International Journal of *Environmental Research and Public Health*

MDPI

Type of the Paper (Review)

Effects of Cannabis Legalization on Road Safety: A Literature Review.

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Abstract: Background: Legalizing medical and recreational cannabis and decriminalizing this substance may have unanticipated effects on traffic safety. The present study aimed to assess the impact of cannabis legalization on traffic accidents. Methods: A systematic review was carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) declaration of the articles included in the Web of Science (WoS) and Scopus databases. The number of papers included in the review was 29. Results: The results show that in 15 papers, there is a relationship between the legalization of medical and/or recreational cannabis and the number of traffic accidents, while in five papers, no such relationship is observed. In addition, nine articles indicate a greater number of risk behaviors related to driving after consumption, identifying young, male and alcohol consumption together with cannabis as the risk profile. Conclusions: It can be concluded that the legalization of medical and/or recreational cannabis has negative effects on road safety if the number of articles that find an effect on the number of fatal accidents is taken into account.

Keywords: cannabis; marijuana; legalization; traffic accidents; road safety; systematic review

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Received: date
Accepted: date
Published: date

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1. Introduction

Drug consumption is a market that generates a high amount of profit. Although cannabis is not the illegal substance that generates the most money due to its low cost, it is the most consumed, abused, and trafficked substance [1]. Currently, a series of policies are being adopted in different countries in favor of the legalization of this substance, whether medicinal or recreational, as well as decriminalization campaigns in relation to its use.

Colorado and Washington were the first US states to legalize this substance for recreational use in 2012. In 2013, Uruguay became the first country in the world to legalize the sale and cultivation of recreational marijuana. Canada was the following country to join, adopting the measure in 2018, being the first G7 country [2,3].

With all these changes, different studies have begun to collect scientific evidence of the effects that the implementation of this measure can produce on various public areas, such as health [4], the prevalence of consumption or its relationship with road safety and traffic [5-7] among others.

Regarding traffic and driving, Hartman and Huestis [5] point out that recent THC consumption of between 2 to 5 nG/mL in blood is associated with the inability to drive a vehicle. Along the same lines, Li et al. [6] conducted an extensive meta-analysis in which they concluded that cannabis use by drivers is associated with a significant increase in the risk of being involved in a traffic accident. Similarly, Woo et al. [8] indicate that cannabis use predicts risky behavior in fatal traffic crashes, despite alcohol remaining a better predictor. Regarding the consequences brought by the legalization of recreational cannabis, according to Roffman [7], the number of drivers driving under the influence of cannabis increased after its legalization in Washington, from 22.2% of cases to 32.7%. Likewise, they also observed a 111% increase in the number of fatal traffic accidents where cannabis was involved in 2014 versus the 4 years prior to legalization. Kamer et al. [9] report an increase in fatal traffic accidents following the legalization of recreational cannabis in the states of Alaska, Colorado, Oregon, and Washington compared to 20 states that had not legalized either medical or recreational cannabis.

In Canada, according to National Cannabis Survey [10], there is no detectable increase in drivers who have consumed in the two hours after consumption before and after legalization, but there is an increase in cases of drivers who tested positive for cannabis of which 20% also report having consumed alcohol, after legalization.

Other studies contradict these results. Romano et al. [11] do not find a significant relationship between testing positive for cannabis as a driver and the risk of having an accident, but there is a relationship with other illegal drugs and mainly alcohol [12]. For their part, Fergusson and Horwood [13] attribute the association between cannabis use and the risk of having a traffic accident to the characteristics of young people, who tend to use cannabis, rather than to the effects of this substance on driving ability, since cannabis users have a greater tendency to drive under the influence of alcohol and engage in risky driving behaviors, as well as a greater tendency to violate traffic regulations [14-16].

These contradictory results only increase the uncertainty regarding the actual effect of cannabis legalization on trafficking, which makes the search for scientific evidence even more necessary. In this regard, Palamar et al. [17] point out that with legalization, marijuana consumption may increase due to an increase in the acceptability of this substance and a decrease in the perception of its danger, causing, in turn, a significant increase in the number of individuals who drive under the influence of cannabis. Regarding causality, Cavazos-Rehg et al. [18] argue that the risk of an accident is not a direct cause of legalization, since the decision to drive under the influence of cannabis is a purely individual act.

The aim of the present study was to determine the effect of the legalization or decriminalization of medical and/or recreational cannabis on fatal and non-fatal traffic accidents by means of a systematic review, providing arguments based on scientific evidence to help in decision-making and the design of preventive programs. The following hypotheses are proposed as hypotheses of the study:

- Hypothesis 1: There is a positive relationship between the legalization of medical cannabis and the incidence of traffic accidents.

- Hypothesis 2: There is a positive relationship between the legalization of recreational cannabis and the incidence of traffic accidents.

- Hypothesis 3: There is a positive relationship between cannabis legalization and a higher number of risky behaviors associated with driving, such as lower use of protective driving devices, reckless driving and riding as a passenger with a driver who has consumed before driving.

- Hypothesis 4: There is a higher risk profile in drivers who test positive for cannabis while driving, such as being male and young.

2. Materials and Methods

Search strategy

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [19], (for further details of the PRISMA process, see Supplementary Table S1). The search was performed in August 2022 in the Web of Science Core Collection (WOS) database and Scopus. The keywords selected in the subject field were ("driver* OR motor vehicle* OR road safety* OR car accident* OR crash fatalit* OR driving risk* OR injured driver* OR vehicle*") AND ("legalization*") AND ("marijuana*" OR cannabis*"). The search period covered the last 10 years, from 2012 to 2021.

Selection criteria

The inclusion criteria were scientific articles written in English or Spanish that compared results on traffic accidents and marijuana use before and after legalization or between states or countries that have legalized recreational and/or medical marijuana and those that have not.

As exclusion criteria, other documentary typologies were established, such as reviews, letters to the editor, conference proceedings or book chapters written in languages other than English and Spanish, or did not compare between legalization and post-legalization periods or between states.

Study selection

The number of papers found in WoS was 103 and in Scopus 86 (see Figure 1). After reviewing the references of the selected articles in a reverse search process [20] in order to identify useful references that had not appeared in the initial search, 8 more articles were included. After eliminating the duplicates, 68 papers, a first review of the title and abstract was performed, eliminating 77 papers, mainly because they did not include a comparison between countries or states that had or had not legalized the use of cannabis or because they did not compare between the period before and after legalization. After downloading and reading the 48 selected articles, 19 were eliminated for not being able to download through the VPN of the University of Valencia (4 articles), one for being a conference and for not analyzing the effects of legalization in relation to road safety (14 articles), bringing the total number of articles included in this review to 29 (see Figure 1).

This entire process of analysis to determine the suitability or otherwise of the articles to the research objective, as well as the extraction of the results according to the variables under study, was carried out independently by two researchers who acted as "blinded" evaluators. In cases in which there was disagreement, mainly in some results related to the objectives of the systematic review, a third researcher participated in the decision-making, and the results were accepted as valid by consensus after addressing the discrepancies between evaluators.

The methodological quality of the articles selected for the present systematic review was assessed through 10 of the 18 indicators included in the SQUIRE Guidelines 2.0 quality scale [21]. These indicators were title, abstract, problem description, specific aims, measures, analysis, results, limitations and conclusions. The articles were classified into three categories according to their quality - low, medium and high -. This process was carried out by two of the researchers, who concluded that the articles included in the review were in a high category, so none of the selected articles were eliminated.

