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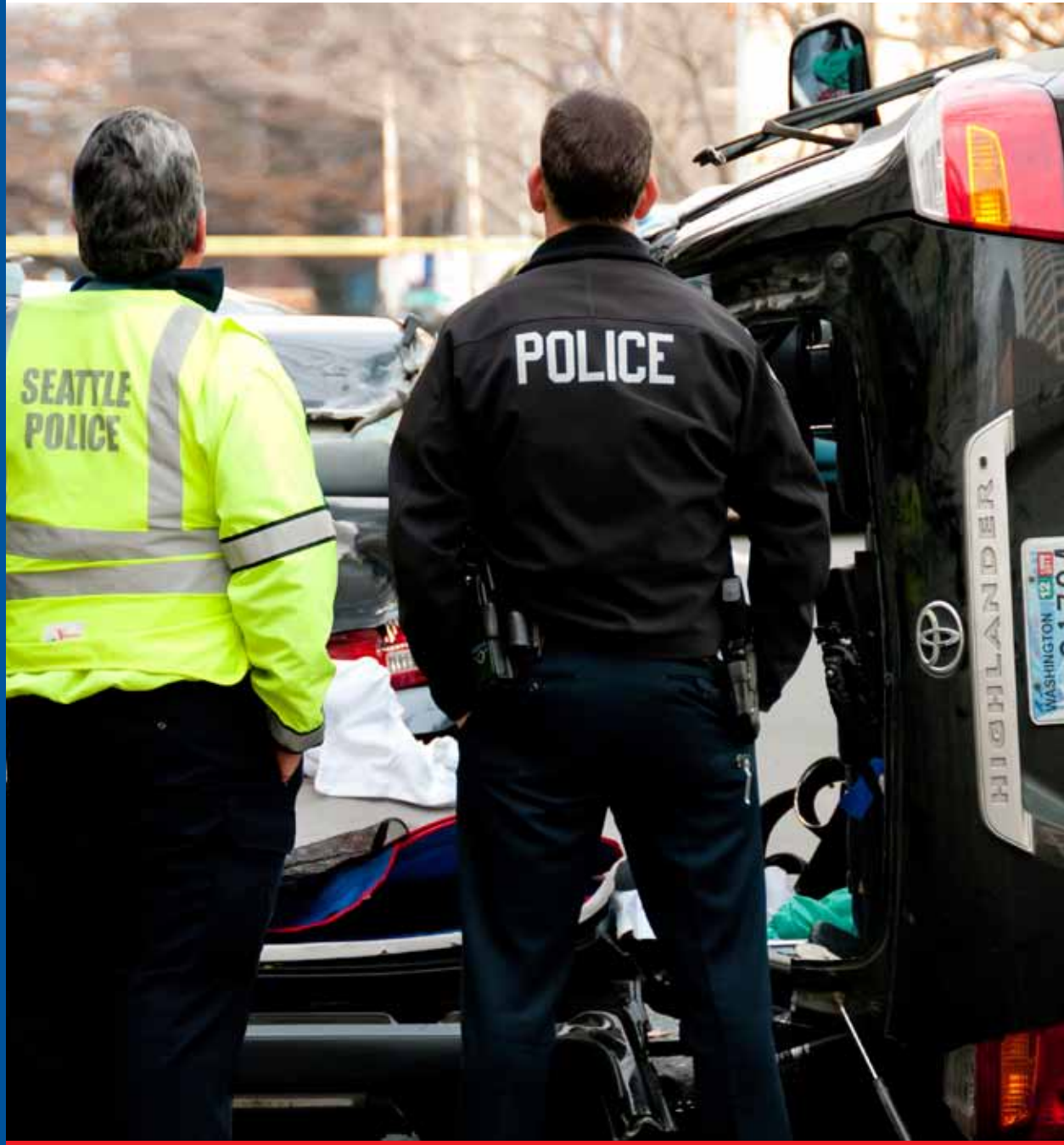

Prevalence of Marijuana Involvement in Fatal Crashes: Washington, 2010-2014

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Title

Prevalence of Marijuana Involvement in Fatal Crashes: Washington, 2010 – 2014. *(May 2016)*

Authors

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About the Sponsor

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Executive Summary

The purpose of this study was to quantify the prevalence of marijuana involvement in fatal crashes in the state of Washington in years 2010 – 2014 and to investigate whether the prevalence changed after Washington Initiative 502, which legalized recreational use of marijuana for adults aged 21 years and older and also created a new *per se* limit for driving under the influence of marijuana, took effect on 6 December 2012.

The data examined were obtained from the Washington Traffic Safety Commission and comprised a census of all motor vehicle crashes that occurred on public roads in the state of Washington and resulted in a death within 30 days. This study examined the presence and concentration of delta-9-tetrahydrocannabinol (hereafter *THC*), the main psychoactive chemical in marijuana, in the blood toxicological test results of drivers involved in fatal crashes. THC presence and concentration in the subset of drivers whose blood was not tested or whose test results were unavailable were estimated using the method of multiple imputation. The imputation method explicitly accounted for changes implemented during the study period in the cutoff levels used in the state laboratory for detection of THC.

