Trends in Cannabis Involvement and Risk of Alcohol Involvement in Motor Vehicle Crash Fatalities in the United States, 2000–2018

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Objectives. To assess cannabis and alcohol involvement among motor vehicle crash (MVC) fatalities in the United States.

Methods. In this repeated cross-sectional analysis, we used data from the Fatality Analysis Reporting System from 2000 to 2018. Fatalities were cannabis-involved if an involved driver tested positive for a cannabinoid and alcohol-involved based on the highest blood alcohol concentration (BAC) of an involved driver. Multinomial mixed-effects logistic regression models assessed cannabis as a risk factor for alcohol by BAC level.

Results. While trends in fatalities involving alcohol have remained stable, the percentage of fatalities involving cannabis and cannabis and alcohol increased from 9.0% in 2000 to 21.5% in 2018, and 4.8% in 2000 to 10.3% in 2018, respectively. In adjusted analyses, fatalities involving cannabis had 1.56 (95% confidence interval [CI] = 1.48, 1.65), 1.62 (95% CI = 1.52, 1.72), and 1.46 (95% CI = 1.42, 1.50) times the odds of involving BACs of 0.01% to 0.049%, 0.05% to 0.079%, and 0.08% or higher, respectively.

Conclusions. The percentage of fatalities involving cannabis and coinvolving cannabis and alcohol doubled from 2000 to 2018, and cannabis was associated with alcohol coinvolvement. Further research is warranted to understand cannabis- and alcohol-involved MVC fatalities. (*Am J Public Health*. 2021;111(11):1976–1985. https://doi.org/10.2105/AJPH.2021.306466)

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Motor vehicle crashes (MVCs) are a leading cause of injury death in the United States, and more than 35% of MVC fatalities result from crashes in which at least 1 driver has a positive blood alcohol concentration (BAC).[1,2] Cannabis use is a risk factor for driving impairment and the second-most-common substance involved in fatal MVCs after alcohol.[3,4] The impairing effects of Δ9-tetrahydrocannabinol (THC) in cannabis on driving ability include lane weaving, delayed reaction time, decreased coordination, and distorted perception.[4–9] Laboratory tests show that low-dose cannabis (< 10% THC) used in combination with alcohol may increase impairment more than either substance alone, particularly for skills relevant to driving.[10–13]

Throughout the past 2 decades, cannabis policy in the United States has dramatically shifted as states have legalized medical cannabis, decriminalized possession of cannabis, and legalized recreational cannabis; correspondingly, rates of cannabis use in the United States have increased among adults.[14] Between 2002 and 2017, past-month cannabis use assessed through the National Survey on Drug Use and Health (NSDUH) increased among adults aged 26 years and older from 4.0% to 7.9%, and among adults aged 18 to 25 years from 17.3% to 22.1%.[15] Among nighttime drivers, rates of cannabis prevalence in oral fluid also increased, from 8.6% in the 2007 National Roadside Survey to 12.6% in the 2013–2014 National Roadside Survey.[16,17] More recently, a study utilizing NSDUH data from 2016 to

2018 found that 29.5% of cannabis users reported driving under the influence of cannabis.[18] While the proportion of US crash deaths that involve alcohol has remained constant over time despite significant safety improvements in cars and car driving services,[2,19] positive toxicology results for substances other than alcohol in fatally injured drivers has increased to approximately 30%.[20]

Little consideration has been given to trends in co-use of alcohol and cannabis, in particular cannabis involvement at various alcohol levels in MVC deaths. Alcohol coinvolvement may be 1 explanation for the inconsistent findings of cannabis policy changes on cannabis-involved MVC fatalities, in addition to the difficulties in disentangling whether cannabis and alcohol are used as substitutes or complements, and whether changes in actual cannabis involvement stem from changes in testing for cannabis, given suboptimal testing.[21–27] Thus, there is still a need to describe cannabis involvement in MVC fatalities at various levels of alcohol involvement and to assess whether cannabis is a contributing risk factor for alcohol-involved crashes.

To fill this gap in the literature, the objectives of this study were 3-fold. First, we sought to describe drug testing rates in MVC fatalities overall and by BAC level. Second, we sought to describe patterns of alcohol and cannabis coinvolvement in MVC fatalities overall and by BAC level, and evaluated differences in decedent characteristics across crashes with varying substance involvement and coinvolvement. Finally, we assessed the cannabis involvement as a risk factor for alcohol coinvolvement by BAC level in MVC fatalities. Given the conflicting evidence regarding cannabis and alcohol as potential substitutes or complements, we did not have prespecified hypotheses regarding the direction or magnitude of potential associations between cannabis and alcohol.

METHODS

The methods of this study were similar to those conducted by our study team in past analyses.[2,19,28] This was a repeated cross-sectional analysis of MVC fatalities from the Fatality Analysis Reporting System (FARS), a census of MVC fatalities in US states and Washington, DC, from 2000 to 2018.[29]

Participants

In this study, we utilized distinct participant groups for each stage of the analysis. For the first objective, describing drug testing rates in MVC fatalities overall and by BAC level, participants included FARS decedents from 2000 to 2018 who died in MVCs in which at least 1 driver was identified. For the second objective, describing patterns of alcohol and cannabis coinvolvement, participants were restricted to those with crash-level drug testing, defined as at least 1 driver having valid drug test results. For the third objective of the study, assessing cannabis involvement as a risk factor for alcohol coinvolvement, the group was further restricted to those with individual- and crash-level characteristics.

