JAMA Internal Medicine | Original Investigation | HEALTH CARE POLICY AND LAW

Association of Recreational Cannabis Laws in Colorado and Washington State With Changes in Traffic Fatalities, 2005-2017

Julian Santaella-Tenorio, DrPH; Katherine Wheeler-Martin, MPH; Charles J. DiMaggio, PhD; Alvaro Castillo-Carniglia, PhD; Katherine M. Keyes, PhD; Deborah Hasin, PhD, PhD; Magdalena Cerdá, DrPH

Invited Commentary
Related article
Supplemental content

IMPORTANCE An important consequence of cannabis legalization is the potential increase in the number of cannabis-impaired drivers on roads, which may result in higher rates of traffic-related injuries and fatalities. To date, limited information about the effects of recreational cannabis laws (RCLs) on traffic fatalities is available.

OBJECTIVE To estimate the extent to which the implementation of RCLs is associated with traffic fatalities in Colorado and Washington State.

DESIGN, SETTING, AND PARTICIPANTS This ecological study used a synthetic control approach to examine the association between RCLs and changes in traffic fatalities in Colorado and Washington State in the post-RCL period (2014-2017). Traffic fatalities data were obtained from the Fatality Analysis Reporting System from January 1, 2005, to December 31, 2017. Data from Colorado and Washington State were compared with synthetic controls. Data were analyzed from January 1, 2005, to December 31, 2017.

MAIN OUTCOME(S) AND MEASURES The primary outcome was the rate of traffic fatalities. Sensitivity analyses were performed (1) excluding neighboring states, (2) excluding states without medical cannabis laws (MCLs), and (3) using the enactment date of RCLs to define pre-RCL and post-RCL periods instead of the effective date.

RESULTS Implementation of RCLs was associated with increases in traffic fatalities in Colorado but not in Washington State. The difference between Colorado and its synthetic control in the post-RCL period was 1.46 deaths per 1 billion vehicle miles traveled (VMT) per year (an estimated equivalent of 75 excess fatalities per year; probability = 0.047). The difference between Washington State and its synthetic control was 0.08 deaths per 1 billion VMT per year (probability = 0.674). Results were robust in most sensitivity analyses. The difference between Colorado and synthetic Colorado was 1.84 fatalities per 1 billion VMT per year (94 excess deaths per year; probability = 0.055) after excluding neighboring states and 2.16 fatalities per 1 billion VMT per year (111 excess deaths per year; probability = 0.063) after excluding states without MCLs. The effect was smaller when using the enactment date (24 excess deaths per year; probability = 0.116).

CONCLUSIONS AND RELEVANCE This study found evidence of an increase in traffic fatalities after the implementation of RCLs in Colorado but not in Washington State. Differences in how RCLs were implemented (eg, density of recreational cannabis stores), out-of-state cannabis tourism, and local factors may explain the different results. These findings highlight the importance of RCLs as a factor that may increase traffic fatalities and call for the identification of policies and enforcement strategies that can help prevent unintended consequences of cannabis legalization.

Author Affiliations: Author affiliations are listed at the end of this article.

Corresponding Author: Julian Santaella-Tenorio, DrPH, Division of Epidemiology, Department of Population Health, New York University School of Medicine, 180 Madison Ave, New York, NY 10016 (js4222@caa.columbia.edu).

JAMA Intern Med. doi:10.1001/jamainternmed.2020.1757
Published online June 22, 2020.

In the past 2 decades, the prevalence of adult past-month cannabis use has increased[1]; 33 states have legalized medical cannabis, and 11 have legalized recreational cannabis.[2,3] As cannabis use increases, driving under the influence of cannabis may also increase, potentially resulting in more traffic injuries.

Although many believe that driving under the influence of cannabis is safe,[4-7] cannabis use increases response time and lane weaving[8,9] and is associated with limitations in neurocognitive and neuromotor skills needed to drive safely.[10-12] Although some degree of impairment awareness and compensation (eg, reduced speed) occurs,[8,13] (unlike driving behavior after alcohol use[13-15]), cannabis use can increase the risk of vehicle crashes.[16-18] Moreover, cannabis combined with alcohol use is associated with greater levels of impairment for driving performance than either substance alone.[12,15,19]

Although medical cannabis laws (MCLs) are associated with increased driving under the influence of cannabis,[20] MCLs are associated with reductions in traffic fatalities.[21,22] Authors hypothesize that although MCLs may increase the number of cannabis-impaired drivers, MCLs may reduce alcohol-impaired drivers through substitution of cannabis for alcohol,[21] resulting in a net reduction of serious traffic events. Findings on MCLs may not apply to recreational cannabis laws (RCLs), which may increase cannabis availability and use to a greater extent than MCLs,[23] resulting in a higher number of cannabis-impaired drivers on roads.