Statewide, 3,031 drivers were involved in fatal crashes in years 2010 – 2014. Overall, considering both the actual blood toxicology test results and imputed results, an estimated 303 drivers—10.0% of all drivers involved in fatal crashes in Washington between 2010 and 2014—had detectable THC in their blood at or shortly after the time of the crash. Of all THC-positive drivers involved in fatal crashes, an estimated 34.0% had neither alcohol nor other drugs in their blood, 39.0% had detectable alcohol in addition to THC, 16.5% had other drugs in addition to THC, and 10.5% had had both alcohol and other drugs in addition to THC in their blood.

From 2010 through 2013, the estimated number and proportion of drivers involved in fatal crashes who had a detectable concentration of THC in their blood ranged from a low of 48 (7.9%) to a high of 53 (8.5%); the number and proportion both approximately doubled from 49 (8.3%) in 2013 to 106 (17.0%) in 2014. Analysis of trends over time before and after Initiative 502 took effect indicated that the proportion of drivers positive for THC was generally flat before and immediately after Initiative 502 took effect, but began increasing significantly at a rate of 9.7 percentage points per year approximately 9 months after Initiative 502 took effect. It was not clear whether this increasing trend was attributable to Initiative 502 or to other factors that were beyond the scope of the study.

THC levels in blood fall rapidly shortly after cannabis consumption, thus, it is possible that some surviving drivers in fatal crashes may have had a detectable concentration of THC in their blood at the time of the crash but that their THC levels had fallen below the minimum detectable level by the time a blood sample was drawn. Also, results of this study do not indicate that drivers with detectable THC in their blood at the time of the crash were necessarily impaired by THC or that they were at-fault for the crash; the data available cannot be used to assess whether a given driver was actually impaired, and examination of fault in individual crashes was beyond the scope of this study.

Introduction

On 6 November 2012, the citizens of the state of Washington approved by popular vote ballot Initiative 502, which allows adults aged 21 years and older to possess up to 1 ounce of marijuana, 16 ounces of marijuana-infused product in solid form, or 72 ounces of marijuana-infused product in liquid form (Revised Code of Washington 69.50.4013; Revised Code of Washington 69.50.360(3)). Initiative 502 also established a *per se* legal limit for driving under the influence [DUI] such that a person aged 21 years or older is guilty of DUI if he or she, "has, within two hours after driving, a THC concentration of 5.00 or higher," where *THC* denotes delta-9-tetrahydrocannabinol, the main psychoactive chemical in marijuana, and *THC concentration of 5.00* denotes 5 nanograms of THC per milliliter of whole blood (Revised Code of Washington 46.61.502). The new laws also made it illegal for a person under the age of 21 to drive with any measurable amount of THC in their blood (Revised Code of Washington 46.61.503). The laws legalizing possession of marijuana and creating a *per se* THC limit for DUI became effective on 6 December 2012.

Data from population-based surveys indicate that the proportion of Washington state residents who report having used marijuana at least once in the past month and the proportion who reported having ever used marijuana both increased after the new law took effect (Washington State Institute for Public Policy, 2015). However, not much is known about the prevalence of driving after using marijuana or the prevalence of recent marijuana use among drivers involved in crashes in Washington primarily due to data limitations.

In January 2016, the Washington Traffic Safety Commission (WTSC) made available for the first time the quantitative results of toxicology tests for THC performed on drivers involved in fatal crashes in the state of Washington, and appended these new data to their database of all drivers involved in fatal crashes statewide. This study uses these new data from the WTSC to estimate the proportion of drivers in fatal crashes in the state of Washington who had a detectable concentration of THC in their blood at or soon after the time of the crash and to investigate whether that proportion changed after Washington Initiative 502 took effect on 6 December 2012.

Methods

Overview

The purpose of this study was to estimate the number and proportion of drivers involved in fatal crashes in Washington state who had a detectable concentration of THC in their blood at or shortly after the time of the crash each year for years 2010 – 2014, and to investigate whether the proportion of fatal-crash-involved drivers with detectable THC changed after recreational use of marijuana by adults was legalized. Some drivers were not tested for drugs. The method of multiple imputation was used to estimate the proportion of drivers not tested for drugs who likely would have tested positive for THC had they been tested. This was done by analyzing the relationships between other available data and the probability of being tested for drugs and the probability of testing positive for THC if tested. Results of actual drug tests were combined with imputed results from drivers not tested for drugs to estimate the overall prevalence of detectable levels of THC among all drivers involved in fatal crashes in Washington during the study period.

Data

The data analyzed for this study was the Washington State Fatality Analysis Reporting System (FARS) data file, which was obtained from the WTSC. The Washington State FARS data file is a census of all crashes that occurred on public roadways in the state of Washington and resulted in a death within 30 days of the crash. Data pertaining to the details of each crash and the vehicles and drivers involved were recorded by police officers and entered into a database by Washington State FARS Analysts for submission to the National Highway Traffic Safety Administration (NHTSA) FARS data system. The data included records of 3,031 drivers involved in 2,070 fatal crashes that occurred in the state of Washington between 1 January 2010 and 31 December 2014.

NHTSA's FARS data includes some information regarding the results of toxicological tests, however, FARS data are very limited with respect to toxicology results related to marijuana (Berning & Smither, 2014). To address this limitation, Washington State FARS Analysts collaborated with the Washington State Toxicologist to manually abstract from actual toxicology reports data on the presence and concentration of delta-9-tetrahydrocannabinol (hereafter *THC*), its inactive metabolite carboxy-tetrahydrocannabinol (hereafter *carboxy-THC*), and unspecified cannabinoids, and append these data to the Washington State FARS data file. The process by which this was accomplished is described by Grondel (2015). Analyses pertaining to detection of THC, carboxy-THC, and unspecified cannabinoids were based on the data abstracted from toxicology reports and appended to the FARS data file, not the standard FARS variables reported in the FARS data file published by NHTSA.