Variables

The main predictor, crash-level cannabis involvement, was defined as at least 1 driver with valid drug test results indicating the presence of a cannabinoid (FARS drug test results from 600 to 695). Before 2018, FARS reported up to 3 substances in drug test results based on a hierarchy, such that narcotics would be given top priority, followed by depressants, stimulants, hallucinogens, and then cannabinoids.[30] In 2018, FARS began reporting all positive substances. To use more recent data and maintain a uniform definition, the hierarchy used through 2017 was applied to data from 2018. The outcome, alcohol involvement by BAC level, was similarly calculated at the crash level such that the highest BAC from all drivers was assigned to all decedents from the crash. BAC levels were 0.00%, 0.01% to 0.049%, 0.05% to 0.079%, and 0.08% or higher. Because it is unlikely that alcohol test results are missing completely at random or missing completely not at random, missing results are an important threat to validity. Therefore, we utilized validated, imputed data sets from FARS to estimate missing BAC levels.[31]

Potential confounders were year (continuous); decedent-level characteristics: sex (male [reference] vs female), age category (< 21 years [reference], 21–34 years, 35–54 years, ≥ 55 years), race/ethnicity (White [reference], non-Hispanic Black, Hispanic, other, unknown); crash-level characteristics: opioid involvement (no [reference] vs yes), other substance involvement (i.e., ≥ 1 driver positive for substance other than alcohol, cannabis, or opioids; no [reference] vs yes), urbanicity (rural [reference] vs urban); and continuous state-level characteristics: percentage male, percentage non-Hispanic White, percentage Hispanic, percentage aged 21 years or older, percentage with college degree or higher, percentage Catholic population, median household income, law enforcement officers per 1000 residents, annual vehicle miles traveled, and state–year drug testing rate.[32–35] Decedents with missing individual- or crash-level characteristics were excluded from analyses provided that missingness was not substantial (< 1%). Approximately 9% of decedents had missing information on race/ethnicity, so an "unknown" category was created.

Statistical Methods

We calculated crash-level drug testing rates and cannabis involvement rates overall and by BAC level over the study period. Because testing rates changed over time, we also calculated rates of cannabis involvement after restricting the data to state–years with testing rates of at least 50%, restricting to states with testing rates of at least 50% for all years, and restricting to states with testing rates of at least 33.3% for all years. We calculated prevalence rates of cannabis involvement by demographic and crash-level characteristics in all MVC fatalities, as well as among various BAC strata.

We calculated the prevalence of cannabis by BAC level and demographic and crash characteristics. Because alcohol values were imputed for some decedents, it was possible that the level of alcohol involvement could change across imputations. The data set was therefore transformed from a wide format to a long format, such that there were 10 observations for each decedent. Cannabis involvement was tabulated overall and for each BAC level by the variable rows in Table 1. Values were then divided by 10 and rounded to the nearest whole number to return the data set to its original size.

We used mixed-effects multinomial logistic regression models with the multiply imputed alcohol data using Rubin's rules[36] to assess crude and adjusted relationships between crash-level cannabis involvement and alcohol levels (BACs of 0.01%–0.049%, 0.05%–0.079%, and ≥ 0.08% vs 0.00%). Given that there may be similarities within states, we accounted for potential clustering by state random effects. Covariates in adjusted analyses included those listed in the "Variables" section.

Sensitivity Analyses

Given suboptimal drug testing rates and the variation in approaches utilized by similar analyses in the wider literature, we performed a number of sensitivity analyses to assess the robustness of findings. These included further adjusting for the alcohol policy environment,[37] restricting the sample to only include decedents who were drivers, restricting the sample to only include decedents who were drivers and using individual-level toxicology results rather than crash-level toxicology results, conducting a crash-level analysis, utilizing nonimputed data, and restricting the sample to include decedents from state–years with testing rates of at least 50% and 66.67%. We conducted analyses by using Stata version 15.1 (StataCorp LP, College Station, TX).

Effect Modification

Given that age and sex are strong risk factors for cannabis and alcohol use, we conducted posthoc analyses stratified on the basis of decedent sex (male vs female) and age (< 21 years, 21–34 years, 35–54 years, and ≥ 55 years).

RESULTS

Between 2000 and 2018, there were 721 825 MVC fatalities in the United States with at least 1 identified driver. Of these, 327 073 (45.3%) had crash-level drug testing results, constituting the sample for Figures 1 and 2. Of these, 322 773 (98.7%) had complete demographic and crash information, constituting the final sample for analyses (Tables 1 and 2). The 322 773 decedents comprised 254 002 drivers, 52 053 passengers, and 16 718 other victims (i.e., pedestrians, cyclists). Of the 254 002 deceased drivers, 243 926 or 96.0% were actually tested for alcohol. When alcohol results were applied to nondriver decedents at the crash level, 270 311 of the 322 773, or 83.8%, had at least 1 driver with valid alcohol test results.

Drug testing overall increased from 32.9% in 2000 to 47.9% in 2018 (data not shown). Overall and when stratified by crash-level BAC, testing increased for all BAC levels over time (Figure A, available as a supplement to the online version of this article at http://www.ajph.org); however, MVC fatalities not involving alcohol had the lowest rates of drug testing.

The percentage of fatalities involving cannabis increased from 9.0% in 2000 to 21.5% in 2018 (Figure 1). Given that testing and cannabis both increased during the study period, we also assessed cannabis involvement restricting the data to state–years with higher testing rates, and results were consistent (Figure B, available as a supplement to the online version of this article at http://www.ajph.org). After restricting state–years to those with testing rates of at least 50%, restricting the sample to states with testing rates of at least 50% for all years (n = 7: Hawaii, Illinois, New Hampshire, New Jersey, Rhode Island, Washington, and West Virginia), and restricting the sample to states with testing rates of at least 33.3% for all years (n = 16: the aforementioned states as well as California, Connecticut,

TABLE 1— Number and Percentage of Motor Vehicle Crash Fatalities That Were Cannabis-Involved, by Blood Alcohol Concentration (BAC) Level and Demographic and Crash Characteristics: Fatality Analysis Reporting System, United States, 2000–2018