Findings are inconsistent about RCLs and traffic fatalities. One study of 2009-2015 data from the Fatality Analysis Reporting System (FARS)[24] showed that RCL enactment was not associated with traffic fatalities, whereas another study using 2009-2016 FARS data[25] showed a steep increase in fatalities in Colorado and Washington State after legal commercial retail sales of cannabis started, followed by a reduction in fatalities. Hansen et al[26] used a synthetic control approach with 2000-2016 FARS data to show that RCLs were not associated with traffic fatalities in Washington State and Colorado. However, a recent study[27] showed that legal retail sales in Colorado and Washington State were associated with a pooled mean increase in fatalities. Differences in findings may be due to the use of different exposures (eg, legislation[24] vs implementation[25,27]), analytical strategies (eg, differences-in-differences,[24,27] controlled interrupted time series,[25] synthetic control method[26]), and selection of controls (eg, states without RCLs with similar characteristics[24,27] or states without implementation of cannabis laws[25] vs synthetic controls[26]).

Appropriate control selection is paramount for identification of policy effects because controls serve as a counterfactual (ie, what would have occurred had the state not implemented the law) for the RCL-exposed state. This process makes the exposed and unexposed groups comparable on factors (eg, laws concerning alcohol or drug use per se) that influence traffic fatalities. A synthetic control approach may overcome difficulties in control selection by using a transparent, data-driven procedure to produce a counterfactual through a weighted combination of control units,[28] an advantage over other approaches that select controls using subjective measures of comparability or that include all states without RCLs.

To reconcile the mixed findings in the literature, we used a synthetic control group approach to examine the effects of RCL implementation in Colorado and Washington State on traffic fatalities. We focused on these states because they were the first to implement RCLs in the United States, providing an opportunity to examine effects in areas not previously exposed to RCLs directly or indirectly. We used multiple risk factors for traffic fatalities to improve fitting of synthetic controls generated for Colorado and Washington State. We used data from January 1, 2005, to December 31, 2017, to compare 4 years of post-RCL traffic fatality rates in these states against trends in generated synthetic groups to track shorter- and longer-term effects.

Key Points

Question Have traffic fatalities increased after the implementation of recreational cannabis laws in Colorado and Washington State?

Findings Using a synthetic control approach, this ecological study found that recreational cannabis laws were associated with increases in traffic fatalities in Colorado (mean of 75 excess fatalities per year) but not in Washington State.

Meaning These findings suggest that unintended effects of recreational cannabis laws can be heterogeneous and may be specific to variations in how these laws are implemented (eg, density of recreational cannabis stores).

Methods

Study Population and Assignment of Exposure

We used a quasi-experimental design to compare observed and expected traffic fatality rates for Washington State and Colorado; other states implementing RCLs during the study period (Alaska, Massachusetts, Maine, Nevada, and Oregon) were not included in the donor pool of controls because these states could be considered exposed. However, we included California, Michigan, and Vermont, which implemented RCLs after 2017. Colorado and Washington State were excluded from each other's donor pool. Hawaii, a noncontiguous state, was also excluded. We used public secondary deidentified data in this study that did not require institutional review board approval or informed consent. This study used the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

The effective date for legal commercial retail sale of cannabis for recreational purposes was January 1, 2014, for Colorado, and December 3, 2013, for Washington State. Because all our measures were tabulated annually, we used January 1, 2014, as the starting exposure year for both states. We did not examine RCL effects in states implementing RCLs after 2014 owing to likely spillover effects of RCLs in Colorado and Washington State on cannabis availability and use and traffic fatalities in these other states.

Outcome Assessment

The primary outcome was the rate of traffic fatalities. We obtained annual counts of traffic fatalities from the FARS (2005-2017), a nationwide census of traffic fatality information maintained by the National Highway Traffic Safety Administration. Data are collected for individuals who were fatally injured in motor vehicle crashes on public roads and who died within 30 days of the crash. Aggregated FARS data are compiled from police crash reports, reports from the coroner or medical examiner, and vital statistics. Trained analysts routinely collect this information following standardized protocols.

To calculate fatality rates for each state and year, we used the denominator of state annual vehicle miles traveled (VMT) (in billions of miles) from statistics compiled by the Federal Highway Administration, US Department of Transportation[29] (eTable 1 in the Supplement). We also calculated age-adjusted fatality rates using total state populations (US Census Bureau).[30]

Statistical Analysis

Data were analyzed from January 1, 2005, to December 31, 2017. We used a synthetic group approach[28,31] to identify counterfactual synthetic controls separately for Colorado and Washington State. Separate analyses were conducted owing to variations in RCL implementation and local factors that may influence RCL effects. The synthetic group approach uses an algorithm that identifies the weighted combination of states from the eligible pool of control states that best resembles fatality rates of the exposed state in the pre-RCL period. The weighted combination of states is based on the minimized mean square prediction error (MSPE) between a vector of traffic fatality rates and other risk factors in the exposed state in the pre-RCL period and vectors of these rates and risk factors for all states in the donor pool. The outcome trend for the resulting synthetic control during the post-RCL period can be interpreted as the expected trend that would have been observed in the exposed state had the RCL not been implemented. This rate trend can be directly compared with the rate trend observed for exposed state. The effect is the mean of the annual differences across years in the post-RCL period (2014-2017). If weights exist such that the outcome trend for the synthetic control in the pre-RCL period matches that of the exposed unit during this period, then the bias caused by time-varying unobserved factors (including secular trends) tends toward zero as the pre-law period increases.[31]

To identify the 2 synthetic cohorts, we used values of the different state-level risk factors that have been previously used in similar research.[21,22] In final models, we removed 2 risk factors owing to lack of variability across states: blood alcohol level laws (0.08 g/dL) and administrative license revocation laws. eTable 1 in the Supplement shows detailed information about risk factors.