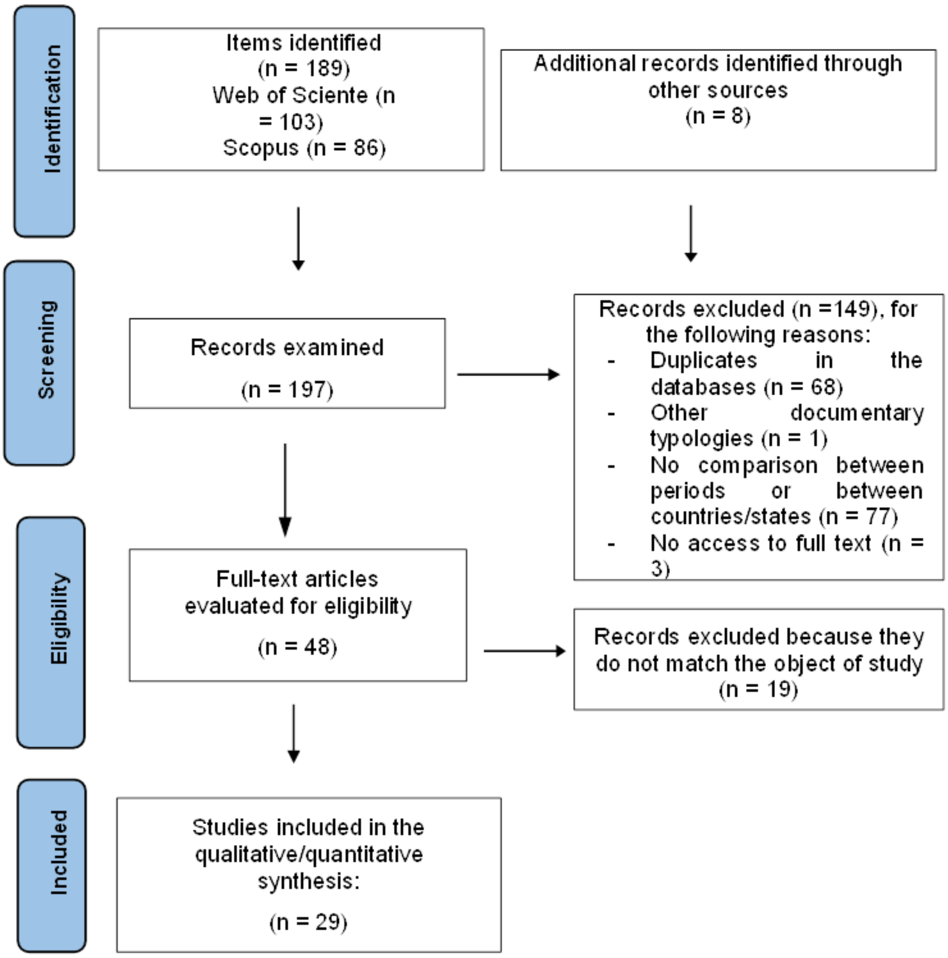

Figure 1: *Flow of information through the different phases of a systematic review*

3. Results

3.1. Characteristics of the studies included in the systematic review.

Of the 29 articles included in this review eight of them have focused on the legalization of medical cannabis [33,34,36,38,43,46-48]. With respect to recreational cannabis, there are 13 papers that have addressed the impact of its legalization with respect to traffic accidents [3,23,25-32,39,40,41], two papers have included both medical and recreational cannabis [22,37] and seven papers discuss decriminalization and legalization of cannabis in general [8,24,35,37,42,44,45].

Regarding the origin of the samples, two papers are from Canada [23,29], one paper is from Uruguay [28], one paper has samples from three countries, the United States, Canada and England [34] and the remaining papers, 25 in total, are from the United States, with the States of California, Colorado and Washington being the most represented. In relation to the samples, it should be noted that these are mainly made up of men, except for two works that have a greater presence of women [3,34], with a minimum age of 14 years [43,45], with a large number of studies that in addition to collecting data on cannabis use, they also report on alcohol use [3, 8, 24, 30, 31 ,33-36, 38, 42, 47, 48].

The data (16 studies) are collected from the Fatality Analysis Reporting System (FARS) database [8,25,26,31,32,36-40,42-44,46-48]. This database collects information at a national level on some 100 indicators related to the driver, the vehicle and the circumstances associated with the accident in those cases in which the death of the driver or a person who was not a driver occurred in the 30 days after the accident. The relevance of this database for studies that have addressed the effect of cannabis legalization on road safety is due to the fact that it collects tests for different drugs, including the presence of cannabis in blood and/or urine, although It also has limitations as reflected in the studies analyzed, such as the fact that drug tests are not always carried out [illegible] the differences between states in the regulation of the THC level in the blood when testing positive for this aspect, which has been collected as limitation in different studies [22, 24, 30, 31, 37, 38, 42].

3.2. Relationship between the legalization of medical cannabis and traffic accidents.

Table 1 and Table 2 list the articles that have addressed the impact of the legalization of medical cannabis in relation to traffic accidents. Three studies have compared the effect of legalization at two points in time, before and after legalization [33,36,47], five studies have compared between states that have legalized medical cannabis versus states that have not legalized it [38,43,46,47,48] and a study has compared countries with legalization laws, the United States and Canada, against England, a country that has not legalized cannabis [34].

As can be seen in Table 2, two papers found increases in the number of fatal accidents after legalization [33,36]. Regarding the pre- and post-legalization period Jones et al. [33], after analyzing the 14,710 drivers who had been tested for cannabis, found that 2,590 tested positive for this substance, which is 17.6% of the total. Of these, 42% also tested positive for alcohol. The results also point to a slight significant increase in the proportion of drivers under the influence of cannabis compared to the pre-legalization period, from 5.6% to 9.6%; the same effect was also observed for drivers under the influence of alcohol and for dual alcohol and cannabis use. Steinemann et al. [36] analyze traffic crashes occurring pre- and post-MCL in Hawaii, concluding that crashes resulting in death nearly tripled from 5.5% between 1993 and 2000 to 16.3% between 2011 and 2015. However, they find no change in the prevalence of alcohol or other substances such as methamphetamine. Drivers who tested positive for THC in drug tests were usually younger, the accident occurred at night and used fewer protective mechanisms, such as seat belts. In addition, in 63% of cases, dual use of alcohol and cannabis was observed. When compared between states that have legalized medical cannabis and those that have not, Solomonsen-Sautel et al. [47] detect a positive trend in the proportion of fatal traffic crashes involving cannabis in Colorado compared to those states that had not legalized it; however, this trend was not observed in the proportion of fatal traffic crashes involving alcohol consumption. More specifically, Colorado saw an increase in drivers testing positive for cannabis between 1994 and 2011, decreasing in the pre-legalization period (-0.19(0.08) $p = 0.0227$) and increasing again significantly after legalization (2.16 (0.45) $p = 0.0001$). This trend is significantly different from that in states that have not legalized medical cannabis use, which remains stable over the years.

Other studies find mixed results, noting increases only in some states [38,43,46] while one study finds no effect between legalization and fatal traffic accidents [48].

Sevigny et al. [38] find that the MCL does not have an effect on the number of drivers under the effect of cannabis detected, except in the case where the sale through dispensaries has been regulated, where he does find a significant increase of 14% in the number of drivers with cannabis use in 2014, this means going from 87 to 113 drivers testing positive in this type of accident per year. In addition, among illegal drugs, it is cannabis for which a greater presence in drivers was found (8.8%) compared to stimulants (6.1%) or narcotics (4.2%), among others. In the case of alcohol, the percentages are around 25%. The highest percentage of cannabis-positive drivers involved in fatal accidents is in states with marijuana decriminalization policies (28%), 16% in states with THC laws, 14% in states with medical marijuana laws and just 0.2% in states with recreational marijuana laws.

Santaella-Tenorio et al. [43] find a decrease in fatal accidents after legalization, although this decrease only occurs in 7 states and in drivers between 15 and 44 years of age.

Masten and Guenzburger [46] detect an increase in the number of drivers under the impact of cannabis in the period from 1992 to 2009, this research employs an interrupted series design analyzing twelve states (Alaska, California, Colorado, Hawaii, Michigan, Montana, Nevada, New Mexico, Oregon, Rhode Island, Vermont and Washington) in which medical marijuana had already been legalized. Still, they only find a significant trend increase in the states of Washington, with an increase of 3. 4 percentage points in the number of cases and a 4.6 percentage point increase for injured drivers; Hawaii, with a 6 percentage point increase in the number of drivers and a 9.6 percentage point increase for those drivers with injuries, and California with a 2.1 percentage point increase in the number of drivers and a 5.7 percentage point increase among drivers with injuries.

