
DiD (ever- vs. never-MML states)		
95% CI	– (reference)	0.59 (0.06, 1.12)
P value	–	0.03
Driving under the influence of alcohol		
1991–1992	4.00 (0.39)	3.22 (0.26)
2012–2013	4.09 (0.28)	3.62 (0.33)
Difference in prevalence	0.09 (−1.07, 1.25)	0.40 (−0.58, 1.38)
DiD (ever- vs. never-MML states)		
95% CI	– (reference)	0.31 (−0.45, 1.07)
P value	–	0.43

SE = standard error; DiD = difference in difference; MML = medical marijuana law; CI = confidence intervals. [a]Ever MML states (1996–2012): Arizona, California, Colorado, Connecticut, Maine, Maryland, Massachusetts, Michigan, Montana, Nevada, New Jersey, New Mexico, Vermont, Oregon, Washington. [b]Prevalence based on participants in the 39 states included in all three surveys. States omitted: Alaska, Delaware, Hawaii, Idaho, Nebraska, New Hampshire, North Dakota, Rhode Island, South Dakota, West Virginia and Wyoming. Prevalence back-transformed from marginal log-odds estimated from logistic regression interaction models (MML × survey) that included individual covariates (sex; age; education; race/ethnicity; marital status; urbanicity; poverty) and state covariates (% male; white; <30 years old; ≥25 years without a high school diploma). Predicted prevalence estimated by a model with a dichotomous MML variable (ever-MML states versus never-MML states). [c]Never-MML states (1996–2012): Alabama, Arkansas, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Minnesota, Mississippi, Missouri, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, South Carolina, Tennessee, Texas, Utah, Virginia, Wisconsin.

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1.59%) in late-MML states, 0.82% more (95% CI = 0.06%, 1.58%) in California, and 1.32% more (95% CI = 0.10%, 2.54%) in Colorado compared to the increase in the never-MML states.

Between 2001–2002 to 2012–2013, the predicted prevalence of DUIA also increased. However, DiD results showed that the predicted prevalence of DUIA changed similarly in never-MML states, all early-MML states (except California and Colorado), all late-MML states, California, and Colorado (Supporting information, Table S3).

Sensitivity analyses

Sensitivity analyses did not yield meaningful changes in results, indicating robustness of the main models (Supporting information, Tables S4–S9). By adding participants from all states included in each survey, the magnitude of the estimated relationship between MMLs and DUIC and DUIA decreased slightly, but not meaningfully (Supporting information, Tables S4–S6). When including the 1–11 time lifetime cannabis users in the DUIC late-period model, the DiD estimate was largely unchanged (Supporting information, Tables S7–S9). Categorizing participants into the four-level outcome (neither DUIC nor DUIA, DUIC-only, DUIA-only, DUIC+DUIA; Supporting information, Tables S11–S13), results presented in Table 1 and Supporting information, Tables S3 and S4 remained largely unchanged, although DiD estimates for DUIC-only and DUIC+DUIA were slightly attenuated compared to the primary DUIC estimates.

DISCUSSION

In three cross-sectional nationally representative surveys spanning 20 years, we examined changes in the predicted prevalence of driving under the influence of cannabis (DUIC) and under the influence of alcohol (DUIA) by state MML status. Over the entire period from 1991–1992 to 2012–2013, predicted prevalence of DUIC increased across all states, with greater increases in states that enacted MML than in other states. In contrast, although DUIA also increased between 2001–2001 and 2012–2013, changes in DUIA prevalence were similar in states that enacted MML and in other states, suggesting that MML effects on the prevalence of driving under the influence were cannabis-specific.