We used permutation-based tests (also termed *placebo tests*)[28] to quantify the uncertainty of effect estimates. We repeated analyses to generate synthetic controls for each of the 42 states in the donor pool, with each state serving as the exposed state. We then compared the pre-RCL:post-RCL MSPE ratios for Colorado and Washington State vs all other states.[28] Low MSPE in the pre-RCL period suggests a good-fitting synthetic control that provides a strong estimate of the expected outcome rate in the exposed state; paired with high MSPE in the post-RCL period, this suggests that the exposed state diverged from its synthetic control in the post-RCL period. We were interested in a high MSPE ratio (post-RCL divided by pre-RCL MSPE) as evidence of post-RCL effects, and the probability of observing a large to a larger ratio of MSPE by chance alone.[28]

In addition, we graphed the gap in fatality rates in the post-RCL period between the exposed state and its synthetic control. These graphs also include the gap for each of the 42 states not implementing RCLs compared with their own synthetic controls. Figures include states with MSPE no higher than twice the MSPE of the exposed state in the pre-RCL period.

Sensitivity Analyses

We conducted the following 3 sensitivity analyses: (1) excluding neighboring states of the exposed states, which could be susceptible to spillover effects of RCL implementation in the exposed state; (2) excluding states without MCLs during the preintervention period, because states with MCL are more similar to exposed states in terms of cannabis sales and use; and (3) using RCL enactment rather than effective dates in Colorado and Washington State (November 6, 2012, and November 3, 2012, respectively), given that enactment of RCLs can be linked to increases in cannabis use.[32] We used R, version 3.5.3, with R Studio (R Project for Statistical Computing) for all analyses.

Results

Colorado

Table 1 shows the states contributing to the synthetic Colorado and their weights (ie, the relative contribution of each state to the synthetic control). The mean values of risk factors in the synthetic Colorado during the pre-RCL period accurately reproduced the values of Colorado during this period (eTable 2 in the Supplement), indicating the similarity between the two in terms of risk factors. **Figure 1** shows that traffic fatality rates per 1 billion VMT in synthetic Colorado tracked together with the rates in Colorado in the pre-RCL period (MSPE = 0.097). Fatalities started to increase in Colorado around 2014. **Table 2** shows that the difference between Colorado and its synthetic control in the post-RCL period was 1.46 deaths per 1 billion VMT per year (post-RCL MSPE = 2.44); this translates into an estimated equivalent of 37 excess deaths of 488 traffic fatalities in 2014, 63 of 547 in 2015, 78 of 608 in 2016, and 123 of 648 in 2017 (mean of 75 excess fatalities per year). The permutation ratio test results showed that 1 state (of 42) had a post-RCL: pre-RCL MSPE ratio higher than or equal to that of Colorado (probability = 0.047). eFigure 1 in the Supplement shows that no other state had a gap as large as the observed gap for Colorado.

Results using age-adjusted population rates based on the state population were similar (Table 2), with a difference of 0.98 deaths per 100 000 inhabitants per year between Colorado and

Table 1. States With Nonzero Weights in Contributing to Synthetic Colorado and Synthetic Washington[a]

	Contributing weight	
State	Synthetic Colorado	Synthetic Washington
California	0.052	0.373
Connecticut	0	0.021
Delaware	0.001	0.016
Louisiana	0.001	0
Maryland	0.141	0
Missouri	0.001	0
Nebraska	0.004	0
New Hampshire	0.270	0
New Jersey	0.156	0.466
New York	0.040	0
North Carolina	0.001	0
Rhode Island	0.097	0.140
Tennessee	0.002	0
Texas	0.190	0
West Virginia	0.039	0

[a] Traffic fatalities in Colorado and Washington State before implementation of recreational cannabis laws (RCLs) are best reproduced by a combination of the states listed above (eg, for Washington State, a combination of California, Connecticut, Delaware, New Jersey, and Rhode Island, with New Jersey having the strongest influence on combined estimates). Forty-two states were used in the pool of controls. States implementing RCLs during the study period (Alaska, Massachusetts, Maine, Nevada, Oregon, Colorado, and Washington) and states outside the contiguous 48-state region (Alaska and Hawaii) were not included.

its synthetic control. Three states had a post-RCL:pre-RCL MSPE ratio higher than or equal to that of Colorado (with Pennsylvania experiencing reductions in fatalities after RCL and New Mexico having fluctuations over/under the trend of the synthetic control) (post-RCL MSPE = 1.47; probability = 0.093).