Characteristic	Overall (n = 322 773), No. (%)	BAC 0.00% (n = 192 367), No. (%)	BAC 0.01%–0.049% (n = 12 182), No. (%)	BAC 0.05%–0.079% (n = 9146), No. (%)	BAC ≥ 0.08% (n = 109 078), No. (%)
Fatalities					
All fatalities	45 512 (14.1)	22 108 (11.5)	2 302 (18.9)	1 846 (20.2)	19 256 (17.7)
Drivers	34 048 (13.4)	16 047 (10.8)	1 596 (17.3)	1 224 (18.3)	15 181 (16.9)
Passengers	9 461 (18.2)	4 642 (15.1)	595 (24.5)	540 (26.0)	3 684 (21.9)
Others[a]	2 003 (12.0)	1 420 (10.4)	110 (21.5)	82 (22.6)	390 (18.4)
Sex					
Male	34 765 (14.9)	16 318 (12.5)	1 763 (19.3)	1 416 (20.2)	15 268 (17.7)
Female	10 747 (12.0)	5 790 (9.4)	539 (17.6)	430 (20.1)	3 988 (17.5)
Age, y					
< 21	9 469 (19.1)	5 437 (17.3)	528 (25.7)	427 (26.7)	3 077 (24.4)
21–34	18 939 (19.3)	7 858 (17.2)	921 (24.0)	813 (23.8)	9 348 (20.7)
35–54	12 011 (12.3)	5 593 (10.5)	573 (15.1)	441 (16.7)	5 403 (14.4)
≥ 55	5 093 (6.6)	3 221 (5.4)	280 (11.2)	165 (11.1)	1 427 (10.5)
Race/ethnicity					
Non-Hispanic White	29 151 (13.9)	14 410 (11.1)	1 410 (18.2)	1 159 (20.3)	12 172 (18.2)
Non-Hispanic Black	6 327 (18.7)	3 052 (16.3)	371 (23.4)	289 (24.5)	2 615 (21.2)
Hispanic	4 856 (12.8)	2 204 (11.4)	272 (18.8)	199 (16.9)	2 182 (13.6)
Other	1 605 (13.1)	701 (9.8)	68 (17.2)	63 (19.9)	774 (17.7)
Unknown	3 573 (12.5)	1 742 (10.0)	181 (18.1)	137 (17.8)	1 514 (15.9)
Involvement of other drugs					
No other drugs	30 672 (12.6)	14 235 (9.7)	1 391 (16.7)	1 202 (19.1)	13 843 (16.9)
Other drugs	14 840 (18.6)	7 873 (17.1)	910 (23.8)	644 (22.5)	5 412 (20.1)
Urbanicity					
Rural	24 139 (13.4)	12 093 (10.9)	1 221 (18.0)	959 (19.7)	9 866 (17.1)
Urban	21 373 (15.0)	10 016 (12.3)	1 080 (20.0)	888 (20.8)	9 390 (18.3)
No. of vehicles					
Single vehicle crash	23 959 (14.9)	9 695 (11.6)	1 137 (19.8)	1 044 (21.7)	12 084 (18.0)
Multiple vehicle crash	21 553 (13.3)	12 414 (11.4)	1 165 (18.1)	803 (18.5)	7 172 (17.0)
Day					
Weekday	24 910 (13.3)	14 426 (11.1)	1 162 (18.4)	851 (20.2)	8 471 (17.9)
Weekend	20 602 (15.2)	7 683 (12.2)	1 139 (19.4)	995 (20.2)	10 785 (17.4)
Time of day					
06:00–08:59	3 901 (12.1)	2 748 (10.6)	162 (16.9)	109 (20.6)	882 (18.2)
09:00–11:59	3 207 (10.3)	2 652 (9.8)	128 (15.5)	71 (17.8)	356 (12.8)
12:00–14:59	4 782 (11.3)	3 705 (10.5)	219 (15.4)	113 (16.4)	745 (14.5)
15:00–17:59	6 607 (12.6)	4 332 (11.3)	355 (17.1)	235 (17.5)	1 685 (15.6)
18:00–20:59	7 168 (14.8)	3 315 (12.6)	413 (19.2)	325 (19.2)	3 116 (17.0)
21:00–23:59	7 316 (16.3)	2 409 (13.5)	419 (21.3)	342 (20.3)	4 146 (17.8)
00:00–02:59	7 820 (18.3)	1 492 (15.1)	376 (22.6)	428 (24.5)	5 523 (18.8)
03:00–05:59	4 711 (16.6)	1 454 (12.4)	229 (20.7)	224 (21.1)	2 804 (19.3)

[a]Pedestrians, cyclists, etc.

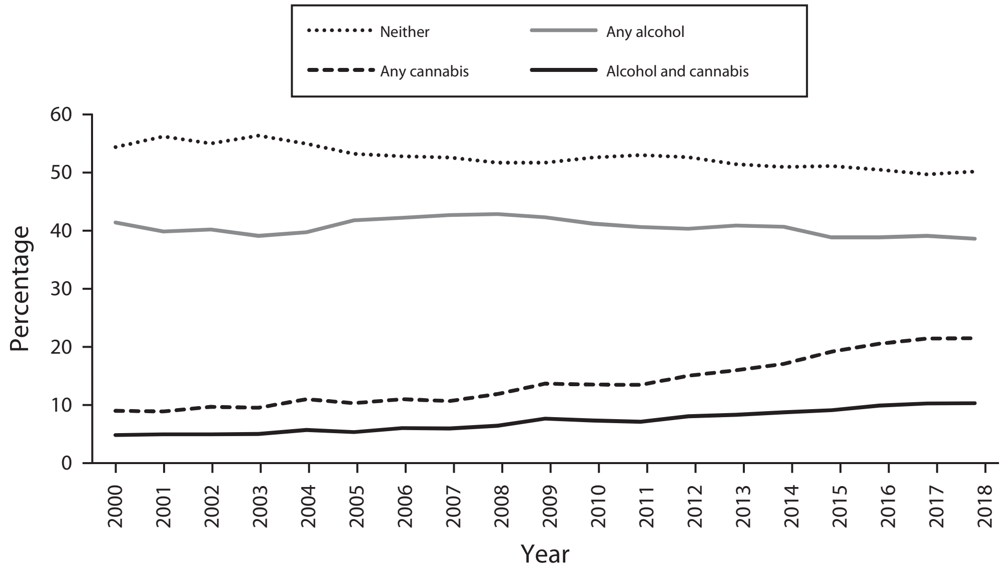

FIGURE 1— **Percentage of Motor Vehicle Crash Fatalities With Crash-Level Drug Testing With Neither Alcohol nor Cannabis Involvement, Any Alcohol Involvement, Any Cannabis Involvement, or Both Alcohol and Cannabis Involvement: Fatality Analysis Reporting System, United States, 2000–2018**

Note. Alcohol involvement defined as a crash-level blood alcohol concentration greater than 0.00%.