Drug testing

The FARS data file includes variables to indicate the type of specimen on which toxicological tests were performed; values include blood, urine, both blood and urine, other specimen type, unknown specimen type, specimen type not reported, unknown if tested, and not tested. For the purpose of this study, drug test specimen type was classified as:

- Blood
- Other/unknown/unreported specimen type
- Not tested

Drivers coded as having had both blood and another specimen tested were coded as having had blood tested; for the purpose of this study, the fact that another type of specimen in addition to blood was also tested was not of substantive interest. Overall, 1,508 drivers (49.8%) had a blood specimen tested, 280 (9.2%) had an other/unknown/unreported type of specimen tested (239 urine; 41 other/unknown specimen type), 37.8% of drivers were not tested for drugs at all, and 3.2% were reported as "unknown if tested," which for the purpose of this study were assumed to have not been tested for drugs and thus were grouped with those who were not tested.

Determination of THC presence and concentration

The main outcome of interest in this study was the number and proportion of drivers who had a detectable level of THC in their blood. Toxicology test results for THC were reported in the Washington State FARS data file as an indicator for whether THC was detected, and the concentration of THC, measured in nanograms of THC per milliliter of blood (ng/mL), if THC was detected. Because THC may not be reliably detected in urine (Huestis & Smith, 2007), only results from tests of blood specimens were used; results from tests of specimens other than blood were treated as unknown.

The minimum concentration of THC that would be recorded as a positive test result changed twice during the study period. At the beginning of the study period, the threshold for detection of THC in blood was 1 nanogram of THC per milliliter of blood (ng/mL), which was increased to 2 ng/mL on 3 December 2012 and then returned to 1 ng/mL on 8 May 2014. To produce results that had the same physical meaning for the entire study period, negative toxicology results for THC during the period when the 2 ng/mL threshold was in effect were treated as unknown if the same driver also tested positive for carboxy-THC, because the presence of carboxy-THC suggests that the driver had consumed cannabis at some point which may or may not have been recent enough for THC to remain in the driver's blood; this resulted in 27 negative results for THC being treated as unknown. Drivers who tested negative for carboxy-THC as well as for THC were assumed truly THC-negative, because carboxy-THC is detectable in blood for a longer period of time subsequent to cannabis consumption than is THC (Desrosiers et al., 2014).

Blood toxicological test results for THC were also treated as unknown if a driver was not reported to have tested positive for THC nor for carboxy-THC but was reported to have tested positive for unspecified cannabinoids, which typically suggests that a specimen was screened for the presence of cannabinoids and cannabinoids were found but no confirmatory test was performed to confirm the presence of THC and/or carboxy-THC. This resulted in test results from an additional 11 drivers being treated as unknown for both THC and carboxy-THC.

For the purpose of this report, a driver is said to have had a *usable blood toxicology test result* if the driver was given a blood toxicology test, results were available, and results

were not treated as unknown for any of the previously-mentioned reasons. A total of 1,470 drivers (48.5% of all drivers) had usable blood toxicology test results.

Missing information about THC

Slightly more than half of all drivers had an unknown (missing) values for THC presence and concentration, including 1,243 (41.0%) who were not tested for drugs at all, 280 (9.2%) whose test for drugs was not performed on a blood specimen, 27 (0.9%) who tested negative for THC but positive for carboxy-THC during the period of time when a positive test result for THC was based on a threshold of 2 ng/mL rather than the 1 ng/mL threshold in use during most of the study period, and 11 drivers (0.4%) who tested positive for unspecified cannabinoids which could have been THC or carboxy-THC.

Multiple imputation of missing THC values

To estimate the distribution of THC values and proportion positive for THC in the entire population of drivers involved in fatal crashes including those not tested for drugs or whose results were unknown, the method of multiple imputation (Rubin, 1987) by chained equations (van Buuren et al., 1999) was used to create ten independent estimates of what would have been each driver's THC test result had the driver's blood been tested at a detection threshold of 1 ng/mL and the results known. A variable was included in the imputation model if it was significantly associated with the probability of a driver being subject to a blood toxicology test (χ^2 test, $P<0.05$; see Table 1), if it was significantly associated with the probability of testing positive for THC if tested, or if the variable's relationship to THC was of analytical interest. Variables included in the final imputation model for THC are shown in the Appendix. All variables included in the model except day of week were significantly associated with the probability of being tested for drugs, the probability of testing positive for THC if tested, or both; day of week was included because it was of interest for subsequent analyses.

The imputation procedure replaced each missing value of THC with a value selected randomly from among the cases most similar to the case of interest with respect to the values of the explanatory variables specified in the imputation model, yielding a new copy of the data file in which all drivers had a THC value (i.e., their actual toxicology test result if known, or else an imputed value). THC values were imputed in two stages: first a binary indicator was imputed (THC present vs. absent), and then THC concentration was imputed in cases in which THC was imputed as present. Missing values of explanatory variables included in the imputation model were imputed similarly in order to enable the imputation of THC to proceed. Imputation was performed 10 times, yielding 10 independent copies of the data file in which observed values of THC were copied from the original data file and missing values of THC were replaced by imputed values.