Although MML states exhibited greater increases in DUIC than other states over the entire period, MML was not uniformly associated with increased DUIC across all time periods and states. During the earlier period (1991–1992 to 2001–2002), the prevalence of DUIC in the five early-MML states (excluding California) changed little, while in California, DUIC prevalence decreased. In 1991–1992, even before California became the first state to legalize cannabis for medical purposes in 1996, California had a sharply higher prevalence of DUIC than in the other early-MML states and the non-early MML states. California's high prevalence of DUIC in 1991–1992 was a bellwether for future changes. By 2001–2002, the prevalence of DUIC in the five early-MML states (excluding California) had escalated to the levels observed in California a decade earlier, and never-MML states reached similar levels of DUIC by 2012–2013. However, California's uncharacteristic reduction in DUIC during the earlier period was unmatched in other states and requires future research. One potential explanation is that a set of laws targeting DUIA during this period had spillover effects on DUIC. During the late-1980s and early-1990s, California passed a series of laws, both reducing the threshold for (0.10% to 0.08%) and increasing DUIA penalties [58–60], previously found to deter DUIA and reduced all types of accidents in the state [60]. These laws targeting DUIA may have signaled to drivers a reduced toleration of impaired driving due to any substance, resulting in an overall reduction in driving under the influence, including DUIC.

During the later period (2001–2002 to 2012–2013), nearly twice as many Americans reported DUIC as during the earlier period, with marginally greater increases in DUIC among late-MML states than non-MML states. The increased DUIC in the nine late-MML states is consistent with increase in cannabis use and cannabis use disorder in the US during the later period, particularly in MML states [2, 4, 61], strengthening our inferences that MML contributed to increased DUIC during this period. Two early-MML states, California and Colorado, experienced substantial increases in DUIC prevalence during the later period. The greater increases in DUIC prevalence in California and Colorado may be linked to 2009 policy changes and subsequent dispensary proliferation in these states, particularly because similar increases in DUIC did not occur in California during the early period that preceded these shifts. The 2009 Ogden memo coincided with nationwide increases in both positive public attitudes toward cannabis legalization [62], and with increases in cannabis dispensaries in some MML states. The increased availability of medical cannabis through dispensaries has been found to be positively related to cannabis use [25] and high frequency use [63]. Additional research is needed on MML and DUIC during the later period, how the Ogden memo and other major policy changes relate to DUIC non-MML states, and whether medical cannabis dispensaries mediate this relationship in MML states.

The increase in DUIC during the late period are concerning and could represent the emergence of a serious public health problem. To our knowledge, this is the first study to indicate a nationwide increase in DUIC after 2000, consistent with other national trends in cannabis use during this time period [1, 2, 4]. For example, although

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the National Roadside Survey on Alcohol and Drug use found the prevalence of weekend nighttime drivers testing positive for THC, based on the combined oral fluid and/or blood tests, increased from 8.6% in 2007 to 12.6% in 2013–2014 [9], THC blood concentrations do not directly correlate with recent use, intoxication, or driving impairment because THC can be detected in the blood even after 7 days of abstinence [64, 65]. Given that THC concentrations in oral and blood tests remain detectible long after exposure, the rise in the prevalence of weekend nighttime drivers testing positive for THC is indicative of overall increases in cannabis use, rather than direct estimates of DUIC prevalence. However, our results suggest that the prevalence of DUIC is related to the increasing prevalence of cannabis use at a given time and place. Because further cannabis policy liberalization is likely to further increase the availability of medical and recreational cannabis, social and behavioral interventions are needed to prevent DUIC in people who use cannabis.

Our findings did not support the premise that MML affect the likelihood of DUIA. Thus, increases in DUIC associated with MML appear linked to population-level changes in cannabis use across states and over time [4], while changes in DUIA are likely to result from factors other than MMLs (e.g. changing adult drinking norms or changes in alcohol-specific policies). Nonetheless, research has documented that policies targeting one substance can affect consumption of other substances [5, 66–71], suggesting a need for further research into the extent to which individuals exchange the use of alcohol and cannabis, and the circumstances in which this occurs.