Finally, Anderson et al. [48] found no significant differences in the increase in fatal accidents after the MCL in the 19 states that took this measure but a decrease in the number of fatal accidents where alcohol was present, suggesting that cannabis consumption exerts a substitutive effect to alcohol consumption. The study also indicates a significant decrease between 10% and 13% in the mortality rate in the first 4 years after legalization, although this effect ceases to be significant in the fifth year.

In a comparative analysis between the United States, Canada and England conducted by Wadsworth and Hammond [34], they observed higher cannabis use, greater access to cannabis, lower risk perception and a higher prevalence of cannabis-impaired drivers in these first two countries compared to England, this is due according to the authors, to the prohibitive laws in England, as well as to previous trends already existing in relation to consumption. Specifically, 15.4% in Canada, 9.4% in England and 27.7% in the United States have driven within two hours after consuming cannabis, 18%, 11% and 25%, respectively, have been passengers in a car in which the driver had consumed and with regard to the perceived risk of having an accident after consumption, 53.2% in Canada, 56.7% in England and 43.6% in the United States consider this risk to be high.

Table 1. *Studies related to the legalization of medical cannabis: Country, sample and most relevant variables.*

Article	**Country / Years / Most relevant characteristics of the sample**	**Variables / Data collected**
Jones et al (2019) [33]	U.S. Arizona. (2008-2014) N= 30,083 injured driver. Aged ≥ 16 years . THC+: N=2,590, 71% Male. Alcohol+: N=5266, 75.6% Male. THC+ aand any alcohol: N=1086, 77.8% Male).	Use of cannabis, alcohol or both substances after a traffic accident. Pre-legalization: Jan 2008 - Apr 2011 Post-legalization: Apr 2011 - Dec 2014. Urine drug screens for cannabis metabolites and BAC.
Wadsworth & Hammond (2019) [34]	Canada N = 4008 (Male 34,7%), England N = 3970 (Male 42.7%), U.S. N = 4086 (Male 39.6%) 16-19 years old. July, 2017	Use, access, perceptions of harm and driving after cannabis and/or alcohol use. Sociodemographic variables. Self-report completed web-based surveys.
Steinemann et al. (2018) [36]	U.S. Hawaii (1993-2015). N = 1578 drivers killed in traffic crashes. Pre-legalization (1993-2000): N = 560, Age 27±17, Male 80%. THC+ 31(6%). Post-legalization (2001-2015): N = 1018, Age 39±17, Male 84%. THC+ 151(15%).	THC+ and alcohol in drivers. Pre and post-legalization. Fatality Analysis Reporting System database. Cannabis and others drugs: Urine toxicology. Alcohol: Blood drug test.
Sevigny (2018) [38]	U.S. (1993-2014). Nearly 1.2 million drivers involved in fatal traffic accidents. THC+ 8.8% BAC ≥ 0.08 = 20.1%. Male 74%. Mean age 40 years	Presence of THC, other illicit drugs and alcohol. Variables related to the regularization of cannabis. Contextual and control variables. FARS. Blood drug test.
Santaella-Tenorio et al. (2017) [43]	U.S. 50 States. (1985-2014). N=1,220,610 deaths in traffic accidents.	Fatal traffic accidents. Age 14-24, 25-44 and 45< years. Date MML by State. Dispensaries. FARS. Blood drug test.
Masten & Guenzburger (2014) [46]	U.S. 14 States legalizing cannabis before 2010 and 37 jurisdictions without medical cannabis laws (1992-2009). Drivers involved in fatal crashes: THC+ N=19,977.	Presence of THC in drivers involved in fatal traffic accidents. FARS.. Blood and/or urine drug test.

Article	**Country / Years / Most relevant characteristics of the sample**	**Variables / Data collected**
Article	**Country / Years / Most relevant characteristics of the sample**	**Variables / Data collected**
Salomonsen- Sautel et al. (2014) [47]	U.S. Colorado and compares with 34 states where it has not been legalized. (1994-2011). Drivers involved in fatal crashes.	THC+ or alcohol BAC ≥ 0.08. Pre-comercial Jun 1994–Jul 2009 Post-comercialization Jul 2009-2011. FARS.. Blood and/or urine drug test.
Anderson et al. (2013) [48]	U.S. (1990-2010) Age: 15 – 60< years old.	Fatal traffic accidents. Sociodemographic variables. Control states and MCL states. FARS. Blood drug test.

Note: BAC (blood alcohol concentration), FARS (Fatality Analysis Reporting System database), MCL (Medical cannabis legalization).

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Table 2. *Studies related to the legalization of medical cannabis: Design, main results and limitations.* 250

Article	Study design / Statistical analysis	Main result	Limitations
Jones et al (2019) [33]	Interrupted Time Series	Before legalization positive drivers decreased by 0.5%/year (95% CI: −1.0/year, 0.0/year). After legalization significant increase in driver trend THC+ 0.6%/year (95% CI: 0.0/year, 0.8/year).	Differences between and within States in drug testing protocols. Testing positive for THC does not imply recent use. No control group.
Wadsworth & Hammond (2019) [34]	Chi-squared tests, nominal logistic regression and multinomial logistic regression models	There are significant differences in driving after cannabis use between countries. England less likely to drive after consumption than Canada ($p<0.001$) and the U.S. ($p<0.001$). Canada less likely than U.S. ($p<0.001$).	Self-report measures. Social desirability. Biases in recall. General legislation of the country is taken and differences between different districts/cities are not taken into account. Non-random subject selection.
Steinemann et al. (2018) [36]	T-tests and Chi-squared tests.	Significant increase ($p<0.001$) in the number of drivers testing positive for THC after legalization in 2000 in fatal accidents.	THC+ does not imply recent consumption. A THC level cannot be extrapolated to an accident risk level. There is no discrimination between acute, heavy and chronic use.
Sevigny (2018) [38]	Differences-in-Differences (DiD) design. Generalized linear model (GLM) with a binomial distribution and logit link function. Sensitivity analyses.	There is no relationship between the MCL and the number of fatal traffic accidents OR [95% CI] 1.05 [0.93, 1.19]. The implementation of medical cannabis dispensaries does correlate with a higher number of accidents involving cannabis OR [95% CI] 1.14 [1.02, 1.29] ($p<0.01$).	THC+ does not imply recent use. Differences between states in drug testing protocols, as well as changes in trends after legalization. Not all crash victims are drug tested. Levels of cannabis use are not systematically quantified.

Article	**Study design / Statistical analysis**	**Main result**	**Limitations**
Article	**Study design / Statistical analysis**	**Main result**	**Limitations**
Santaella-Tenorio et al. (2017) [43]	Multilevel regression models with state-level random intercepts.	States with MCL laws have lower traffic fatality rates than states without MCL laws (26.3% lower; 95% confidence interval [CI] = 13.9%, 36.9%). 10.8% reduction in deaths after MCL (95% CI=9.0%). 12.5% reduction = [1 – exp(–0.114)]. Following the legalization of cannabis, there is a reduction in fatal traffic accidents in 7 States.	Causal relationships cannot be established. Local aspects that may have an influence are not taken into account. Short post-legalization periods. THC tests are not done.
Masten & Guenzburger (2014) [46]	Time series analyses Auto-Regressive Integrated Moving Average analysis.	MCL is only associated with an increase in fatal traffic accidents in California, Hawaii and Washington (out of a total of 12 states) after adjusting for frequency of drug testing by state and prevalence of cannabinoids in drivers in states that they have no legalization laws.	They only study fatal traffic accidents. State differences in drug testing protocols and changes in trends after legalization. Not all crash victims are tested for drugs. THC+ does not imply recent use.
Salomonsen-Sautel et al. (2014) [47]	Linear Regression Analysis. Estimated generalized least squares (EGLS) methods.	Significant trend change (2.16 (0.45), $p<0.0001$) in Colorado (not in the rest of the States) after legalization, with an increase in THC positives in drivers involved in fatal accidents.	They only study fatal traffic accidents. THC+ does not imply recent use. Levels of marijuana use are not systematically quantified. .
Anderson et al. (2013) [48]	Linear Regression Analysis by ordinary least squares (OLS) estimates	Legalization implies a significant decrease in fatal traffic accidents, although when state-specific time trends lines are included, the decrease is not significant ($p=0.139$). Legalization implies a reduction in accidents where the driver tests positive for alcohol ($R=-.141$, $p < 0.01$) and in cases where the alcohol level is higher than .10 ($R=.168$, $p < 0.05$).	Not specified

3.3. Relationship between legalization of recreational cannabis and traffic accidents.

Table 3 and Table 4 list the studies that have addressed the impact of the legalization of recreational cannabis in relation to traffic accidents. Eleven studies have compared the effect of legalization at two points in time, before and after legalization [3,23,25,26,28-30, 32,39-41] and six studies have compared between states that legalized cannabis recreational versus states that have not legalized it [3,27,31,39-41].