Results based on imputed values of THC in conjunction with actual THC test results were obtained by calculating the statistic of interest (e.g., the proportion of drivers who had a THC concentration of 1 ng/mL or greater) in each of the ten copies of the data file separately and then averaging the results. Standard errors and confidence intervals were calculated using the method of Rubin (1987) to account for both the variability in the observed data and the uncertainty in the imputed values.

Validation of imputation model

To assess the performance of the imputation model, half of all drivers with usable blood toxicology test results and complete data for all variables included in the imputation (hereafter *complete cases,* n=1,253) were selected at random and their toxicology test results for THC, carboxy-THC, and cannabinoids were replaced with missing values and were imputed. The proportion imputed THC-positive was compared to the proportion actually THC-positive. This procedure was repeated 500 times with 500 independent random samples of half of all complete cases. The mean difference over the 500 repetitions between the imputed versus actual proportion of drivers who were THC-positive was -0.2 percentage points. The mean absolute difference (i.e., regardless of the sign of the difference) was 1.5 percentage points. The 95th percentile absolute difference between the proportion imputed THC-positive vs. actually THC-positive was 3.4 percentage points (i.e., the difference was 3.4 percentage points or smaller in 95% of the 500 repetitions). The actual proportion of drivers who were THC-positive fell within the 95% confidence interval of the imputed proportion in 484 of the 500 repetitions (96.8%), indicating that the nominal 95% confidence intervals of the imputed values were slightly wider than true 95% confidence intervals.

Analysis

Descriptive statistics

The numbers and proportions of drivers who tested positive for THC or were imputed to have had a detectable concentration of THC were tabulated in relation to crash, vehicle, and driver characteristics. The proportion of drivers with THC concentrations of 5 ng/dL or greater was tabulated overall and in relation to year and survival status. The prevalence of alcohol and other drugs in THC-positive drivers was also examined by year and survival status.

Estimating the effect of Initiative 502

A binomial regression model with an identity link function was used to assess whether the proportion of drivers with detectable THC changed subsequent to the effective date of Washington Initiative 502 (6 December 2012), which legalized marijuana use in Washington for adults aged 21 years and older and established a *per se* legal limit of 5 ng/mL of THC for DUI. The model used to estimate the effect of the new law included a binary indicator for whether the Initiative 502 was in effect (0 before 6 December 2012, 1 after) to account for the immediate effect of Initiative 502 on the average proportion of drivers in fatal crashes who were THC-positive, indicator variables for seasons to account for seasonal variation in the proportion of drivers who were THC-positive, and a piecewise linear spline representing time in days before or after Initiative 502 became effective to account for any underlying trend in THC involvement in fatal crashes before Initiative 502 took effect and any change in the slope of the trend associated with Initiative 502.

Alternative models were also fit to the data with the change in the slope of the linear time trend occurring up to 1 year (at 1 week increments) before or after Initiative 502 took effect, to assess whether the data were more consistent with a change in the slope of the trend at some point before or after Initiative 502 became effective rather than requiring that any

change in the slope of the trend occur at the same time as Initiative 502 became effective. The deviance of alternative models was compared, with lower deviance indicating better fit.

Several sensitivity analyses were also performed, including: using the 2 ng/mL detection threshold rather than the 1 ng/mL threshold, using only actual blood toxicology test results (with missing values excluded rather than imputed), using only fatally-injured drivers with actual blood toxicology test results, and using only fatally-injured drivers with both actual blood toxicology test results and blood alcohol concentration test results that indicated a BAC lower than 0.08.

All results are based on both actual observations and imputed data for THC, other drugs, and blood alcohol concentration (BAC) unless otherwise noted. Imputed values of other variables whose missing values were imputed in the course of imputing the missing values of THC (age, sex, etc.) are not shown; those variables are presented with respect to their original values only.

Results

A total of 3,031 drivers were involved in fatal crashes in Washington state in years 2010 – 2014. Blood toxicology tests were performed on 49.8% of all drivers (Table 1, at end of report). The proportion of drivers tested for drugs (at all) varied by year. Also importantly, the proportion of tested drivers whose tests were performed on blood specimens increased substantially over the study period. At the beginning of the study period, approximately one in four drivers tested for drugs was not subject to a blood test, whereas in 2013 and 2014, almost all drivers tested for drugs were subject to a blood test. Drivers who died within 2 hours of the crash were the most likely to be tested for drugs, drivers who died later were somewhat less likely to be tested, and drivers who survived were much less likely to be tested. The likelihood of a driver's blood being tested for drugs was also associated with the driver's age, sex, license status, driving record, vehicle type, vehicle age, circumstances of the crash (time of day, number of vehicles in crash, whether the vehicle departed the roadway, pedestrian involvement, unsafe driving actions or errors), type of police agency investigating (state patrol vs. county sheriff vs. city or municipal police), officer suspicion of alcohol or drug involvement, and blood alcohol concentration (Table 1).