Georgia, Kentucky, Nevada, New Mexico, North Dakota, Ohio, and Wyoming), the rates of cannabis involvement were similar, indicating that changes in testing have not substantially affected observed levels of cannabis involvement in fatal crashes.

We examined the percentage of decedents from crashes with any alcohol, any cannabis, cannabis and alcohol, and neither alcohol nor cannabis over the study period (Figure 1). Alcohol was consistently involved in approximately 40% of MVC fatalities from 2000 to 2018. However, the

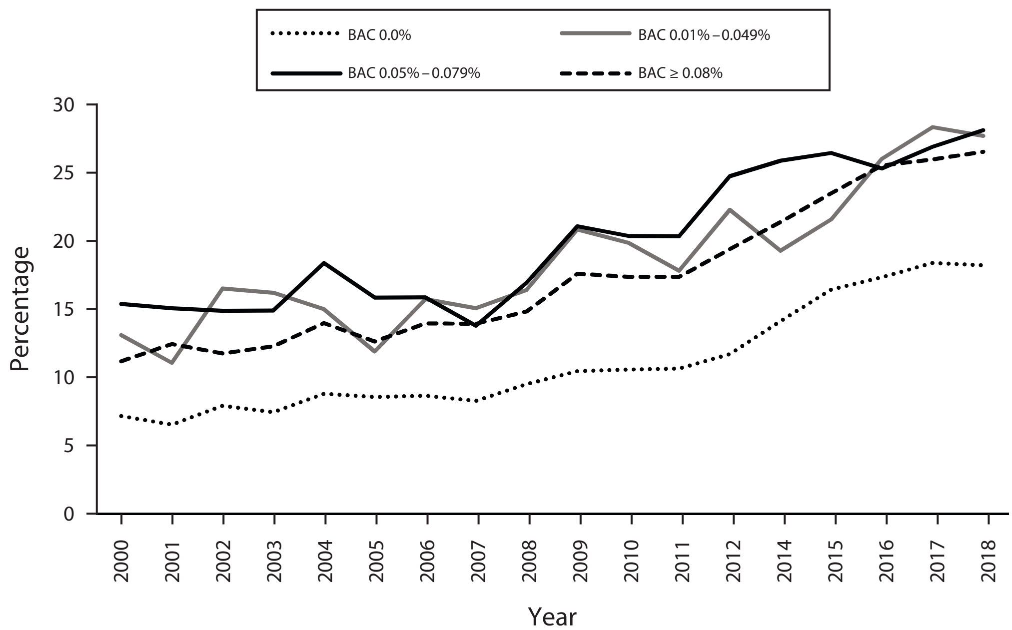

FIGURE 2— **Percentage of Motor Vehicle Crash Fatalities Involving Cannabis by Blood Alcohol Concentration (BAC) Level: Fatality Analysis Reporting System, United States, 2000–2018**

TABLE 2— Mixed Effects Multinomial Logistic Regression Models of Blood Alcohol Concentration (BAC) Level Based on Prevalence of Cannabis Involvement: Fatality Analysis Reporting System, United States, 2000–2018

Predictor: Cannabis Involvement	No.	Outcome, OR (95% CI)[a]		
		BAC 0.01%–0.049%	BAC 0.05%–0.079%	BAC ≥ 0.08%
Main analyses				
Overall unadjusted	322 773	1.77 (1.68, 1.86)	1.95 (1.84, 2.06)	1.67 (1.63, 1.71)
Overall adjusted[b]	322 773	1.56 (1.48, 1.65)	1.62 (1.52, 1.72)	1.46 (1.42, 1.50)
Stratified analyses				
Adjusted, stratified by sex[c]				
Men	232 899	1.49 (1.41, 1.59)	1.53 (1.43, 1.63)	1.38 (1.34, 1.42)
Women	89 874	1.84 (1.66, 2.04)	1.99 (1.76, 2.25)	1.78 (1.69, 1.86)
Adjusted, stratified by age,[d] y				
< 21	49 530	1.69 (1.52, 1.89)	1.83 (1.61, 2.08)	1.66 (1.57, 1.75)
21–34	98 262	1.49 (1.37, 1.62)	1.49 (1.36, 1.63)	1.29 (1.24, 1.34)
35–54	97 435	1.44 (1.30, 1.58)	1.62 (1.44, 1.82)	1.46 (1.40, 1.53)
≥ 55	77 546	2.06 (1.80, 2.36)	1.96 (1.63, 2.35)	1.96 (1.82, 2.10)
Sensitivity analyses				
Adjusted,[b] with addition of Alcohol Policy Scale[38] score	322 773	1.56 (1.48, 1.65)	1.62 (1.52, 1.71)	1.46 (1.42, 1.50)
Adjusted,[b] restricted to drivers, crash-level test results	254 002	1.46 (1.36, 1.56)	1.48 (1.38, 1.59)	1.42 (1.39, 1.46)
Adjusted,[e] restricted to drivers, individual-level test results	243 528	1.45 (1.36, 1.55)	1.56 (1.45, 1.68)	1.52 (1.48, 1.56)
Adjusted,[f] crash-level	287 230	1.74 (1.65, 1.84)	1.93 (1.81, 2.05)	1.68 (1.64, 1.73)
Adjusted,[b] nonimputed data	270 311	1.45 (1.37, 1.54)	1.48 (1.38, 1.58)	1.41 (1.38, 1.45)
Adjusted,[b] restricted to state–years with testing rates ≥ 50%	211 336	1.58 (1.48, 1.69)	1.63 (1.52, 1.76)	1.48 (1.44, 1.53)
Adjusted,[b] restricted to state–years with testing rates ≥ 66.67%	65 887	1.68 (1.50, 1.88)	1.45 (1.26, 1.66)	1.52 (1.45, 1.60)

Note. CI = confidence interval; OR = odds ratio.