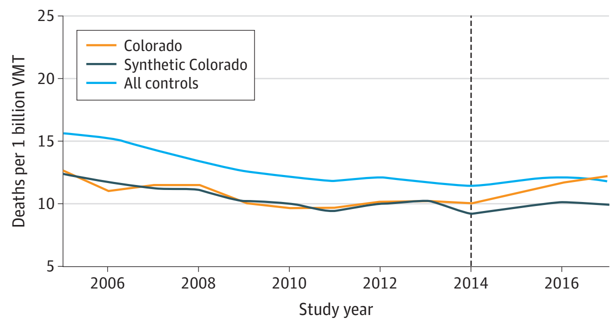
Washington State

Table 1 also shows the states that were used to generate the synthetic Washington State. eTable 1 in the Supplement shows the mean values of risk factors of the synthetic Washington State during the pre-RCL period. **Figure 2** shows that traffic fatality rates in Washington State and its synthetic control tracked together during the pre-RCL period. Although fatality rates in Washington State started to increase in 2014, rates in Washington and its synthetic control did not diverge after RCL (mean post-RCL outcome gap, 0.08) (Table 2). The permutation ratio test results showed that 28 states (of 42) had a post-RCL: pre-RCL MSPE ratio higher than or equal to that of Washington State (probability = 0.674). eFigure 2 in the Supplement shows that the gap for Washington State in the post-RCL period was similar to that of other control states. Results using age-adjusted population rates were similar (Table 2).

Combined Effects

The overall effect when pooling Colorado and Washington State data was 0.87 deaths per 1 billion VMT per year (pre-RCL MSPE = 0.047; post-RML MSPE = 0.803). In permutation ratio tests, 3 states (of 42) had a post-RCL:pre-RCL MSPE ratio

Figure 1. Traffic Fatalities per 1 Billion Vehicle Miles Traveled (VMT), Colorado vs Synthetic Colorado



All controls included the 42 states with no recreational cannabis laws (RCLs) or that implemented RCLs after 2017. States implementing RCLs during the study period or that were noncontiguous were not included. 2014 indicates year of RCL implementation.

higher than or equal to that of Colorado or Washington State (probability = 0.09).

Sensitivity Analyses

Excluding neighboring states resulted in a difference between Colorado and synthetic Colorado of 1.84 fatalities per 1 billion VMT per year (Table 2) (94 excess deaths per year); only 1 control state (of 35) had a post-RCL:pre-RCL MSPE ratio higher than or equal to that of Colorado (probability = 0.055). Exclusion of states without MCL resulted in a difference of 2.16 fatalities per 1 billion VMT per year (111 excess deaths per year); none of the other states (of 15) had an MSPE ratio higher than or equal to that of Colorado (probability = 0.063). Compared with the main findings, a smaller difference was observed, using 2013 as the first post-RCL year: the difference was of 0.46 fatalities per 1 billion VMT per year (24 excess deaths per year); 4 states (of 42) had an MSPE ratio higher than or equal to that of Colorado (probability = 0.116). No differences were found between Washington State and synthetic Washington in sensitivity analyses (probability >0.50).

Discussion

This study provides evidence that implementation of legal commercial retail sales of cannabis was associated with increased traffic fatalities in Colorado but not in Washington State. We used an empirical approach to generate control groups whose rates closely match the values of traffic fatality rates of states implementing these laws during the pre-RCL period; thus, controls more appropriately served as proxies for the counterfactuals to test these effects than controls selected using subjective measures of similarity between exposed and unexposed states.

These findings suggest that RCL outcomes can be heterogeneous and may be specific to variations in how RCLs are implemented. Colorado and Washington State RCLs differ in many ways, including purchasing limits, sales taxes, ability to

Table 2. Difference in Traffic Fatalities Between States Implementing RCLs and Synthetic Controls in the Postimplementation Period (2014-2017)

State by outcome	Mean post-RCL outcome gap	Pre-RCL MSPE	Post-RCL MSPE	Post-RCL:pre-RCL MSPE ratio[a]	Permutation ratio test result[b]	Probability
Main analysis, fatalities per 1 billion VMT						
Colorado	1.46	0.097	2.44	25.00	1/42	0.047
Washington State	0.08	0.16	0.31	1.88	28/42	0.674
Main analysis, age-adjusted rates (state population)						
Colorado	0.98	0.07	1.47	22.24	3/42	0.093
Washington State	0.04	0.11	0.25	2.20	28/42	0.674
Using enactment date, fatalities per 1 billion VMT						
Colorado	0.46	0.19	2.71	14.22	4/42	0.116
Washington State	0.25	0.08	0.20	2.99	23/42	0.558
Excluding neighbor states, fatalities per 1 billion VMT						
Colorado	1.84	0.07	3.60	48.50	1/35	0.055
Washington State	0.07	0.17	0.31	1.86	30/41	0.738
Excluding non-MCL states, fatalities per 1 billion VMT						
Colorado	2.16	0.19	4.98	25.89	0/15	0.063
Washington State	0.14	0.15	0.23	1.56	10/15	0.687

Abbreviations: MCL, medical cannabis law; MSPE, mean square prediction error; RCL, recreational cannabis law; VMT, vehicle miles traveled.

[a] Ratios were calculated prior to rounding.