Examining only drivers who were tested for drugs and who had usable blood toxicology test results (i.e., excluding cases with (n=1,470; 48.5% of all drivers), 14.5% tested positive for the presence of THC (Table 2). The proportion positive for THC varied substantially by year. From 2010 through 2013, an average of 12.2% of drivers whose blood was tested for drugs tested positive for THC (range: 10.8% – 13.4%); in 2014, the proportion increased to 22.1%. To investigate whether this increase was attributable to the change in the threshold that the state laboratory used for the detection of THC from 2 ng/mL to 1 ng/mL in May of 2014, the proportion of drivers with usable toxicology results whose THC concentrations were equal to or greater than 2 ng/mL were also examined: an average of 11.5% of drivers whose blood was tested for drugs between 2010 and 2013 had a THC concentration of 2 ng/mL or greater (range: 10.1% - 12.5%); that proportion increased to 17.1% in 2014 (not shown in table). Drivers who died within one hour of the crash were much more likely to test positive for THC (at either threshold) than were drivers who died later or who survived. The proportion of those subject to blood test who tested positive for THC varied significantly in relation to most of the same variables as the probability of receiving a blood test, with the exceptions of seatbelt use, previous DWI convictions, road type, pedestrian involvement, and unsafe actions or errors reported, which were associated with the probability of being tested for drugs but were not significantly associated with the detection of THC.

Including drivers whose values of THC were imputed as well as those that were confirmed by usable blood toxicology test results, an estimated 303 drivers, representing 10.0% of all drivers involved in fatal crashes in the state of Washington over the five-year study period, had a THC concentration of at least 1 ng/mL at the time of the crash (213 confirmed by toxicology and an additional 90 imputed).

There was a large increase in the estimated number and proportion of THC-positive drivers in 2014. In each year of 2010 – 2013, the estimated annual number of drivers in fatal crashes who were THC-positive ranged from a low of 48 to a high of 53, which represented 7.9 – 8.5% of all drivers involved in fatal crashes each year. In 2014, the estimated number

(106) and percentage (17.0%) of drivers in fatal crashes who were THC-positive were both double the largest number (53) and largest percent (8.5%) estimated in any of the prior four years.

Drivers whose license was suspended or revoked at the time of the crash were much more likely than drivers with a valid license to have been THC-positive (23.9% vs. 8.1%). Drivers who tested positive for alcohol were much more likely to have been THC-positive than were drivers who were tested for alcohol and were found alcohol-negative (19.2% vs. 8.7%). Drivers who left the scene of the crash were much more likely to have been THC-positive than were drivers who remained at the scene (27.6% vs. 9.4%). After excluding deceased drivers, who by definition were unable to leave the scene, drivers who left the scene of the crash were fully 4 times as likely to have been THC-positive as were drivers who remained at the scene (27.6% vs. 6.8%). Drivers who died were significantly more likely to have been THC-positive than drivers who survived, the proportion THC-positive was greater for drivers ages 18-20 than for any other age group, males were more likely than females to have been THC-positive, drivers of vehicles that were more than 15 years old were more likely to have been THC-positive than drivers of newer vehicles, drivers involved in crashes between 8 PM and 5:59 AM were more likely to have been THC-positive than were drivers who crashed during daytime hours, and drivers involved in single-vehicle road-departure crashes were more likely to have been THC-positive than were drivers in multiple-vehicle crashes or other types of single-vehicle crashes.

THC-positive drivers who died tended to have higher THC concentrations than did drivers who survived. The proportion of all deceased drivers whose THC concentration was equal to or greater than 5 ng/mL (67.6%) was nearly double the corresponding proportion of surviving drivers (36.3%) (Table 3). While the proportion of all drivers with THC concentrations of 5 ng/mL or greater did not vary significantly by year (P=0.071), the proportion of deceased drivers with THC concentrations of 5 ng/mL or greater increased by a statistically significant 7.8 percentage points (95% CI: 2.8 – 12.8 percentage points) from 2013 to 2014.

The majority of drivers who had detectable levels of THC also had alcohol and/or other drugs in their blood at the time of the crash (Table 4). Of all THC-positive drivers involved in fatal crashes over the study period, an estimated 34.0% were positive for THC only, 39.0% were positive for both THC and alcohol, 16.5% were positive for both THC and one more other drugs (but not alcohol), and 10.5% were positive for THC, alcohol, and one or more other drugs. (Note that not all drugs included in the category of "other drugs" were necessarily illegal nor impairing; however, sample sizes were insufficient to examine specific drugs.) THC-positive drivers who died were relatively more likely to be positive for alcohol and/or other drugs; only 24.1% were positive for THC alone. In contrast, 47.0% of surviving drivers in fatal crashes who were THC-positive were positive for THC alone. *Post hoc* analysis suggest this was largely a function of seatbelt use: drivers positive for alcohol and/or other drugs in addition to THC had much lower rates of seatbelt use than did drivers positive for THC alone, and thus were more likely to die given involvement in a crash. The proportions positive for other substances besides THC fluctuated somewhat from year to year but did not exhibit any clear evidence of a trend. Notably, however, the raw number of drivers positive for THC alone, THC in conjunction with alcohol, THC in conjunction with other drugs, and THC in conjunction with both alcohol and other drugs all were greater in

2014 than in any of the preceding four years, as were their shares of all drivers involved in fatal crashes.