[a]Ref = BAC 0.00%.
[b]Adjusted for year; decedent-level characteristics: sex (male [Ref] vs female), age category (< 21 y [Ref], 21–34 y, 35–54 y, ≥ 55 y), race/ethnicity (White [Ref], non-Hispanic Black, Hispanic, other, unknown); crash-level characteristics: opioid involvement (no [Ref] vs yes), other substance involvement (no [Ref] vs yes), urbanicity (rural [Ref] vs urban); and continuous state-level characteristics: percentage male, percentage non-Hispanic White, percentage Hispanic, percentage aged ≥ 21 y, percentage with college degree or higher, percentage Catholic population, median household income, law enforcement officers per 1000 residents, and state–year drug testing rate.
[c]Adjusted for covariates in footnote a, except sex.
[d]Adjusted for covariates in footnote a, except age.
[e]Adjusted for covariates in footnote a, but using individual-level alcohol, cannabis, opioid, and other drug involvement.
[f]Crash-level analyses adjusted for crash- and state-level characteristics but not decedent-level characteristics.

percentage of crashes involving any cannabis more than doubled from 9.0% in 2000 to 21.5% in 2018, and the percentage of fatalities involving both cannabis and alcohol more than doubled from 4.8% to 10.3%. When we examined cannabis involvement by BAC level (Figure 2), cannabis involvement increased over time for all groups. Cannabis involvement was more prevalent among fatalities that involved alcohol at all 3 BAC-level categories compared with fatalities that were not alcohol-involved.

We examined cannabis involvement by decedent and crash characteristics overall (Table 1). Crash-level cannabis involvement was more prevalent among decedents who were younger than 35 years and who were non-Hispanic Black, and in crashes that involved other drugs, occurred at night, and occurred on weekends. Decedents who were passengers were also more likely to have died in accidents involving cannabis, suggesting that these crashes are more likely to involve deaths of individuals other than the driver. Cannabis involvement by decedent and crash characteristics were also examined and stratified by level of alcohol involvement. Cannabis involvement was more prevalent among decedents with alcohol involvement among all BAC strata than decedents without alcohol involvement. Specifically, cannabis was involved in 11.5% of alcohol-uninvolved fatalities, versus 18.9% of fatalities involving BACs of 0.01% to 0.049%, 20.2% of fatalities involving BACs from 0.05% to 0.079%, and 17.7% of fatalities with BACs of 0.08% or higher. Among decedents who were younger than 21 years, 17.3% of deaths from alcohol-uninvolved crashes involved cannabis, whereas approximately 25% of deaths from alcohol-involved crashes involved cannabis. Similarly, among decedents who died in evening crashes, 13.2% of alcohol-uninvolved deaths involved cannabis, but approximately 20% of alcohol-involved deaths also involved cannabis.

Regression Analyses

In unadjusted, multinomial, multiple imputation analyses, fatalities involving cannabis had 1.77 (95% confidence interval [CI] = 1.68, 1.86) times the odds of involving a BAC from 0.01% to 0.049%, 1.95 (95% CI = 1.84, 2.06) times the odds of involving a BAC from 0.05% to 0.079%, and 1.67 (95% CI = 1.63, 1.71) times the odds of involving a BAC of 0.08% or higher compared with fatalities not involving cannabis (Table 2). In models adjusted for year, decedent-level characteristics, crash-level characteristics, and state-level characteristics, fatalities involving cannabis had 1.56 (95% CI = 1.48, 1.65) times the odds of involving a BAC from 0.01% to 0.049%, 1.62 (95% CI = 1.52, 1.72) times the odds of involving a BAC from 0.05% to 0.079%, and 1.46 (95% CI = 1.42, 1.50) times the odds of involving a BAC of 0.08% or higher compared with fatalities not involving cannabis. The full adjusted model can be found in Table B (available as a supplement to the online version of this article at http://www.ajph.org).

Additional Analyses

Results were similar across the aforementioned sensitivity analyses further adjusted for alcohol policies, restricted to drivers, at the crash-level, using nonimputed data, and restricted to fatalities from state–years with various thresholds for testing. Given that decedent sex and age were associated with alcohol involvement, we conducted posthoc analyses stratified by age and sex to assess whether the relationship between cannabis and alcohol coinvolvement differed on the basis of these factors (Table 2). Although females, individuals younger than 21 years, and individuals aged 55 years or older had lower odds of alcohol involvement in the main analysis (Table B), the relationship between cannabis and alcohol coinvolvement appeared stronger for these groups.

DISCUSSION

In this study, we assessed trends in cannabis and alcohol involvement in MVC decedents in the United States from 2000 to 2018 and examined how cannabis involvement relates to alcohol coinvolvement. To our knowledge, this is the first study to examine recent trends over time of cannabis involvement in relation to alcohol involvement in the United States, and the first to examine these relationships among all crash decedents rather than only drivers. We found that cannabis involvement and cannabis and alcohol coinvolvement in fatal MVCs are increasing nationally. While rates of alcohol involvement have remained steady over time, the rates of cannabis coinvolvement have increased. This does not offer support for the idea of cannabis and alcohol being substitutes, at least in terms of MVC fatalities. In adjusted regression analyses, cannabis was associated with alcohol involvement, even at BAC levels below 0.08%, indicating that cannabis use is a risk factor for alcohol-involved MVC fatalities even at levels of alcohol below the legally permissible level for driving.