Study limitations are noted. First, background differences between MML and non-MML states (e.g. cannabis use) might confound the causal effect of MML on DUIC and DUIA. The strength of our statistical approach, however, is that, in addition to adjusting for many important individual- and state-level factors, the difference-in-differences model adjusts for unobserved time-stable factors that might confound the causal effect of MML on DUIC and DUIA [55, 56]. Despite this, time-varying factors, unobserved or not explicitly adjusted for in the model, may still confound the effect estimates presented. Second, DUI measures were self-reported, and perceived stigma may cause underreporting. However, we found no evidence of differential nonresponse to the DUI measures by MML status (Supporting information, Table S14). Third, participants from 11 states were not included in all three surveys (NLAES, NESARC, NESARC-III) and therefore were excluded from the main analysis. However, results were essentially unchanged in supplementary analyses that included participants from the omitted states (Supporting information, Tables S4–S6). Fourth, although there is no direct test of the parallel-paths assumption [56, 72], an indirect check of the parallel paths assumption was conducted by comparing the slopes of DUIC in MML states with non-MML states in the pre-MML years. The pre-MML parallel-path assumption was supported by the absence of significant increases in late-MML states and Colorado compared to change in DUIC in non-MML states (Supporting information, Table S15). This reduces concerns that the parallel paths assumption was violated. Finally, our data do not extend past 2012–2013. Other U.S. national surveys did not begin covering DUIC specifically until 2016 [73]. In 2017, the estimated prevalence of DUIC in those age ≥16 years was 4.6% [73, 74], notably higher than our 2012–2013 estimate of 1.92% (Table 1), suggesting that increases are continuing, and underscoring the need for further study of trends when sufficient data become available. The relationship of MML to DUIC in states that more recently enacted MML remains unknown and warrants investigation. Additionally, since 2012, 13 states passed MML, and 11 MML states and Washington D.C. enacted recreational marijuana laws (RML). Relative to MML, RML may lead to greater health consequences, including DUIC. In 2009–2016 U.S. traffic fatality data, an additional one traffic fatality per million residents followed RML enactment compared to non-RML states, with modest reduction in the months thereafter [75]. However, only the first three RML states were analyzed [75]. Moreover, two studies suggest RML in Washington state has been associated with increases in DUIC, with one study finding a nearly 40% increases in the prevalence of THC in suspected impaired driving cases [76] and one study finding a doubling in the daytime prevalence of THC-positive drivers immediately before RML (7.8%) and 1 year after implementation (18.9%) [77]. When more data become available, research should address the relationship of RML to DUIC and DUIA, and morbidity and mortality associated with those behaviors.

CONCLUSIONS

Using the only U.S. national data available that includes the pre-MML period, our study addressed the relationship of MML to DUIC and DUIA. Our results suggest that MMLs were specifically associated with increased prevalence of driving under the influence of cannabis, but not under the influence of alcohol. Despite previous studies finding that MML are associated with reductions in traffic fatalities, we failed to find evidence that these reductions arose from changes in either DUIC or DUIA, which are much broader indicators of driving safety. Future studies that consider changes in ecological and individual-level factors are needed to better understand the relationship of MML to traffic fatalities and non-fatal injuries. However, the cannabis-specific findings on MML and driving indicate an immediate need to take the findings seriously and provide them to state policymakers tasked with designing and implementing state marijuana programs. Moreover, the nationwide increases in DUIC during the late period should be a stimulus to designing and improving interventions to reduce the risk of cannabis-impaired driving, regardless of MML status. Additional studies are needed to identify characteristics of people most likely to drive under the influence of cannabis in general, and the effects of MML and RML on driving behaviors. Given the rapid changes in state policies regarding cannabis, this work is urgently needed.

Declarations of interest

None.

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Supporting Information

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

Table S1 Years that medical marijuana laws (MML) were enacted for the 50 US states up to 2012 and how participants in these states were coded in Models 1–3.