Analysis of whether the proportion of drivers in fatal crashes who were THC-positive or the trend therein changed after Washington Initiative 502 took effect on 6 December 2012 showed that the new law was not associated with a significant shift in the average proportion of fatal-crash involved drivers who were THC-positive (P=0.65), but was associated with a statistically significant change in the slope of the trend (P=0.004). However, the change in the slope of the trend appeared to have actually occurred several months after the effective date of Initiative 502. The model that provided the best fit to the data modeled the increasing trend in the proportion THC-positive as beginning 39 weeks after the effective date of Initiative 502 (Figure 1). In this model, after adjustment for seasonal variation, the proportion of drivers in fatal crashes who were THC-positive had been decreasing at a statistically non-significant rate of 0.1 percentage points per year prior to the effective date of Initiative 502, continued to follow this trend for approximately 39 weeks after Initiative 502 took effect, and then began increasing at a rate of 9.7 percentage points per year (95% CI 4.4 – 14.9 percentage points per year) beginning in September 2013 (Figure 1).

To investigate whether this result was confounded by the timing of changes in the state laboratory's minimum threshold for detection of THC, changes in practices regarding whether drivers already found to have been legally intoxicated by alcohol were tested for drugs, or other issues related to the imputation procedure, sensitivity analyses were performed:

1) Using 2 ng/mL rather than 1 ng/mL as the threshold for classifying drivers as THC-positive,
2) Including only fatally-injured drivers who were tested for both alcohol and drugs and had usable test results for both,
3) Using only drivers who had a BAC below 0.08.

Results were similar. There was no discernible trend in the proportion of drivers with THC concentrations of 2 ng/mL or greater before or immediately after Initiative 502 took effect; in September 2013 the proportion THC-positive at 2 ng/mL began increasing by an average of 5.7 percentage points per year (95% CI 1.6 – 9.7). Analyses based only on actual blood toxicology test results of fatally-injured drivers (with missing values excluded rather than imputed) produced the same general pattern of results. Limiting analyses to actual blood toxicology test results from fatally-injured drivers with BAC<0.08 yielded the largest estimates of the rate of increase in the prevalence of THC-positive drivers beginning in September 2013 (estimated rate of increase = 12.5 percentage points per year).

Discussion

This study examined the prevalence of THC, the main psychoactive chemical in marijuana, in the blood of drivers involved in fatal crashes in Washington state in years 2010 – 2014. Results showed that overall, 10% of drivers involved in fatal crashes over the study period had a detectable concentration of THC in their blood at the time of the crash. The prevalence was not constant over the study period. The proportion of fatal-crash-involved drivers with detectable THC in their blood was approximately twice as great in 2014 as in prior years.

Analysis of trends before and after the Initiative 502 legalized the recreational use of marijuana for adults suggested that the proportion of drivers in fatal crashes who had detectable THC in their blood was basically flat before and immediately after the new law went into effect, but then began increasing rapidly in or around September 2013, or approximately 9 months later. It is possible—because Initiative 502 not only legalized recreational use of marijuana but also established a *per se* THC limit for DUI—that new users of marijuana may have refrained from driving after using marijuana out of concern of arrest for DUI, but that such concern subsided somewhat in the months following Initiative 502, leading to a gradually increasing prevalence of THC-positive drivers on the road and in fatal crashes. This, however, is merely speculative. This study could not determine whether the increase beginning in or around September 2013 in the proportion of drivers in fatal crashes who were THC positive was a delayed effect of Initiative 502 or whether it was attributable to some other phenomenon that was beyond the scope of the study.

Another factor that might have been expected to have been associated with an increase in the proportion of drivers positive for THC was the opening of marijuana retail stores in Washington state in July of 2014. It was not possible to evaluate the impact of the opening of marijuana retail stores on the prevalence of THC-positive drivers in fatal crashes, because this occurred only 6 months before the end of the study period. However, this does not appear to have been a major contributor to the increase in prevalence of THC-positive drivers observed in this study, because most of the increase clearly occurred prior to the date when the first marijuana retail stores opened in Washington. This should be investigated in future research when newer data become available.

This study analyzed data compiled by the Washington Traffic Safety Commission in collaboration with the state toxicologist and appended to Washington state's FARS file. These data were more detailed than the data on drug test results reported in the relevant variables included in the NHTSA's version of the FARS data file, without which this study could not have been performed. The drug test result variables in the NHTSA's version of the FARS data file allow for the reporting of a positive drug test result for: "marijuana;" THC; cannabinoids, type unknown; and several other related substances not coded for any drivers in Washington over the study period. A *post hoc* analysis was performed to compare the presence of THC and other cannabinoids in the standard FARS variables versus in the supplemental variables produced by the WTSC. While both the standard FARS variables and the supplemental WTSC variables agreed regarding the presence or absence of any cannabinoids of any kind in 99.7% of all cases, the two disagreed regarding specifically the presence of THC in 4.7% of all cases and 27.5% of all cases in which either set of variables indicated that THC was detected over the study period. Notably, the level of agreement

between the standard FARS variables and the supplemental WTSC variables with respect to THC presence varied substantially by year, with relatively poor agreement in years 2010-2012 (disagreed in 8.5% of all cases and 46.6% in which either indicated that THC was detected) but much better agreement in 2013 and 2014 (disagreed in 0.4% of all cases and 2.7% of cases in which either indicated that THC was detected). Also importantly, the supplemental WTSC data included quantitative test results for THC, which made it possible to examine the number and proportion of drivers whose THC concentration exceeded Washington's *per se* legal limit of 5 ng/mL. The standard FARS variables do not report the actual concentration of THC that was detected, thus precluding such analysis.