The proportion of MVC fatalities that were cannabis-involved more than doubled during the study period. This could be attributable to shifting cannabis policies enabling expansion of medical and recreational cannabis markets, changing societal attitudes toward cannabis, and other factors such as increased cannabis potency. Although low drug testing rates are a known limitation of FARS, they increased from 32.9% to 47.9% over the study period. However, trends in increased cannabis involvement over time were consistent when we looked at subsets of states and state–years with higher testing rates, as has been done in past studies.[39] Drug testing procedures and rates are heterogeneous across states, and some states may conduct drug testing selectively, either opting for crashes in which alcohol use is already suspected, or the opposite, not conducting drug testing when alcohol is already known to be involved as a cost-saving measure, potentially resulting in biases in either direction.[39–41]

Cannabis involvement was more prevalent among fatalities that involved alcohol than fatalities that did not involve alcohol (Table 1). These findings were remarkably consistent by demographic and crash-level characteristics, with the highest prevalence of cannabis and alcohol coinvolvement in crashes involving younger decedents (aged < 35 years) and passenger deaths. Although most alcohol-involved fatalities occur at BACs of 0.08% or higher, the legal limit in all states but Utah (which in 2019 implemented a limit of 0.05%), cannabis coinvolvement was similar across BAC levels in crashes involving any alcohol. In regression analyses, cannabis involvement was associated with increased odds of also involving alcohol, regardless of BAC level. This finding was consistent across multiple sensitivity analyses and suggests that cannabis is a risk factor for alcohol-involved MVCs.

This study builds on past epidemiological studies of alcohol- and cannabis-involved MVC fatalities. While laboratory studies have shown driving impairment from cannabis and synergistic effects with alcohol, only a handful of recent epidemiological studies have examined the combined effects of alcohol and cannabis on the risk of crashes. Two case–control studies found a dose-effect of alcohol and cannabis on unsafe driving actions,[42,43] and another study found that culpable drivers in fatal MVCs were more likely to test positive for alcohol, cannabis, or both.[44] A meta-analysis conducted by the same authors found a pooled effect of marijuana on crash risk to be 2.66 (95% CI = 2.07, 3.41).[45] Contrasting results were seen in 2 studies that compared fatally injured drivers from FARS with matched drivers from the National Roadside Survey: one reported marijuana being associated with 83% increased odds of being a fatally injured driver rather than a control,[46] and the other reported statistically nonsignificant findings regardless of alcohol involvement.[47] These diverging results were later attributed to methodological differences, such as inclusion factors for states based on testing rates, and the authors recommended future research should "account for as many factors as possible when assessing crash risk," which we have tried to do in this analysis.[39(p324)] More precise estimates of the degree of cannabis involvement, and the nature of alcohol–cannabis coinvolved crash fatalities, would require testing levels of cannabinoids in drivers.

Given that the percentage of MVC fatalities involving alcohol has remained relatively stable at approximately 40% over the past 2 decades, it could be that increases in coinvolvement of cannabis are undercutting attempts at reducing alcohol-involved crash fatalities. There is a known relationship between alcohol policies and alcohol involvement in MVCs among adults and children, and within crashes involving alcohol at levels below the legal limit of 0.08%.[2,19,28] However, future research is warranted to understand whether cannabis changes the protective associations between alcohol policies and alcohol-involved crashes.

A number of studies have analyzed the effect of various forms of cannabis legalization on cannabis-involved MVC fatalities; however, results have been conflicting, and these studies have not consistently examined interactions with alcohol or alcohol policies.[21–27] Adopting a lower permissible BAC threshold for those with cannabis in their system may be a policy strategy to reduce MVC harms from concurrent and simultaneous use of alcohol and cannabis. Indeed, even without consideration for cannabis, the National Highway Traffic Safety Administration and the National Academies of Sciences, Engineering, and Medicine have recommended decreasing the legal alcohol limit to 0.05% to reduce alcohol-involved MVC fatalities.[48]

Limitations

This study is subject to a number of limitations. Most importantly, these data cannot provide information on whether cannabis caused the crash. The mere presence of cannabis without a level is not alone indicative of impairment as, depending on frequency and amount of use, individuals can test positive for days or even weeks after use. Cannabinoid test results were collapsed such that individual cannabinoids were not analyzed. Previous research has suggested a blood THC limit of 5 nanograms per milliliter as a cutoff for impairment; however, FARS reports binary results.[7,8] There has been variation in drug testing practices between states and over time, and some states may systematically not test for cannabis. This would, however, likely lead to an underestimation of the prevalence and bias toward the null in regression results. In addition, there is some evidence to suggest that simultaneous alcohol use increases THC levels and that there are lingering impairment effects once THC levels have declined, further complicating this.[10]

Although we conducted sensitivity analyses to understand the effect of limited testing on the prevalence of cannabis, it is possible that cannabis positivity was nevertheless subject to testing bias. In addition, because only 1 valid drug test from drivers in a crash was required for the definition of cannabis involvement, it is possible that cannabis involvement was undercounted if one driver tested negative and another was not tested. However, this would have likely resulted in a bias toward the null, and the sensitivity analysis restricted to drivers and involving their individual-level test results mitigates this concern. Alcohol testing was similarly not uniform, and we used imputed data from FARS to account for suboptimal testing.[31] Our regression analyses assessed the odds of alcohol involvement, to which the counterfactual is a fatality without alcohol involvement. This is distinct from incidence rate ratios but allows for adjusting for individual-level characteristics in models. However, our figures assessing rates over time support similar conclusions (Figure B).

Public Health Implications

Between 2000 and 2018, the percentage of MVC fatalities involving cannabis and coinvolving cannabis and alcohol more than doubled. Fatalities involving cannabis had increased odds of also involving alcohol, regardless of BAC level, suggesting that cannabis use is a risk factor for alcohol-involved MVC fatalities in the United States. Future research is needed to understand how cannabis and alcohol relate to cannabis and alcohol policies, both separately and together. AJPH

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M. C. Lira, M. Buczek, and T. S. Naimi conceptualized the study. M. C. Lira conducted the analyses with statistical expertise provided by T. C. Heeren. All authors contributed to interpretation of the analysis. M. C. Lira drafted the article, and all authors provided critical feedback.

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CONFLICTS OF INTEREST

The authors have no conflicts of interest to report.

HUMAN PARTICIPANT PROTECTION

This study was determined to be not human participant research by the institutional review board at Boston University Medical Campus (protocol H-37378).