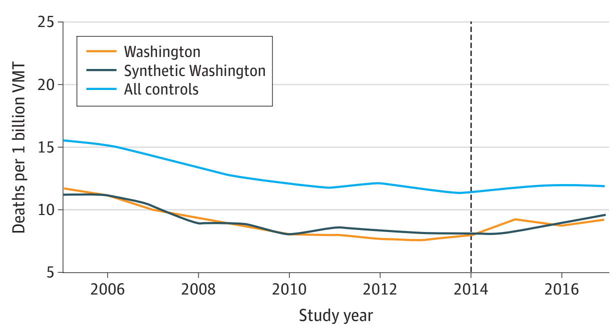
[b] Indicates the number of states (numerator) of included controls (denominator) with a post-RCL:pre-RCL MSPE ratio higher than or equal to that of Colorado or Washington State.

grow cannabis at home,[33-35] and density of retail stores. In December 2018, Colorado had 549 retail stores and 474 medical marijuana centers[36] compared with 433 retail stores in Washington State,[37] with retail store density per 100 000 adults of 23.32 in Colorado and 7.37 in Washington State. These factors may have contributed to higher cannabis availability and driving under the influence in Colorado than in Washington State. Consistent with these data, national survey data[38] show that from 2012 to 2015, the prevalence of past-month cannabis use in Colorado increased by 6% in those aged 18 to 25 years and by 41% in those 26 years or older, whereas in Washington State, the prevalence decreased by 14% and 15%, respectively. State differences in plant potency and routes of cannabis administration that can affect potency (eg, vaping, dabbing) may also have influenced state-level differences in outcomes, an important area for future research.

We observed that traffic fatalities did not follow reductions in the prevalence of past-month cannabis use in Washington State in 2014 to 2015. This may have occurred if other mechanisms through which RCLs affect traffic fatalities were stable or increased during this period, for example, daily or near-daily cannabis use among ongoing users, cannabis use with other drugs or alcohol, and driving under the influence of cannabis or other drugs or alcohol.

Cannabis tourism could also explain the finding in Colorado, because a higher number of neighboring states without RCLs can lead to a higher volume of out-of-state drivers buying, using, and driving under the influence of cannabis. Colorado has no neighboring states with RCLs, whereas in contrast, Washington State shares borders with Oregon, which implemented RCLs in 2015, and with Canada, which implemented MCLs in 2001. Cannabis tourism in Colorado is associated with increased cannabis-related emergency department visits among out-of-state residents.[39]

Figure 2. Traffic Fatalities per 1 Billion Vehicle Miles Traveled (VMT), Washington State vs Synthetic Washington



All controls included the 42 states with no recreational cannabis laws (RCLs) or that implemented RCLs after 2017. States implementing RCLs during the study period or that were noncontiguous were not included. 2014 indicates year of RCL implementation.

Other local factors may also influence the association between RCLs and traffic fatalities. For example, although both states enacted "drug per se" laws that consider blood concentration of at least 5 ng/mL of tetrahydrocannabinol in drivers a criminal offense, these laws may have been enforced differently. Although actions have been taken to reduce impaired driving in Colorado and Washington State, data to test this hypothesis are limited.

Our findings are consistent with research showing increases in cannabis-related traffic deaths[40] and in the proportion of injured patients with positive test results for cannabis in trauma centers in Colorado.[41] However, because cannabis can be stored in human tissue for as long as 5 days, these studies may simply reflect overall increase in the prevalence of cannabis use.

Our results are also consistent with research showing an increase in all traffic crashes after the implementation of RCLs in Colorado but not in Washington State.[42] Results for Colorado are also partially consistent with those from Lane and Hall.[25] However, these authors[25] found evidence of a steep increase in fatalities after legalization, followed by a nonsignificant reduction. We observed a continuous increase in fatalities, with the gap between Colorado and its synthetic control widening over time. Lane and Hall[25] also found a steep increase in fatalities in Washington State after RCLs, followed by a subsequent reduction. Although we observed increased fatalities in Washington State in 2015, fatality rates in 2016 to 2017 were similar to rates for the synthetic control. We used a synthetic control approach because it offers a transparent, data-driven procedure to select controls to approximate a counterfactual for exposed states while allowing a visual and analytical strategy to identify changes in outcome measures. The different findings in our study from those in Lane and Hall[25] may be attributable to the use of different controls and the analytical approach to estimate effects. Our findings also differ from those of Hansen et al.[26] This difference may be owing to inclusion of 2017 data and additional risk factors that enabled us to generate synthetic controls that closely matched fatality rates of Colorado and Washington State in the pre-RCL period.

Results from sensitivity analyses were in the same direction and consistent with results from the main analysis, although the effect was smaller using the enactment date instead of the implementation date. Because consequences of increased cannabis availability are expected when retail sales begin, a smaller effect was expected using the enactment date.

Previous studies on the association of MCL with traffic fatalities[21,22] have shown that MCLs are associated with reductions in fatalities. A potential explanation for these reductions is that cannabis could work as a substitute for alcohol,[21] an important risk factor for traffic events.[14] Although this may be true for a segment of the population, the much higher availability of cannabis after RCLs could increase the number of cannabis-impaired drivers to the point that it balanced out reductions from any substitution effects. Moreover, higher rates of traffic events are likely if more drivers are driving under the influence of cannabis in combination with alcohol and/or other drugs. The number of individuals with traffic fatalities who have positive findings for multiple substances, including alcohol, has increased in recent years in Colorado and Washington State,[43,44] suggesting that this may be the case. In addition, cannabis use may not only influence driving skills but could also lead to increased risky behavior, for example, reduced seatbelt use in drivers and passengers.[45,46] The prevalence of not wearing seatbelts among fatally injured passengers in Colorado was more than 50% in 2015, and approximately 30% in Washington State.[47] Whether such risky behavior was influenced by RCL implementation remains to be studied.