The Washington Traffic Safety Commission also performed analysis of the same data that were analyzed in this study (Grondel, 2015), yielding similar but not identical results. There were a number of important differences between the current study and the WTSC study. Most importantly, the WTSC study reported the proportion of drivers who tested positive for THC as a proportions of all drivers who were tested for drugs and alcohol. Those proportions should not be projected onto the entire population of drivers involved in fatal crashes in the state unless the probability of being tested for drugs is assumed to be independent of the probability that the driver was actually THC-positive. The current study found that the probability of being tested for drugs was strongly associated with numerous driver, vehicle, and crash-related characteristics that were also predictive of THC presence among those drivers who were tested. In addition, the WTSC study reported THC-positive drivers as a percent of all drivers tested for drugs, including some for whom only a urine specimen and not a blood specimen was tested, and treated as THC-negative all drivers who were tested for drugs and did not produce a positive result for THC. However, THC may not be reliably detected in urine (Huestis & Smith, 2007). Thus, the current study treated drug test results as unknown if they were not from a blood specimen.

To produce estimates of THC prevalence applicable to the entire population of drivers involved in fatal crashes in the state of Washington, the current study used the method of multiple imputation to estimate the distribution of THC presence and levels among drivers for whom drug test results were not available or were not altogether interpretable with respect to THC. The imputation model accounted for the relationships of the probability of being tested for drugs and the probability of being positive for THC if tested with numerous crash, vehicle, and driver-related characteristics found to be associated with either or both probabilities. By producing ten independent data sets containing both actual and imputed THC values, this study was able to produce statistical estimates of the proportion of all drivers involved in fatal crashes—not only those who were tested for drugs—who had a detectable amount of THC in their blood at the time of the crash, and account for the uncertainty introduced into the estimates through the imputation process.

NHTSA has been using the method of multiple imputation since 2001 to estimate the distribution of the BACs of drivers for whom test results were unavailable (Subramanian, 2002). The data analyzed in this study were obtained from the Washington Traffic Safety Commission and did not include NHTSA's imputed BAC values in cases when BAC test results were unavailable. Thus, missing values of BAC were imputed in this study along with missing values of THC, to ensure that imputed values of THC reflected the strong relationship with alcohol presence that was observed among drivers tested for both alcohol and drugs. To compare the performance of the imputation model used in the current study with that developed and validated by NHTSA (Rubin et al., 1998), the distribution of BAC

values imputed in the present study were compared to those imputed by NHTSA and published in NHTSA's version of the FARS data file. This study estimates that 711 drivers involved in fatal crashes in Washington over the 5-year study period had a BAC of 0.08 mg/dL or greater, compared with NHTSA's estimate of 701, a discrepancy of 10 drivers out of 1,183 for whom BAC was imputed; the largest discrepancy in any single year was 4 drivers out of 236 in 2011.

Limitations

THC is metabolized rapidly after consumption in a living human body (Desrosiers et al., 2014). Consequently, if a driver had used cannabis at some point relatively shortly (e.g., in the past few hours) prior to driving, toxicology tests performed on a blood sample drawn from a surviving driver hours after the occurrence of a crash are likely to underestimate the concentration of THC that was present in the driver's blood at the time of the crash, or even fail to detect THC at all. In another AAA Foundation study, Banta-Green et al. (2016) estimated that the average time between contact with police and the collection of a sample of a driver's blood was over two hours and that THC concentrations present in drivers' blood decreased by an average of 5 ng/mL over the first two hours between initial contact with police and the time that blood was drawn. In the current study, deceased drivers were significantly more likely than surviving drivers to have had any THC detected, and deceased drivers who tested positive for THC had higher THC concentrations than surviving drivers who tested positive for THC. Thus, it is possible that some surviving drivers who were tested for THC and tested negative actually had what would have been a detectable concentration of THC in their blood at the time of the crash, but that it was no longer detectable by the time their blood was drawn for testing. Thus, the results of this study may underestimate the proportion of drivers in fatal crashes who had a detectable concentration of THC in their blood at the actual time of the crash, especially among drivers who survived.

This study used the presence of at least 1 ng/mL of THC in blood as an indicator of recent use of marijuana. In a study of 14 frequent marijuana smokers (defined as smoking marijuana at least 4 times per week) and 11 occasional marijuana smokers (less than twice per week), Desrosiers et al. (2014) found that none of the occasional users had a blood THC concentration of 5 ng/mL or greater, the *per se* limit for DUI in Washington, 2 hours after having smoked one 6.8% THC cannabis cigarette, and the longest time that any of the occasional users had any detectable THC in their blood was 6 hours after smoking. However, all of the frequent users had a detectable concentration of THC in their blood for at least 24 hours after smoking the same one 6.8% THC cannabis cigarette, and four still had a blood THC concentration of 5 ng/mL or greater 24 hours after smoking. Another study of chronic marijuana users found a small proportion still had at a blood THC concentration of 1 ng/mL or greater 7 full days after the last time that they had used marijuana (Karschner et al., 2009). Thus, it is possible that some of the THC-positive drivers in the current study may have last used marijuana several hours or even days prior to the crash. In a population-based survey conducted in Washington State in 2014, 9.2% of licensed drivers aged 18 years and older reported having used marijuana at least once in the past 30 days; 45% of those reported having used marijuana on 15 days or more out of the past 30, including 28% who reported having used marijuana every single day for the past 30 days (Washington State Department of Health, 2014). Another study, however,

found that chronic daily marijuana users may experience some degree of psychomotor impairment for days or even weeks after the last time that they used marijuana (Bosker et al., 2015), suggesting that it is possible that impairment might have still been present even if the marijuana use that resulted in the detection of THC among drivers in the current study occurred days earlier.