REFERENCES

1. Centers for Disease Control and Prevention. 10 leading causes of death by age group, United States—2017. 2018. Available at: https://www.cdc.gov/injury/images/lc-charts/leading_causes_of_death_by_age_group_unintentional_2017_1100w850h.jpg. Accessed September 21, 2020.
2. Lira MC, Sarda V, Heeren TC, Miller M, Naimi TS. Alcohol policies and motor vehicle crash deaths involving blood alcohol concentrations below 0.08%. *Am J Prev Med.* 2020;58(5):622–629. https://doi.org/10.1016/j.amepre.2019.12.015
3. National Institute on Drug Abuse. Drugged driving drugfacts. 2019. Available at: https://www.drugabuse.gov/publications/drugfacts/drugged-driving. Accessed September 21, 2020.
4. 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. https://doi.org/10.1136/bmj.e536
5. Hall W, Degenhardt L. Adverse health effects of non-medical cannabis use. *Lancet.* 2009;374(9698):1383–1391. https://doi.org/10.1016/S0140-6736(09)61037-0
6. Hartman RL, Huestis MA. Cannabis effects on driving skills. *Clin Chem.* 2013;59(3):478–492. https://doi.org/10.1373/clinchem.2012.194381
7. Ramaekers JG, Berghaus G, van Laar M, Drummer OH. Dose related risk of motor vehicle crashes after cannabis use. *Drug Alcohol Depend.* 2004;73(2):109–119. https://doi.org/10.1016/j.drugalcdep.2003.10.008
8. Brubacher JR, Chan H, Erdelyi S, et al. Cannabis use as a risk factor for causing motor vehicle crashes: a prospective study. *Addiction.* 2019;114(9):1616–1626. https://doi.org/10.1111/add.14663
9. Arkell TR, Vinckenbosch F, Kevin RC, Theunissen EL, McGregor IS, Ramaekers JG. Effect of cannabidiol and Δ9-tetrahydrocannabinol on driving performance: a randomized clinical trial. *JAMA.* 2020;324(21):2177–2186. https://doi.org/10.1001/jama.2020.21218
10. Downey LA, King R, Papafotiou K, et al. The effects of cannabis and alcohol on simulated driving: influences of dose and experience. *Accid Anal Prev.* 2013;50:879–886. https://doi.org/10.1016/j.aap.2012.07.016
11. Sewell RA, Poling J, Sofuoglu M. The effect of cannabis compared with alcohol on driving. *Am J Addict.* 2009;18(3):185–193. https://doi.org/10.1080/10550490902786934
12. Hartman RL, Brown TL, Milavetz G, et al. Controlled cannabis vaporizer administration: blood and plasma cannabinoids with and without alcohol. *Clin Chem.* 2015;61(6):850–869. https://doi.org/10.1373/clinchem.2015.238287
13. Hartman RL, Brown TL, Milavetz G, et al. Cannabis effects on driving lateral control with and without alcohol. *Drug Alcohol Depend.* 2015;154:25–37. https://doi.org/10.1016/j.drugalcdep.2015.06.015
14. Smart R, Pacula RL. Early evidence of the impact of cannabis legalization on cannabis use, cannabis use disorder, and the use of other substances: findings from state policy evaluations. *Am J Drug Alcohol Abuse.* 2019;45(6):644–663. https://doi.org/10.1080/00952990.2019.1669626
15. Substance Abuse and Mental Health Services Administration. Key substance use and mental health indicators in the United States: results from the 2017 National Survey on Drug Use and Health. Publication no. SMA 18-5068, NSDUH Series H-53. 2018. Available at: https://www.samhsa.gov/data/sites/default/files/cbhsq-reports/NSDUHFFR2017/NSDUHFFR2017.pdf. Accessed February 20, 2021.
16. Berning A, Compton R, Wochinger K. Results of the 2013–2014 National Roadside Survey of Alcohol and Drug Use by Drivers. Report No. DOT HS 812 118. National Highway Traffic Safety Administration. February 2015. Available at: https://www.nhtsa.gov/sites/nhtsa.gov/files/

812118-roadside_survey_2014.pdf. Accessed September 23, 2021.