In relation to the legalization of recreational cannabis, seven studies do find an increase in traffic accidents in one of the states that legalized recreational cannabis after its legalization [3,25,26,28,30,32,41], one study indicates increases after the opening of dispensaries [40], while two studies did not find an effect on road safety [23,39]. On the other hand, the studies that have compared between states that have legalized cannabis and those that have not, four of them find a greater effect in the states that have legalized recreational cannabis [3,27,40,41] and two works do not find significant effects [31,39].

Table 3. *Studies related to the legalization of recreational cannabis: Country, sample and most relevant variables.*

Article	Country / Years / Most relevant characteristics of the sample	Variables / Data collected
Callaghan et al. (2021) [23]	Canada. (2015-2019). Alberta N=52,752. Mean age 38.8(SD=16.4). 45,8% female. Youth-driver N=3,265, Mean age 17.2 (SD=0.80). 54.7% female. Ontario N=186,921. Mean age 41.3(SD=17.2). 48.6% female. Youth-driver N=4,565. Mean age 16.6(SD=0.75). 49.2% female.	Weekly visits to medical emergencies for injuries in traffic accidents. Young drivers and total drivers. Pre-legalization Apr 1, 2015 – Oct 16, 2018. Post-legalization Oct 17, 2018 – Dec 31, 2019. National Ambulatory Care Reporting System database.
Tefft & Arnold (2021) [25]	U.S. Washington. (2008-2019). N = 8.282 THC+: N = 735 (8.9%), Age 23-42 years, 83% Male. Negative: N = 3528 (42.6%). Age 26-57 years, 77% Male. Unknown: 4019 (48.5%), Age 25-56 years, 78% Male.	THC in blood: Positive (1.0 ng/mL or more). Negative no THC detected in blood. Unknown: no drug test or no confirmation. THC concentrations were 0, 1.0–4.9 ng/mL, 5.0–9.9 ng/mL, and ≥10.0 ng/mL. Pre-legalization Jan 1, 2008 – Dec 5, 2012. Post-legalization Dec 6, 2012 – Dec 31, 2019. Vehicle and crash characteristics. FARS.
Windle et al. (2021) [26]	U.S. 10 states and District of Columbia. Recreational cannabis dispensaries (7 states). (2007-2018). 73,982 fatal motor vehicle collisions and 80,402 death. Periods RCL: 17,116 accidents and 18,580 deaths. Periods no legalization: 56,866 accidents and 61,822 death.	Fatal accidents. Deaths following a collision. Recreational cannabis dispensaries (7 states). Cannabis-specific impaired driving law: Zero tolerance, Per se limit ≥ 2 ng/mL THC, Per se limit ≥ 5 ng/mL THC or None. FARS.

Article	**Country / Years / Most relevant characteristics of the sample**	**Variables / Data collected**
Article	**Country / Years / Most relevant characteristics of the sample**	**Variables / Data collected**
Lensch et al. (2020) [27]	U.S. N=17112 adults. Aged 16–65. (2018). Legal sale states: N = 5,548. Age mean 39.8 (SD=16.0), 50.5% Male. Non-legal sale states: N = 11,564. Age mean 40.1 (SD=14.5), 49.7% Male.	Six legal sale states with dispensaries. Non-legal sale states that despite legalizing marijuana, there are no dispensaries. Attitudes and behaviors related to driving, consumption and frequency of cannabis use. Web-based surveys (Self-reported).
Nazif-Muñoz et al. (2020) [28]	Uruguay. Montevideo and 4 rural provinces. (2012-2017). N = 3,037 fatal accidents.	Accidents and mortality rate in traffic accidents. Urban and rural areas. Type of vehicle: automobiles and motorcycles. National Road Safety Agency of Uruguay and the Ministry of Transport and Public Works
Rotermann (2020) [29]	Canada. (2018-2019). Age 15<. Pre-legalization: N=17,683. Post-legalization: N = 21,872.	Prelegalization: first, second, and third quarters of 2018. Postlegalization: first, second, third, and fourth quarters of 2019. Consumption and origin of the product. Driving a vehicle 2 hours after consumption. Accompanying a driver who has consumed. National Cannabis Survey: Internet-based electronic questionnaire
Borst et al. (2020) [30]	U.S. California. (2010-2018). N = 11,491 between 24 and 51 years old. Age mean 34 years old. 61.5% male. THC+: N = 1,345. Age mean 27 years, 74% Male. THC and Alcohol positive: N = 578. Age mean 26 years. 77% Male. No use: N = 7078. Age mean 28 years. 59.7% Male	Type of use: No use, cannabis only, alcohol only (>0.08%), cannabis and alcohol and cannabis with methamphetamines or cocaine. Pre-legalization: 2010-2015. Post-legalization: 2016-2018. Data concerning injuries and protective measures. San Diego County's trauma center registries. Blood and urine test.
Hansen et al. (2020) [31]	U.S. Colorado, Washington and controlled states. (2000-2016).	Fatal traffic accidents, alcohol-involved accidents and marijuana-involved accidents. FARS.
Santaella et al. (2020) [32]	U.S. Colorado and Washington and 42 controlled states. (2005-2017).	Mortality rate per traffic accident and year. Vehicle miles traveled. Age adjusted fatality rates. Pre-legalization 2007-2013. Post-legalization 2014-2017. FARS.
Delling et al (2019) [3]	U.S. Colorado. Controlled states. (2010-2014). N= 88,319. Colorado: Total admissions N = 2,088,909. Age 45±28 years. 42% Male. New York: Total admissions N = 11,726,283. Age 49±28 years. 41% Male. Oklahoma: Total admissions N = 2,334,988. Age 48±28 years. 43% Male.	Admission to hospital due to traffic accidents. Sociodemographic and health variables and alcohol consumption. Healthcare Cost and Utilisation Project database.
Aydelotte et al (2017)	U.S. States Colorado and Washington. 8 control states. (2009-2015). N=60,737 fatal	Number of fatal traffic accidents. Billion vehicle miles traveled. FARS.

Article	**Country / Years / Most relevant characteristics of the sample**	**Variables / Data collected**
[39]	traffic accidents.	

Article	**Country / Years / Most relevant characteristics of the sample**	**Variables / Data collected**
Aydelotte et al (2019) [40]	U.S. Colorado, Washington and 9 control States. (2007-2017). N=25,561 fatal accidents (Prelegalization N = 12,348; Postlegalization N = 12,865)	Fatal traffic accidents. Legalization: Before Nov. 2007 – Oct 2012, After Jan 2013 – Dec 2017. Period commercial dispensaries Aug 2014- Dec 2017. Period opening of the first dispensary Aug 2010 – Dec. 2013. Billion vehicle miles traveled. Gross domestic product. Control variables in control states. FARS.
Lane & Hall (2019) [41]	U.S. 12 States. States LRC (Colorado, Washington and Oregon). 9 adjoining states . (2009-2016)	Rate of fatal traffic accidents per million population. States that have legalized recreative cannabis and neighbouring states. Centers for Disease Control and Prevention'sWide-Ranging Online Data for Epidemiologic Research and RoadSafetyBC report.

Note: FARS (Fatality Analysis Reporting System database), MCL (Medical cannabis legalization).