Limitations

Our study has several limitations. Although the use of a synthetic approach can improve the identification of a counterfactual, changes in other local policies or factors in the post-RCL period (eg, travel patterns, impaired driving, speeding unrelated to cannabis use) could partially explain our results for Colorado. Effects of these laws and factors would be attributed to RCLs in our study. Second, Washington State first opened licensed cannabis retail stores in July 2014. Classifying Washington State as exposed in 2014 could have reduced the magnitude of the RCL-fatality association for this state, because it was only exposed to cannabis retail sales for half of 2014. Third, lack of state-level data on nonfatal traffic injuries precluded testing whether RCLs are associated with these events. Collecting and making available these data could contribute to a better understanding of how cannabis legalization affects traffic events. Fourth, we did not examine the association of RCLs with cannabis-related deaths; because cannabis can be stored in human tissue for as long as 5 days, FARS data do not indicate whether the driver was driving under the influence of cannabis when the event occurred.[48]

Conclusions

Our study found that the implementation of RCLs was associated with increases in traffic fatalities in Colorado but not in Washington State. Findings suggest that adverse unintended effects of RCLs can be heterogeneous and may depend on variations in implementation of these laws (eg, density of recreational cannabis stores). These findings suggest the need for policies, public health programs, and enforcement strategies that will prevent unintended consequences of cannabis legalization, such as increased rates of traffic injuries.

ARTICLE INFORMATION

Accepted for Publication: April 9, 2020.

Published Online: June 22, 2020. doi:10.1001/jamainternmed.2020.1757

Author Affiliations: Center for Opioid Epidemiology and Policy, Division of Epidemiology, Department of Population Health, New York University School of Medicine, New York, New York (Santaella-Tenorio, Wheeler-Martin, DiMaggio, Castillo-Carniglia, Cerdá); School of Basic Sciences, Universidad del Valle, Cali, Colombia (Santaella-Tenorio); Department of Surgery, New York University School of Medicine, New York, New York (DiMaggio); Society and Health Research Center and School of Public Health, Universidad Mayor, Santiago, Chile (Castillo-Carniglia); Department of Epidemiology, Columbia University Mailman School of Public Health, New York, New York (Keyes); Division of Translational Epidemiology, Vagelos College of Physicians and Surgeons, Columbia University, New York, New York (Hasin); Division of Translational Epidemiology, New York State Psychiatric Institute, New York, New York (Hasin).

Author Contributions: Dr Santaella-Tenorio and Ms Wheeler-Martin had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.
Concept and design: Santaella-Tenorio, Castillo-Carniglia, Hasin, Cerdá.
Acquisition, analysis, or interpretation of data: Santaella-Tenorio, Wheeler-Martin, DiMaggio, Castillo-Carniglia, Keyes.
Drafting of the manuscript: Santaella-Tenorio, Wheeler-Martin, Cerdá.
Critical revision of the manuscript for important intellectual content: Santaella-Tenorio, DiMaggio, Castillo-Carniglia, Keyes, Hasin, Cerdá.
Statistical analysis: Santaella-Tenorio, Wheeler-Martin, Castillo-Carniglia, Keyes.

Obtained funding: Cerdá.
Administrative, technical, or material support: Santaella-Tenorio, Cerdá.
Supervision: DiMaggio, Hasin, Cerdá.

Conflict of Interest Disclosures: None reported.

Funding/Support: This study was supported by grant R01-HD087460 from the National Institute of Child Health and Human Development of the National Institutes of Health (Dr DiMaggio) and grant R01DA048860 from the National Institute on Drug Abuse (Dr Hasin).

Role of the Funder/Sponsor: The sponsors had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Additional Contributions: Julia Dilley, PhD (Program Design and Evaluation Services, Multnomah County Health Department and Oregon Public Health Division, Portland), provided important details about retail store availability in Washington State. She was not financially compensated for her contribution.

REFERENCES

1. Azofeifa A, Mattson ME, Schauer G, McAfee T, Grant A, Lyerla R. National estimates of marijuana use and related indicators: National Survey on Drug Use and Health, United States, 2002-2014. *MMWR Surveill Summ*. 2016;65(11):1-28. doi:10.15585/mmwr.ss6511a1

2. ProCon.org. Legal recreational marijuana, states and DC: cannabis laws with possession and cultivation limits. Updated June 25, 2019. Accessed July 28, 2019. https://marijuana.procon.org/view.resource.php?resourceID=006868

3. ProCon.org. Legal medical marijuana, states and DC: laws, fees, and possession limits. Updated July 24, 2019. Accessed July 28, 2019. https://medicalmarijuana.procon.org/view.resource.php?resourceID=000881

4. Cavazos-Rehg PA, Krauss MJ, Sowles SJ, Zewdie K, Bierut L. Operating a motor vehicle after marijuana use: perspectives from people who use high-potency marijuana. *Subst Abus*. 2018;39(1):21-26. doi:10.1080/08897077.2017.1365802

5. Greene KM. Perceptions of driving after marijuana use compared to alcohol use among rural American young adults. *Drug Alcohol Rev*. 2018;37(5):637-644. doi:10.1111/dar.12686