17. Kelley-Baker T, Berning A, Ramirez A, et al. 2013–2014 National Roadside Study of Alcohol and Drug Use by Drivers: drug results. Report No. DOT HS 812 411. National Highway Traffic Safety Administration. 2017. Available at: https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/13013-nrs_drug_092917_v6_tag_0.pdf. Accessed September 23, 2021.
18. Salas-Wright CP, Cano M, Hai AH, Oh S, Vaughn MG. Prevalence and correlates of driving under the influence of cannabis in the US. *Am J Prev Med.* 2021;60(6):e251–e260. https://doi.org/10.1016/j.amepre.2021.01.021
19. Naimi TS, Xuan Z, Sarda V, et al. Association of state alcohol policies with alcohol-related motor vehicle crash fatalities among US adults. *JAMA Intern Med.* 2018;178(7):894–901. https://doi.org/10.1001/jamainternmed.2018.1406
20. Azagba S, Latham K, Shan L, Qeadan F. Positive drug test trends in fatally-injured drivers in the United States from 2007 to 2017. *Subst Abuse Treat Prev Policy.* 2019;14(1):43. https://doi.org/10.1186/s13011-019-0228-z
21. Aydelotte JD, Mardock AL, Mancheski CA, et al. Fatal crashes in the 5 years after recreational marijuana legalization in Colorado and Washington [erratum in *Accid Anal Prev.* 2021;151:105757]. *Accid Anal Prev.* 2019;132:105284. https://doi.org/10.1016/j.aap.2019.105284
22. Santaella-Tenorio J, Wheeler-Martin K, DiMaggio CJ, et al. Association of recreational cannabis laws in Colorado and Washington State with changes in traffic fatalities, 2005–2017. *JAMA Intern Med.* 2020;180(8):1061–1068. https://doi.org/10.1001/jamainternmed.2020.1757
23. Cook AC, Leung G, Smith RA. Marijuana decriminalization, medical marijuana laws, and fatal traffic crashes in US cities, 2010–2017. *Am J Public Health.* 2020;110(3):363–369. https://doi.org/10.2105/AJPH.2019.305484
24. Lane TJ, Hall WJA. Traffic fatalities within US states that have legalized recreational cannabis sales and their neighbours. 2019;114(5):847–856. https://doi.org/10.1111/add.14536
25. Kamer RS, Warshafsky S, Kamer GC. Change in traffic fatality rates in the first 4 states to legalize recreational marijuana. *JAMA Intern Med.* 2020;180(8):1119–1120. https://doi.org/10.1001/jamainternmed.2020.1769
26. Sevigny EL. The effects of medical marijuana laws on cannabis-involved driving. *Accid Anal Prev.* 2018;118:57–65. https://doi.org/10.1016/j.aap.2018.05.023
27. Hansen B, Miller KS, Weber C. Early evidence on recreational marijuana legalization and traffic fatalities. National Bureau of Economic Research, March 2018. Working Paper Series No. 24417. Available at: https://www.nber.org/system/files/working_papers/w24417/w24417.pdf. Accessed September 24, 2021.
28. Hadland SE, Xuan Z, Sarda V, et al. Alcohol policies and alcohol-related motor vehicle crash fatalities among young people in the US. *Pediatrics.* 2017;139(3):e20163037. https://doi.org/10.1542/peds.2016-3037
29. *Fatality Analysis Reporting System (FARS) Analytical User's Manual, 1975–2018.* Washington, DC: National Center for Statistics and Analysis; 2019.
30. National Center for Statistics and Analysis. *2017 FARS/CRSS Coding and Validation Manual.* Report No. DOT HS812559. Washington, DC: National Highway Traffic Safety Administration; 2018.
31. Subramanian R. *Transitioning to Multiple Imputation—A New Method to Estimate Missing Blood Alcohol Concentration (BAC) Values in FARS.* Washington, DC: National Center for Statistics and Analysis; 2002.
32. US Census Bureau. National censal tables. 2019. Available at: https://www.census.gov/data/tables.html. Accessed June 1, 2020.
33. Pew Research Center. US religious landscape survey. 2014. Available at: https://www.pewforum.org/religious-landscape-study. Accessed May 31, 2019.
34. US Department of Commerce. American Community Survey (ACS). 2017. Available at: https://www.census.gov/programs-surveys/acs. Accessed May 31, 2019.
35. Federal Highway Administration. Quick find: vehicle miles of travel. 2017. Available at: https://www.fhwa.dot.gov/policyinformation/quickfinddata/qftravel.cfm. Accessed October 10, 2017.
36. Rubin DB. *Multiple Imputation for Nonresponse in Surveys.* Vol 81. Hoboken, NJ: John Wiley & Sons; 2004.
37. Xuan Z, Blanchette J, Nelson TF, Heeren T, Oussayef N, Naimi TS. The alcohol policy environment and policy subgroups as predictors of binge drinking measures among US adults. *Am J Public Health.* 2015;105(4):816–822. https://doi.org/10.2105/AJPH.2014.302112
38. Naimi TS, Blanchette J, Nelson TF, et al. A new scale of the US alcohol policy environment and its relationship to binge drinking. *Am J Prev Med.* 2014;46(1):10–16. https://doi.org/10.1016/j.amepre.2013.07.015
39. Romano E, Torres-Saavedra P, Voas RB, Lacey JH. Marijuana and the risk of fatal car crashes: what can we learn from FARS and NRS data? *J Prim Prev.* 2017;38(3):315–328. https://doi.org/10.1007/s10935-017-0478-3
40. Slater ME, Castle IJP, Logan BK, Hingson RW. Differences in state drug testing and reporting by driver type in US fatal traffic crashes. *Accid Anal Prev.* 2016;92:122–129. https://doi.org/10.1016/j.aap.2016.03.015
41. Berning A, Smither DD. Understanding the limitations of drug test information, reporting, and testing practices in fatal crashes. *Traffic Safety Facts Research Note.* 2014. Available at: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812072. Accessed September 30, 2020.
42. Dubois S, Mullen N, Weaver B, Bédard M. The combined effects of alcohol and cannabis on driving: impact on crash risk. *Forensic Sci Int.* 2015;248:94–100. https://doi.org/10.1016/j.forsciint.2014.12.018
43. Chihuri S, Li G, Chen Q. Interaction of marijuana and alcohol on fatal motor vehicle crash risk: a case–control study. *Inj Epidemiol.* 2017;4(1):8. https://doi.org/10.1186/s40621-017-0105-z
44. Li G, Chihuri S, Brady JE. Role of alcohol and marijuana use in the initiation of fatal two-vehicle crashes. *Ann Epidemiol.* 2017;27(5):342–347.e1. https://doi.org/10.1016/j.annepidem.2017.05.003
45. Li M-C, Brady JE, DiMaggio CJ, Lusardi AR, Tzong KY, Li G. Marijuana use and motor vehicle crashes. *Epidemiol Rev.* 2012;34(1):65–72. https://doi.org/10.1093/epirev/mxr017
46. Li G, Brady JE, Chen Q. Drug use and fatal motor vehicle crashes: a case–control study. *Accid Anal Prev.* 2013;60:205–210. https://doi.org/10.1016/j.aap.2013.09.001
47. Romano E, Torres-Saavedra P, Voas RB, Lacey JH. Drugs and alcohol: their relative crash risk. *J Stud Alcohol Drugs.* 2014;75(1):56–64. https://doi.org/10.15288/jsad.2014.75.56
48. National Academies of Sciences, Engineering, and Medicine; Board on Population Health Public Health Practice; Committee on Accelerating Progress to Reduce Alcohol-Impaired Driving Fatalities. *Getting to Zero Alcohol-Impaired Driving Fatalities: A Comprehensive Approach to a Persistent Problem.* Washington, DC: National Academies Press; 2018. https://doi.org/10.17226/24951