Focusing in more detail on the studies included in this section (Tabla 3 and 4), Delling et al. [3] focus on whether, after MRL in Colorado, there has been an increase in traffic accidents using Oklahoma and New York as control states, with an increase in fatal accidents in Colorado compared to control states after legalization. In addition, there has been a significant increase in hospitalizations for cannabis use in Colorado and alcohol use compared to the control states.

Hansen et al. [31] sought to test whether MRL has led to an increase in fatal traffic accidents involving marijuana or alcohol. Their results indicate that there is no such increase in the states of Colorado and Washington. In their analyses, they try to look for a causal effect between these two factors by observing similar changes related to marijuana, alcohol and the number of traffic accidents in other states despite the fact that recreational marijuana has not been legalized in these control groups.

Aydelotte et al. [39] seek to analyze the effect of MRL on fatal traffic accidents in Colorado and Washington between 2009 and 2015 compared to other states that have not legalized its use. The study reveals that no significant differences are found in the number of fatal crashes before legalization with respect to control states. In the three years following MRL in Colorado and Washington, there was a slight increase in the total number of fatal traffic accidents, but this is not significant compared to other control states.

Aydelotte et al. [40] analyzed changes in Colorado and Washington following RCL versus states that had MCLs (Hawaii, Montana, New Mexico, Rhode Island,Vermont) or no legalization laws (Idaho, Kansas, Nebraska, South Dakota), finding a non-significant increase in fatal traffic crashes over what was expected in the five years following legalization versus control states. However, there is a significant increase in fatal crashes once commercial, recreational marijuana dispensaries begin to open rather than when the legislative measure is implemented.

Lane and Hall [41] use an interrupted series analysis to analyze the cases of Colorado, where they observed an increase in the rate of fatal traffic accidents after legalization; Washington, where they observed an immediate increase followed by a decrease; and Oregon, where they found no significant difference from the previous trend. The study concludes that after MCL, there is an increase of one fatal crash per million population in the RCL and surrounding states.

Santaella-Tenorio et al. [32] focus on whether RCL is associated with the number of traffic fatalities in Colorado and Washington between the years 2005 to 2017, finding an increase in mortality in Colorado since 2014, the year in which recreational marijuana was legalized, specifically 75 more deaths per year. In contrast, in Washington, no such increase is observed after legalization. Also, in the United States, specifically in California, Borst et al. [30] analyze the presence of cannabis and other drugs in traffic accidents in San Diego. The results indicate an increase over the years of cases of drivers presenting injuries after suffering a traffic accident, from 7.3% in 2010 to 14.8% in 2018. In addition, the THC+ group tend to be younger (X=27 years) than those who do not use any drugs (X=38 years), are more likely to be involved in a motorcycle accident, and use protective mechanisms such as helmet and seat belt use to a lesser extent, differences that proved to be statistically significant between the two groups. Finally, in fatal crashes in which drug testing was performed, in 27% of cases, the driver tested positive for THC.

Windle et al. [26] analyze fatal traffic accidents and traffic fatalities in 10 states and the District of Columbia. The results point to a 15% increase in fatal traffic accidents after legalization and a 16% increase in traffic fatalities, leading to the loss of 308 more deaths each year after RCL.

Tefft and Arnold [25] focused in Washington State on drivers involved in a fatal traffic crash to determine whether THC was present in blood and urine before and after the MRL. Specifically, 735 fatal crashes where the driver tested positive for THC in blood or urine, 3528 crashes where the driver tested negative for THC, and 4019 cases where drug tests were not performed or the drug test results were not subsequently confirmed were analyzed. The results of the study indicate an increase of almost 10 points in the number of drivers who tested positive for THC after legalization, from 9.3% to 19.1%, also increasing THC levels in the blood. At the same time, drivers who tested positive for THC after legalization detected a significant increase in the use of other drugs.

Lensch et al. [27] mainly analyzed the attitudes and behaviors associated with driving after cannabis use in states that have legalized recreational marijuana and have legal marijuana dispensaries versus states that, despite having legalized it, do not have dispensaries and whether the frequency of use may interfere with this type of behavior. The results of the study indicate that the use of cannabis while driving in the last 30 days is higher in states where marijuana has been legalized (7.3%) than in those that have not

(5.5%), and there is also a higher prevalence of traveling with a driver who has used (10.1% vs. 8.4%). However, protective driving behaviors also increase, mainly in states where cannabis has been legalized; there is a greater awareness of the danger of driving after having consumed, 52.1% compared to 39.7% in states that have not legalized it, as well as believing that the probability of having an accident after having consumed increases, 57.1% compared to 52.2%. All of these results were statistically significant. After stratifying the data by frequency of use, in states where recreational marijuana has been legalized, there is a significant decrease in risky driving compared to states that have not.

Meanwhile, Rotermann [29] in Canada analyzed the changes after legalization with respect to the consumption habit, the origin of the cannabis, driving after having consumed, and riding with a driver who had consumed. With respect to these last two variables, the results of the study indicate that there is no significant increase in driving within two hours of having consumed, this behavior being more frequent among men than among women and among those who report higher consumption on a regular basis. In addition, there was a decrease from 5.3% to 4.2% in terms of being a passenger in a vehicle in which the driver had consumed. This decrease occurs among women over 25 years of age and in Newfoundland and Labrador, Ontario and Alberta territories and does not occur in the rest of the country. This type of behavior occurs mainly in males, between 18 and 24 years of age and in cases where there is the consumption by both the driver and the passenger.

Callaghan et al. [23] evaluated whether there was an increase in the number of injuries after a traffic accident before and after the legalization of recreational marijuana. The results indicate no increase in driving-associated injuries after cannabis legalization among young drivers, with a slight decrease of 0.66 medical visits after legalization in Alberta and an increase of 0.09 visits in the case of Ontario. For all drivers, young and not, there are no differences in Alberta, although there is an increase of 9.17 points in the number of medical visits after legalization ($p=0.52$). These differences do exist in Ontario, with an increase of 28.93 visits ($p=0.30$). In the specific case of this study, the researchers point out the role that variables such as the period of decriminalization prior to regulation, a postal service strike, or a higher penalty for driving under the influence of cannabis and cannabis and alcohol after legalization may have played in the results.

In the case of Uruguay, Nazif-Muñoz et al. [28] evaluated mortality rates in traffic accidents after MRL in urban areas and rural areas. The results of the study indicate a 52.4% increase in the mortality rate of drivers after legalization. However, this increase was not significant in the case of motorcyclists, and a significant increase in the number of traffic accidents after legalization. In addition, the study points out how this increase is significant in the country's capital, Montevideo, as opposed to rural provinces.

Table 4. *Studies related to the legalization of recreational cannabis: Design, main results and limitations.*

Article	Study design / Statistical analysis	Main results	Limitatons
Callaghan et al. (2021) [23]	Interrupted time series analysis. Seasonal Autoregressive Integrated Moving Average models	There is no significant effect of increased injury visits among young drivers and in all drivers before and after legalization. Significant differences (95% CI -26.32; 84.19; p=0.30) are observed for all drivers in Ontario in the emergency department visits .	Data are only collected from two states in Canada and from cases that have resulted in moderate to severe injuries.
Tefft & Arnold (2021) [25]	Logistic regression and marginal standardization.	Increase in the proportion 9.3% before and 19.1% after legalization (APR: 2.3, 95% CI: 1.3, 4.1) and concentration of THC (APR: 4.7, 95% CI: 1.5, 15.1) in drivers who tested positive for THC after legalization.	There is a significant number of drivers for which there is no drug test. Bias in the results by not taking into account other variables. Data are not compared with other states that have not legalized RC.
Windle et al. (2021) [26]	Ecologic study. Poisson regression, meta-analyzed estimates and DerSimonian and Laird random-effects models.	Increase in fatal traffic accidents (IRR 1.15, 95% CI 1.06–1.26) and deaths (IRR 1.16, 95% CI 1.06–1.27) in the first year after legalization.	Observational study. Jurisdiction differed among states.
Lensch et al. (2020) [27]	Chi-square tests. APR and 95% CI.	Higher incidence of use in states that legalize cannabis in the last 30 days (APR: 1.34; 95% CI: 1.19, 1.51) and in the last 12 months (APR: 1.16; 95% CI: 1.06, 1.28). Higher protective behaviors in States that have legalized RC.	Cross-sectional study. Non-representative sample of the general population.
Nazif-Muñoz et al. (2020) [28]	Interrupted time-series design. Extension autoregressive integrated moving average.	Significant increase in the light motor vehicle driver's fatality rate (CI = 11.6, 93.3, p=0.012). Significant increase automobile driver mortality in Montevideo (CI = 0.01, 0.11, p=0.025) but not in rural areas.	Prevalence of cannabis use in traffic accidents. Accidents with injuries are not considered. Possible biases in the coding of accidents.
Rotermann (2020) [29]	T-test statistics.	Stability in the number of cases of driving after having consumed before and after legalization, having more frequency in men than in women (p<0.05). In general, decrease in the number of cases of traveling in a vehicle whose driver had consumed.	Self-report data. The type of design does not allow for causal inferences. The study is limited to surveyed households only.