6. Keyhani S, Steigerwald S, Ishida J, et al. Risks and benefits of marijuana use: a national survey of US adults. *Ann Intern Med*. 2018;169(5):282-290. doi:10.7326/M18-0810

7. McCarthy DM, Lynch AM, Pederson SL. Driving after use of alcohol and marijuana in college students. *Psychol Addict Behav*. 2007;21(3):425-430. doi:10.1037/0893-164X.21.3.425

8. Lenné MG, Dietze PM, Triggs TJ, Walmsley S, Murphy B, Redman JR. The effects of cannabis and alcohol on simulated arterial driving: influences of driving experience and task demand. *Accid Anal Prev*. 2010;42(3):859-866. doi:10.1016/j.aap.2009.04.021

9. Ronen A, Gershon P, Drobiner H, et al. Effects of THC on driving performance, physiological state and subjective feelings relative to alcohol. *Accid Anal Prev*. 2008;40(3):926-934. doi:10.1016/j.aap.2007.10.011

10. Ramaekers JG, Kauert G, Theunissen EL, Toennes SW, Moeller MR. Neurocognitive performance during acute THC intoxication in heavy and occasional cannabis users. *J Psychopharmacol*. 2009;23(3):266-277. doi:10.1177/0269881108092393

11. Weinstein A, Brickner O, Lerman H, et al. A study investigating the acute dose-response effects of 13 mg and 17 mg Delta 9-tetrahydrocannabinol on cognitive-motor skills, subjective and autonomic measures in regular users of marijuana. *J Psychopharmacol*. 2008;22(4):441-451. doi:10.1177/0269881108088194

12. Hartman RL, Huestis MA. Cannabis effects on driving skills. *Clin Chem*. 2013;59(3):478-492. doi:10.1373/clinchem.2012.194381

13. Hartman RL, Brown TL, Milavetz G, et al. Cannabis effects on driving longitudinal control with and without alcohol. *J Appl Toxicol*. 2016;36(11):1418-1429. doi:10.1002/jat.3295

14. Sewell RA, Poling J, Sofuoglu M. The effect of cannabis compared with alcohol on driving. *Am J Addict*. 2009;18(3):185-193. doi:10.1080/10550490902786934

15. Robbe H. Marijuana's impairing effects on driving are moderate when taken alone but severe when combined with alcohol. *Hum Psychopharmacol Clin Exp.* 1998;13:S70-S78. doi:10.1002/(SICI)1099-1077(1998110)13:2+<S70::AID-HUP50>3.0.CO;2-R

16. Asbridge M, Hayden JA, Cartwright JL. Acute cannabis consumption and motor vehicle collision risk: systematic review of observational studies and meta-analysis. *BMJ*. 2012;344:e536. doi:10.1136/bmj.e536

17. Li MC, Brady JE, DiMaggio CJ, Lusardi AR, Tzong KY, Li G. Marijuana use and motor vehicle crashes. *Epidemiol Rev*. 2012;34:65-72. doi:10.1093/epirev/mxr017

18. Rogeberg O, Elvik R. The effects of cannabis intoxication on motor vehicle collision revisited and revised. *Addiction*. 2016;111(8):1348-1359. doi:10.1111/add.13347

19. Ramaekers JG, Robbe HW, O'Hanlon JF. Marijuana, alcohol and actual driving performance. *Hum Psychopharmacol*. 2000;15(7):551-558. doi:10.1002/1099-1077(200010)15:7<551::AID-HUP236>3.0.CO;2-P

20. Fink DS, Stohl M, Sarvet AL, Cerdá M, Keyes KM, Hasin DS. Medical marijuana laws and driving under the influence of marijuana and alcohol. [published online ahead of print March 5, 2020]. *Addiction*. doi:10.1111/add.15031

21. Anderson DM, Hansen B, Rees DI. Medical marijuana laws, traffic fatalities, and alcohol consumption. *J Law Econ*. 2013;56(2):333-369. doi:10.1086/668812

22. Santaella-Tenorio J, Mauro CM, Wall MM, et al. US traffic fatalities, 1985-2014, and their relationship to medical marijuana laws. *Am J Public Health*. 2017;107(2):336-342. doi:10.2105/AJPH.2016.303577

23. Hasin DS. US epidemiology of cannabis use and associated problems. *Neuropsychopharmacology*. 2018;43(1):195-212. doi:10.1038/npp.2017.198

24. Aydelotte JD, Brown LH, Luftman KM, et al. Crash fatality rates after recreational marijuana legalization in Washington and Colorado. *Am J Public Health*. 2017;107(8):1329-1331. doi:10.2105/AJPH.2017.303848

25. Lane TJ, Hall W. Traffic fatalities within US states that have legalized recreational cannabis sales and their neighbours. *Addiction*. 2019;114(5):847-856. doi:10.1111/add.14536

26. Hansen B, Miller K, Weber C. Early evidence on recreational marijuana legalization and traffic fatalities. *Econ Inq*. 2020;58(2):547-568. doi:10.1111/ecin.12751

27. Aydelotte JD, Mardock AL, Mancheski CA, et al. Fatal crashes in the 5 years after recreational marijuana legalization in Colorado and Washington. *Accid Anal Prev*. 2019;132:105284. doi:10.1016/j.aap.2019.105284