Table S2 Differences in predicted prevalence of driving under the influence of cannabis or alcohol, 1991–1992 to 2001–2002[a]: non-early and early-MML states (model 2)[d].

Table S3 Differences in predicted prevalence of driving under the influence of cannabis or alcohol, 2001–2002 to 2012–2013[a]: never-MML, early-MML, and late-MML states (model 3).

Table S4 Sensitivity analysis: difference in predicted prevalence of driving under the influence of marijuana or alcohol, with participants in the 11 states not common to the 3 surveys included, 1991–1992 to 2012–2013: never- versus ever-MML states (model 1).

Table S5 Sensitivity analysis: differences in predicted prevalence of driving under the influence of marijuana or alcohol, with participants in the 11 states not common to the 3 surveys included, 1991–1992 to 2001–2002[a]: non-early and early-MML states (model 2)[d].

Table S6 Sensitivity analysis: differences in predicted prevalence of driving under the influence of marijuana or alcohol, with participants in the 11 states not common to the 3 surveys included, 2001–2002 to 2012–2013[a:] never-MML, early-MML, and late-MML states (model 3).

Table S7 Difference in predicted prevalence of driving under the influence of marijuana or alcohol, with participants who only reported using cannabis and alcohol 1–11 times included, 1991–1992 to 2012–2013: never- versus ever-MML states (model 1).

Table S8 Differences in predicted prevalence of driving under the influence of marijuana or alcohol, with participants who only reported using cannabis and alcohol 1–11 times included 1991–1992 to 2001–2002[a]: non-early and early-MML states (model 2).

Table S9 Differences in predicted prevalence of driving under the influence of marijuana or alcohol, with participants who only reported using cannabis and alcohol 1–11 times included, 2001–2002 to 2012–2013[a]: never-MML, early-MML, and late-MML states (model 3).

Table S10 Predicted prevalence of driving under the influence of cannabis only, alcohol only, or both by survey.

Table S11 Sensitivity analysis: difference in predicted prevalence of driving under the influence of marijuana and/or alcohol, using multinomial logistic regression with a four category outcome variable: neither DUI-C nor DUIA, DUIC only, DUIA only, both DUIC and DUIA, 1991–1992 to 2012–2013: never- versus ever-MML states (model 1).

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Table S12 Sensitivity analysis: difference in predicted prevalence of driving under the influence of marijuana and/or alcohol, using multinomial logistic regression with a four category outcome variable: neither DUI-C nor DUIA, DUIC only, DUIA only, both DUIC and DUIA, 1991–1992 to 2001–2002[a]: non-early and early-MML states (model 2)[d].

Table S13 Sensitivity analysis: difference in predicted prevalence of driving under the influence of marijuana and/or alcohol, using multinomial logistic regression with a four-category outcome variable: neither DUIC nor DUIA, DUIC only, DUIA only, both DUIC and DUIA, 2001–2002 to 2012–2013[a]: never-MML, early-MML, and late-MML states (model 3).

Table S14 Response rates to survey questions on driving under the influence by state medical marijuana law (MML) status.

Table S15 Testing the parallel paths assumption for Colorado and the late-MML states: differences in predicted prevalence of driving under the influence of cannabis during the earlier period, 1991–1992 to 2001–2002[a].

Figure S1 Medical marijuana laws (MML) and driving under the influence of marijuana, past 12 months, during (a) overall period (1991–1992 to 2012–2013), (b) early period (1991–1992 to 2001–2002) with California as stand-alone state, (c) late period (2001–2002 to 2012–2013) with California and Colorado as stand-alone states.

Figure S2 Medical marijuana laws (MML) and driving under the influence of alcohol, past 12 months, during (a) overall period (1991–1992 to 2012–2013), (b) early period (1991–1992 to 2001–2002) with California as stand-alone state, (c) late period (2001–2002 to 2012–2013) with California and Colorado as stand-alone states.

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