Article	**Study design / Statistical analysis**	**Main results**	**Limitatons**
Article	**Study design / Statistical analysis**	**Main results**	**Limitations**
Borst et al. (2020) [30]	Multivariate logistic regression. Linear regression. Binomial logistic regressions. Pearson $\chi2$. Time-series regression analaysis	Increase in 7.6 percentage points of THC+ cases in accidents before legalization. The THC+ group used fewer protective measures while driving (8.5% vs 14.3%, $p<0.001$) and more serious injuries (8.4±9.4 vs 9.0±9.9, $p<0.001$) than the non-consumption group.	There is no legal threshold for driving under the influence of cannabis. Time in which cannabinoids are maintained in blood. No toxicological screening of all patients. Variability in detection rates between institutions.
Hansen et al (2020) [31]	Synthetic control approach.	Controlling States show the same increases in the number of accidents por billon de vehicle miles traveled in Colorado ($p=0.361$) and Washington ($p=0.404$).	Levels of marijuana use not quantified and variation among states. Only fatal traffic accidents. No causality can be asserted.
Santaella et al. (2020) [32]	Quasi-experimental design. Ecological study used a synthetic control approach.	Increase ($p=0.047$) in traffic fatalities in Colorado but not in Washington following legalization of RC.	Other variables associated with legalization. Time of legalization in Washington. No data on injuries. Not included if at the time of the accident the driver tested positive for THC.
Delling et al (2019) [3]	Linear, logistical and multinomial models.	An increase ($p<0.05$) in the number of traffic accidents, alcohol abuse, overdose injuries and a decrease in chronic pain admissions is observed following the legalization of RC versus control states.	The post-legalization period is short (two years). They only compare with two control states. Colorado legalized prior to 2012 medical marijuana.
Aydelotte et al (2017) [39]	Random-effects multivariate regression for panel data. Difference-in-differ ences approach.	Despite an increase, there is no significant association between legalization and changes in the rate of fatal traffic accidents (ADDC= +0.2 fatalities/billion vehicle miles traveled; 95% CI = –0.4, +0.9) in the first 3 years of legalization.	They only analyze two states in which the substance has been legalized. They do not study adjacent control states. They study fatal traffic crashes as a whole, not those in which cannabis is involved.
Aydelotte et al (2019) [40]	Retrospective longitudinal cohort study. Difference-indiffere nces analyses.	Significant increase in the number of fatal traffic accidents in states that legalize RC after opening dispensaries to buy recreational marijuana (CI: +0.4 to +3.7, $p=0.020$) compared to control states. This increase is not significant before the dispensaries opened (CI: -0.6 to 2.1, $p=0.087$).	Do not make any statistical adjustments for multiple analyses. Biases in the selection of control states. Missing more states where recreational marijuana use has been legalized. Only study fatal traffic accidents.
Lane & Hall (2019) [41]	Interrupted time–series design. Generalized least	The general trend is an increase in the mortality rate both in states with legalization laws and in neighbouring states. There is a	They do not differentiate between fatal traffic accidents in which marijuana is involved and those in

Article	**Study design / Statistical analysis**	**Main results**	**Limitatons**
	squares regression models.	trend of increased mortality (p<0.001) at the beginning and a decrease in the following months (p<0.001). At 6 months these effects are greater (step: 1.36, p=0.006; trend: -0.07, p<0.001).	which it is not. They do not consider other types of accidents. They do not analyze economic factors or current policies of neighbouring states regarding cannabis.

3.4. Legalization and decriminalization of medical and recreational cannabis.

Only two studies reflect the joint impact of medical and recreational cannabis on road safety [22,37] and seven studies focus on the impact of cannabis discrimination [8,24,35, 37,42,44,45]. Regarding legalization (Table 5 and 6), medical cannabis has a greater effect on the number of fatalities than recreational cannabis legalization [22], while [37] points to a greater effect of recreational cannabis legalization. For its part, decriminalization seems to have an effect on road safety [8,37,42,44,45] while other works find no relationship in the number of traffic accidents [24], or in the number of traumatic injuries [35].

Table 5. *Studies related to the legalization of recreational and medicinal cannabis and its decriminalization: Country, sample and most relevant variables.*

Article	**Country / Years / Most relevant characteristics of the sample**	**Variables / Data collected**
Benedetti et al. (2021) [22]	U.S. (2013-2017). N = 11,170 drivers. Age: 19 or older. 48.4% Male. CR illegal: 10,294 drivers; CR legal: 876 drivers. MC illegal: 5782 drivers; MC legal 5,388 drivers.	Marijuana use in driving in the last year. States with the legalization of MM, MM and MR or no legalization of both. Marijuana policy. Sociodemographic variables. TSCI is a nationally representative annual survey. Self-reported.
Kruse et al. (2021) [24]	U.S. Arizona, California, Ohio, Oregon, New Jersey, and Texas. Pre-legalization 2006-2012. Post-legalization 2013-2018.	Vehicle collisions. THC-positive patients and alcohol-positive patients > .08 g/dL). Data from different universities. Urine and blood analysis.
Woo et al. (2019) [8]	U.S. Washington. (2008-2016). N = 10,155 accidents and 5,931 drivers. Age 16-99 years. Mean age 42.45(SD=18.43). THC > 5.00= 4.2%, THC <5= 3.1%, Clean 92.6%. BAC > 0.08= 19.2%, BAC <0.08= 3.5%, Clean 77.3%.	Fatal accidents. Speeding and driver error. THC (< 5 ng/mL in blood or > 5 ng/mL). Carboxy-THC. Alcohol (0.08 less or more). Control variables. Environmental Contexts. FARS. Blood tested.
Keric et al. (2018) [35]	U.S. Texas and California. (2006 - 2012). N = 127 Surgeons. 84% Male. Age: 49-66.Median age 51.5(9.5). UTHSCSA center: Patients traffic accidents N = 7,171. Alcohol+ 21%,	Alcohol (>0.08 g/dL). Marijuana (>50 ng/ml in Texas and >100 ng/ml in California). Injuries related to traffic accidents. Decriminalization in CA in 2010. Electronic survey completed by members of

Article	**Country / Years / Most relevant characteristics of the sample**	**Variables / Data collected**
	THC+ 4%, Alcohol and THC+ 3%. Center in California: N=16,084, Alcohol+ 50%, THC+ 23%, Alcohol and THC+ 7%.	American Association for the Surgery of Trauma. Trauma center registries at The University of California Irvine and UTHSCSA.
Article	**Country / Years / Most relevant characteristics of the sample**	**Variables / Data collected**
Lee et al (2018) [37]	U.S. 16 states. (2008-2015).	Types of States according to cannabis legalization and decriminalization laws. FARS.
Hamzeie et al (2017) [42]	U.S. 50 States and District of Columbia. (2010-2014). N = 74,633 drivers. THC+ N = 9,301. THC- N = 65,332.	States with legalization and decriminalization laws and States with no laws. Driver, accident and vehicle characteristics. THC+ and THC-. FARS.
Pollini et al. (2015) [44]	U.S. California. (2008-2012). N = 2,860. Age 16<. (2008-2010): N=1,718; THC+ N = 203, Male 173. (2011-2012): N=1,142; THC+ N=175, Male 153	Detection of cannabis use in drivers involved in traffic accidents. Descriminalization period: 2011-2012. No descriminalization period: 2008-2010. FARS.
Couper & Peterson (2014) [45]	U.S. Washington, D.C. (2009-2013) N = 25,179, Age 14-85 years old. Median age 25 years pre-legalization 26 years post-legalization. Male 77%-81% according to the year.	Detection of THC consumption by blood test (Pre.legalization THC+ 0.2 ng/mL, carboxy-THC of 0.10 ng/mL). Pre-lgalization 2009-2012. Post-legalization 2013.