28. Abadie A, Diamond A, Hainmueller J. Synthetic control methods for comparative case studies: estimating the effect of California's tobacco control program. *J Am Stat Assoc*. 2010;105(490):493-505. doi:10.1198/jasa.2009.ap08746

29. US Department of Transportation, Federal Highway Administration. Highway Statistics Series. Modified November 13, 2019. Accessed August 4, 2019. https://www.fhwa.dot.gov/policyinformation/statistics.cfm

30. US Census Bureau. Web-based Injury Statistics Query and Reporting System (WISQARS) website. Reviewed May 8, 2018. Accessed March 15, 2020. https://www.cdc.gov/injury/wisqars/fatal_help/data_sources.html#6.4

31. Abadie A, Diamond A, Hainmueller J. Comparative politics and the synthetic control method. *Am J Pol Sci*. 2015;59:495-510. doi:10.1111/ajps.12116

32. Cerdá M, Mauro C, Hamilton A, et al. Association between recreational marijuana legalization in the United States and changes in marijuana use and cannabis use disorder from 2008 to 2016. *JAMA Psychiatry*. 2019.

33. Municipal Research and Services Center of Washington. Marijuana regulation in Washington State. Modified December 17, 2019. Accessed September 6, 2018. http://mrsc.org/Home/Explore-Topics/Legal/Regulation/Marijuana-Regulation-in-Washington-State.aspx

34. Article XVIII. Section 16: personal use and regulation of marijuana, Colorado Constitution. Accessed September 6, 2019. https://www.colorado.gov/pacific/sites/default/files/Section%2016%20-%20%20Retail.pdf

35. Carnevale JT, Kagan R, Murphy PJ, Esrick J. A practical framework for regulating for-profit recreational marijuana in US States: lessons from Colorado and Washington. *Int J Drug Policy*. 2017;42:71-85. doi:10.1016/j.drugpo.2017.03.001

36. Enforcement Division, Colorado Department of Revenue. 2018 Archived MED medical and retail marijuana licensee lists. Published 2019. Accessed April 29, 2020. https://www.colorado.gov/pacific/enforcement/2018-archived-med-medical-and-retail-marijuana-licensee-lists

37. Washington State Liquor and Cannabis Board. Marijuana sales activity by license number, traceability contingency reporting. Updated April 6, 2020. Accessed April 29, 2020. https://lcb.wa.gov/records/frequently-requested-lists

38. Substance Abuse and Mental Health Service Administration. State reports from the 2016 NSDUH. Posted January 24, 2017. Accessed September 6, 2019. https://www.samhsa.gov/data/nsduh/state-reports-NSDUH-2016

39. Kim HS, Hall KE, Genco EK, Van Dyke M, Barker E, Monte AA. Marijuana tourism and emergency department visits in Colorado. *N Engl J Med*. 2016;374(8):797-798. doi:10.1056/NEJMc1515009

40. Lee J, Abdel-Aty A, Park J. Investigation of associations between marijuana law changes and marijuana-involved fatal traffic crashes: a state-level analysis. *J Transp Health*. 2018;10:194-202. doi:10.1016/j.jth.2018.05.017

41. Chung C, Salottolo K, Tanner A II, et al. The impact of recreational marijuana commercialization on traumatic injury. *Inj Epidemiol*. 2019;6(1):3. doi:10.1186/s40621-019-0180-4

42. Monfort S. Effect of recreational marijuana sales on police-reported crashes in Colorado, Oregon, and Washington. Posted October 2018. Accessed March 18, 2020. https://www.iihs.org/topics/bibliography/ref/2173

43. Reed J. Impacts of marijuana legalization in Colorado: a report pursuant to Senate Bill 13-283. Colorado Department of Public Safety. Division of Criminal Justice. Published October 2018. Accessed January 22, 2020. https://cdpsdocs.state.co.us/ors/docs/reports/2018-SB13-283_Rpt.pdf

44. Washington Traffic Safety Commission. Washington State 2018 traffic safety annual report. Published December 17, 2018. Accessed September 12, 2019. https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/wa_fy2018_ar.pdf

45. Liu C, Huang Y, Pressley JC. Restraint use and risky driving behaviors across drug types and drug and alcohol combinations for drivers involved in a fatal motor vehicle collision on US roadways. *Inj Epidemiol*. 2016;3(1):9. doi:10.1186/s40621-016-0074-7

46. Steinemann S, Galanis D, Nguyen T, Biffl W. Motor vehicle crash fatalities and undercompensated care associated with legalization of marijuana. *J Trauma Acute Care Surg*. 2018;85(3):566-571. doi:10.1097/TA.0000000000001983

47. National Center for Statistics and Analysis, National Highway Traffic Safety Administration. Occupant protection in passenger vehicles: 2015 data. Traffic Safety Facts. Report DOT HS 812 374. 2017:1-8. Accessed April 25, 2020. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812374

48. Hartman RL, Huestis MA. Re: "trends in alcohol and other drugs detected in fatally injured drivers in the United States, 1999-2010". *Am J Epidemiol*. 2014;180(8):862-863. doi:10.1093/aje/kwu251