Note: FARS (Fatality Analysis Reporting System database).

Focusing on studies that have addressed the legalization of cannabis in general or decriminalization (Table 5 and 6) the work by Benedetti et al. [22] aims to find out whether MCL and RCL are related to a higher number of drivers over 18 years of age who have driven under the influence of marijuana. The results of the study indicate that in states where medical marijuana has been legalized, more drivers report driving under the influence of marijuana than drivers in states where neither medical nor recreational marijuana has been legalized, with a higher probability of 29%, and in states where both forms are legalized. In addition, the study picks up the role that the existence of laws controlling the THC threshold may have since, in the states where this threshold is regulated, the probability of driving after consuming marijuana is significantly reduced by 26% compared to states that do not present laws in this regard.

Lee et al. [37] analyzed the number of accidents resulting in death according to legislative changes related to cannabis, observing that there were no significant differences in Arizona and New Jersey compared to states that acted as a control group, there being even a decrease, although this is not significant. In contrast, in Massachusetts, they increase by 174.5%, in Connecticut by 75.3%, in Washington by 31.2% and in Colorado (excluding Denver) by 63.1%. The authors conclude that MCL does not imply an increase in fatal crashes where the driver tests positive for THC. However when these changes affect the decriminalization and legalization of recreational marijuana, there is a significant increase in the number of THC-positive cases of drivers in fatal crashes in both Washington and Colorado.

Couper and Peterson [45] evaluated the possible effect of marijuana legalization on the prevalence of this substance in the blood of drivers suspected of having consumed and showing some inability to drive, noting that after legalization, the number of cases of drivers who tested positive for THC increases from 4809 cases in 2009 to 5468 cases in 2013. The study points out a stabilization in the number of cases between the years 2009 and 2012, when marijuana was not yet legalized, while in 2013, when it is legalized, the number of cases increased considerably, with an increase from 5.8% to 12.1%. These drivers are mostly men, with percentages between 77% and 80% depending on the year of study, with the group between 21 and 30 years of age being the most represented, followed by the group under 21 years of age.

Woo et al. [8] focus on the relationship between THC and risky driving behaviors such as speeding or driver errors such as lane changes, and reckless driving, among others, which may lead to a fatal accident of the driver, passenger or pedestrian. The results of the study indicate that being young, male, driving a motorcycle, testing positive for alcohol in breathalyzer tests, delta 9-THC or carboxy-THC and other drugs are considered risk factors in traffic accidents involving high-speed driving. Carboxy-THC significantly predicted speeding (54% more likely than those who did not test positive) and the presence of driving errors. Positive delta-9-THC was significantly related to speeding but not to driving errors. In relation to driving errors, those with delta-9-THC levels of 5.00ng/mL or more were less likely (41% less) to make errors than those who tested negative. These authors conclude that cannabis predicts risky driving behaviors in fatal accidents, although alcohol has a greater weight in the prediction of these behaviors.

Keric et al. [35] approached the study of marijuana legalization and alcohol consumption through the presence of traffic accident-related injuries. For this purpose, he interviewed surgeons from trauma units in hospitals in Texas and California between the years 2006 and 2012. The results of the study indicate that in those states where marijuana is legal, 90% of the surgeons do not find an increase in injuries associated with traffic accidents. With regard to the presence of cases with injuries resulting from a traffic accident, 4% tested positive for marijuana, 21% for alcohol and 3% for both substances in the state of Texas. In California, 23% of the cases tested positive for marijuana, 50% for alcohol and 7% for both substances. After the legalization of marijuana in 2010, there was no increase in the number of cases of trauma related to traffic accidents before and after legalization.

Along the same lines, Kruse et al. [24] aim to know the impact of marijuana legalization on drug and alcohol detection in traffic accident victims in six American states between 2006 and 2018. In all states, there is an increase in the incidence when detecting THC in blood. These increases are 9.5% in Arizona, and 5.4% in California being this the state with the highest incidence percentages, going from 20.8% to 26.2%. However, this change was not significant, with 5.9% in Ohio, 3% in Oregon, 2.3% in New Jersey and 15.3% in

Texas, a state where marijuana is not legalized, being this the state where there is the greatest change in incidence, going from 3% to 18.3%. With respect to alcohol, there was no change over time in most states. The study points out that there is no relationship between marijuana legalization and the probability of detecting THC in urine after a hospital admission related to a traffic accident, nor with alcohol consumption.

Pollini et al. (2015) focus on the effect of marijuana decriminalization on the detection of THC-positive drivers and the number of fatal traffic accidents in the state of California. The results of the study indicate that after decriminalization, there is a significant increase in the number of drivers involved in fatal crashes who tested positive for THC, although this increase does not occur in drivers who drive on weekend nights.

Finally, Hamzeie et al. [42] focus mainly on the incidence of drivers testing positive for cannabis after being involved in a traffic accident, differentiating between states that have legalized the use of marijuana, those with laws on decriminalization of its use, and those that have not legalized either use or possession. The results of the study show that in states where there are laws on legalization or decriminalization of cannabis use and possession, there is a higher probability that the driver will test positive for THC (48%), compared to those states that have not legalized its use or possession (17%). In addition, they point out that drivers who have tested positive for cannabis have more serious injuries and are younger; specifically, for each year of age, the probability of testing positive for cannabis decreases by 3%. In the case of being a woman, the probability is reduced by 22% and if they have a valid driving license by 14%. The study also shows a positive relationship between cannabis and alcohol consumption, such that for every 1g/dL of alcohol, the probability of testing positive for cannabis increases by 150%.

Table 6. *Studies related to the legalization of recreational and medicinal cannabis and its decriminalization: Design, main results and limitations.*

Article	**Study design / Statistical analysis**	**Main results**	**Limitations**
Benedetti et al. (2021) [22]	Multiple logistic regression model.	States with MCL have a higher number of drivers who have driven under the influence of marijuana versus states that have not legalized MC and/or RC (OR 1.29; 95% CI 0.98, 1.70; p=0.075). THC threshold laws less likely to drive after consumption (OR 0.74; 95% CI 0.57, 0.95; p=0.018).	Biases associated with self-reports. Quasi-experimental design that does not allow inferring causal relationships between marijuana use among drivers with states' policies on marijuana use.
Kruse et al. (2021) [24]	Retrospective analysis of data. Percentages.	There seems to be no relationship between legalization and the probability of finding THC in patients admitted after an accident.	Discrepancies in urine THC detection limits by institution. A lack of standardized laws by the state does not

Article	Study design / Statistical analysis	Main results	Limitations
			allow detection the real THC prevalence.
Article	**Study design / Statistical analysis**	**Main results**	**Limitations**
Woo et al. (2019) [8]	Series of logistic regressions.	Being a young man, driving a motorcycle, and testing positive for alcohol, delta 9-THC or carboxy-THC and other drugs (p<.001) are risk factors for speeding. Cannabis predicts risky driving behavior.	Only fatal accidents are examined. Washington state data only. Not all crashes tested for drugs. Measurement errors in drug rates.
Keric et al. (2018) [35]	Time frame. Percentages.	90% of surgeons report no increase in cases of traumatic injuries in traffic accidents after cannabis legalization.	Not specified.
Lee et al (2018) [37]	Series estimation of crash modification factors.	Increase in fatal accidents in which the driver tests positive for cannabis, mainly with decriminalization (p<0.001) and/or legalization of RC but not MC (p<0.00 Other effects occur between Decriminalization and decriminalization and MCL (p=0.020) and between MCL and Full legalization (p=0.010).	Short post-legalization periods. Differences between states in drug testing protocols and trends after legalization Difficulties in selecting a control group. Cannot assert causality.
Hamzeie et al (2017) [42]	Logistic regression models	Higher probability of testing positive for THC in an accident in States with cannabis decriminalization (17%) and/or legalization laws (48%) (p<0.001). Being young, male, testing positive for alcohol and greater risk behaviors behind the wheel, a higher probability of THC+ (p<0.001).	They only test for CRL in two states and for a short period of time. Not all drivers take the drug test. Differences between states in drug testing protocols and trends after legalization.
Pollini et al. (2015) [44]	Multiple logistic regression analyses	Significant increase in the prevalence of cannabis positives in drivers involved in fatal crashes after descriminalization (17.8%; 95% CI: 14.6, 20.9). No change in THC positives in weekend nighttime drivers after descriminalization (9.2%; 95% CI: 6.3, 12.2).	Differences in drug testing protocols. Changes in consumption trends after legalization. Small and restricted sample. THC+ does not imply recent use.
Couper & Peterson (2014) [45]	Chi-squared tests	After a stable trend, there is a significant increase in the percentage of positive cases for THC consumption in drivers after legalization (p<0.05).	THC concentration can be altered causing problems in the cut-off point for considering a subject positive. Delays in blood collection can influence the concentration of metabolites.

4. Discussion

Based on the objective of the present systematic review, to assess the impact of cannabis legalization on traffic accidents, mainly in relation to fatal accidents and the hypotheses put forward, following the results found regarding the impact of the medical cannabis legalization in relation to traffic accidents, two papers found increases in the number of fatal accidents after legalization [33,36], other articles point to increases in some of the states included in the study [43,46, 47], while other studies point to the role of medical cannabis dispensaries in the increase in traffic accidents after legalization [38,47]. Two articles [37,48] find no increase in traffic accidents after legalization. These results partially accept the first of the study's hypotheses, which pointed to a positive relationship between medical cannabis legalization and the prevalence of traffic accidents.

Something similar happened with respect to the study's second hypothesis, which pointed to a relationship between la legalización del cannabis recreativo and traffic accidents. Three studies [29,31,39] do find an increase in traffic accidents while nine papers report an increase in traffic accidents after legalization or between states that have legalized recreational cannabis and those that have not [3, 25,26,27,28,30,32,40,41].

For their part, Pollini et al. [44] find an increase in cases where cannabis use is present in fatal traffic accidents following legalization. However, the study does not specify whether this is with respect to medical or recreational cannabis.

Regarding visits to hospital centers for injuries after suffering a traffic accident, three articles did not find an increase in the number of cases [23,24,35] while one study [30] did find an increase in traffic accident-related injuries following legalization.

As a summary, as shown in Table 7, there is a greater number of articles that find scientific evidence that supports an impact of the legalization or decriminalization of cannabis on road safety, both in the comparison between states or countries and in the periods of pre-legalization, decriminalization and post-legalization of medicinal and/or recreational cannabis.

Table 7. *List of articles used in the review according to legalization period and state or country and effect of legalization.*

Effect of legalization / decriminalization on traffic accidents	States / Countries	Periods Pre and post-legalization
YES	3, 22, 27, 34, 37, 38,40-43, 46, 47	3, 8, 25, 26,28, 30, 32,33,36,37,40, 41,44,45,47
NO	31, 39, 48	23, 24, 29, 35, 39

The study's third hypothesis proposed a positive relationship between cannabis legalization and a greater number of risk behaviors associated with driving. The results of the studies lead to the acceptance of this hypothesis. Couper and Peterson [45], Rotermann et al. [29], Lensch et al. [27] and Benedetti et al. [22] report an increase in the number of cases of drivers who drive after consuming. Lensch et al. [27] found a higher prevalence after the legalization of riding as a passenger of a driver who had consumed cannabis, while Rotermann et al. [29] found a lower prevalence of this behavior.

Regarding protective driving behaviors such as wearing a seat belt or wearing a helmet on a motorcycle, Lensch et al. [27] point to a higher use after legalization, while Borst et al. [30] and Steinemann et al. [36] indicate a lower use of these measures. Woo et al. [8] point to a relationship between testing positive for THC and fatal driving errors and increased speeding, behaviors that lead to a higher probability of a fatal traffic accident and Hamzeie et al. [42] point to a higher probability of an accident after legalization.

Regarding the fourth hypothesis about identifying risk factors among drivers who test positive for cannabis, this hypothesis is accepted. Among the risk factors mostly identified are being male [8,29,42,45], being a young person between 18 and 30 years old [8,29,30,36,42,45] and the use of alcohol in conjunction with cannabis [3,8,33,36,42]. Other risk factors are driving a motorcycle [8,30], although, as noted by Nazif-Muñoz et al. [28] in Uruguay, motorcyclists have lower death rates in traffic accidents where cannabis is involved than drivers of other types of vehicles, while Steinemann et al. [36] note driving at night as a risk factor.

The presence of marijuana dispensaries may be another risk factor in the increase of traffic accidents if the work of Sevigny [38] with respect to MCL and that of Aydelotte et al. [40] with respect to RCL are taken into account.

As protective factors to prevent traffic accidents related to marijuana use, Callaghan et al. [23] point to an increase in penalties for driving under the influence of this substance and Benedetti et al. [22] point to the need to regulate the permitted consumption rates for driving.

When interpreting the results of the studies analyzed, the limitations of these studies, many of them significant, should be taken into account, such as the number of states participating [3,8,23,25,39,40,42,44], laws about decriminalization and/or legalization of marijuana, and differences among states regarding THC detection limits [22,24,30,31,37,38,42], the type of studies that do not allow causality to be established [26,27,29,37,43] or the collection of data through self-reports [22,29,34] among others.

Regarding the limitations of the present study, we only selected articles whose language was English, and we did not include non-English research carried out in countries such as Canada, where French is also spoken. Another limitation refers to the databases used, using only Web of Science and Scopus. On the other hand, future work should address the longitudinal impact of marijuana legalization in those states that have legalized it, controlling for a greater number of variables. In addition, it may be important to find out what role marijuana dispensaries play with respect to traffic accidents, as well as the establishment of laws on the levels of consumption allowed in driving.

Among the practical implications, it is worth mentioning, firstly, the reflection to be made by those countries or states that have not legalized marijuana and are considering its legalization, taking into account not only economic factors but also aspects directly or indirectly related to health. On the other hand, the presence of risk factors in traffic accidents involving cannabis makes it possible to develop communication campaigns and prevention programs aimed at controlling these variables or risk groups, focusing on not consuming if driving, not accompanying a driver who has consumed or the use of safety mechanisms when driving [49].

5. Conclusions

The results of the studies are not conclusive, although a greater number of studies (22 articles) [3,8,22,25-28,30,32-34,36-38,40-47], show a negative effect of the legalization or decriminalization of cannabis on road safety, mainly in an increase in traffic accidents after the legalization or in some of the states that participated in the studies. In contrast, only seven studies [23,24,29,31,35,39,48], show no increase in traffic accidents or in the number of visits to hospital centers after suffering an accident. Regarding attitudes and risk behaviors associated with driving after consumption, it can be concluded that these behaviors are greater if we consider that nine studies report some type of risk behavior compared to only one study that reports a greater use of protective measures after legalization. Finally, we can conclude about the existence of different risk factors in traffic accidents associated with cannabis consumption, such as being male, young and having also consumed alcohol.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Figure S1: title; Table S1: title; Video S1: title.

Author Contributions: Conceptualization, F.G.-S. and FT; methodology, F.G-S, M.T., M.P-O, and F.T.; writing—original draft preparation, F.G.-S. and M.P-O.; writing—review and editing, M.T. and F.T. All authors have read and agreed to the published version of the manuscript.

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Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.
Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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