Some research also suggests that THC may be redistributed in the body after death and thus that the concentration of THC in a sample of blood would vary depending upon the location in the body from which the blood was drawn (e.g., Lemos et al., 2015). However, it is unlikely that this phenomenon would have led to THC-positive drivers being classified as THC-negative, and it would not result in drivers who had not used any cannabis testing positive for THC, and thus should have had little if any impact on the main results of this study.

Approximately half of all drivers had missing values of THC, either because they were not tested for drugs, because the drug test administered was not a blood test (results of urine tests were treated as unknown for THC because THC is not reliably detected in urine), or because the results of the test were unclear (e.g., indicated "cannabinoids," but did not specify whether the cannabinoid detected was THC, carboxy-THC, or another metabolite of cannabis). The imputation model was found to perform very well in imputing the presence of THC in cases when drug test results were actually known but were treated as unknown and imputed for validation purposes. However, in those cases, missing values were by definition missing completely at random, because they were deleted randomly. If the probability that a driver was tested for drugs was associated with whether the driver actually had detectable THC in his or her blood in ways not specifically accounted for in the model (i.e., if THC values were not missing at random conditional upon the explanatory variables included in the model), bias could still be present in the imputed values.

Finally, this study examined the presence of detectable concentrations of THC in drivers' blood. Drivers who had detectable THC in their blood at the time of the crash were not necessarily experiencing impairment in their ability to drive safely, nor were they necessarily at fault for the crash. Determination of actual impairment or fault status was beyond the scope of the study. Relatedly, many of those who were positive for THC were also positive for alcohol and/or other drugs, which in some cases likely contributed more significantly to the crash than did the THC. Research on the relationship between THC presence and risk of crash involvement has been inconclusive. One systematic review and meta-analysis of studies of the relationship between THC and crash risk (Asbridge et al., 2012) reported that THC was associated with significantly elevated crash risk, however, another systematic review & meta-analysis (Elvik, 2013) found that THC was not significantly associated with elevated crash risk after controlling for other factors. A recent case-control study by the National Highway Traffic Safety Administration found a statistically significant but small association between THC and crash risk before controlling for other factors, but this association was reduced to zero (adjusted odds ratio = 1.00) after controlling for driver demographic characteristics and blood alcohol concentration (Compton & Berning, 2015).

Conclusion

This study estimates that an average of 10% of all drivers involved in fatal crashes in Washington between 2010 and 2014 had detectable THC in their blood at the time of the crash. There was evidence that the proportion of drivers in fatal crashes who were positive for THC increased after Initiative 502 legalized recreational use of marijuana for adults aged 21 years and older, however, the increase was not immediate and appeared to have begun approximately 9 months after the effective date of Initiative 502. In 2014, the number and proportion of drivers in fatal crashes who were positive for THC were both more than double the averages from the prior four years. Researchers and policymakers should continue to monitor trends in THC presence and concentrations among drivers involved in crashes. Other states should follow the model of the Washington Traffic Safety Commission in recording quantitative toxicology test results and appending them to their motor vehicle crash databases to make such surveillance possible.

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Tables

Table 1. Toxicology test status of drivers involved in fatal crashes in relation to crash, vehicle, and driver characteristics, Washington, 2010 – 2014.

	Drug test type				
	Blood	Other/ unknown	None	Total	*P*
		Row %		N	
All	49.8	9.3	41.0	3,031	
Year					
2010	45.2	15.8	38.9	619	
2011	39.9	17.2	42.9	606	
2012	47.5	11.0	41.5	591	<0.001
2013	61.7	1.9	36.5	592	
2014	54.6	0.5	44.9	623	
Survival status / time to death					
Died < 1 hour after crash	72.2	22.2	5.6	985	
Died 1-2 hours after crash	71.4	15.6	13.0	77	<0.001
Died > 2 hours after crash	57.2	11.4	31.4	334	
Survived	33.5	0.5	66.0	1,617	
Age (years)					
<16	62.5	0.0	37.5	8	
16-17	54.7	9.3	36.0	75	
18-20	59.4	10.4	30.2	212	
21-24	52.9	11.9	35.3	329	0.039
25-34	51.4	9.8	38.8	580	
35-49	47.9	8.0	44.1	714	
50-64	47.2	8.8	44.0	702	
65+	50.9	9.6	39.5	375	
Sex					
Female	44.7	6.2	49.1	754	<0.001
Male	52.2	10.4	37.4	2,244	
Seatbelt used					
Yes	43.0	6.8	50.2	1,759	<0.001
No	60.7	14.1	25.2	1,044	
Driver's license status (non-CDL)					
Valid	47.3	9.7	43.1	2,601	
Unlicensed	66.7	8.7	24.6	69	<0.001
Suspended/Revoked	74.7	6.5	18.8	292	
Expired/Cancelled/Denied	69.2	15.4	15.4	13	
Convicted of DWI in past 3 years					
Yes	75.8	6.5	17.7	62	<0.001
No	49.9	9.4	40.7	2,896	
License suspended in past 3 years					
Yes	66.3	9.1	24.6	460	<0.001
No	47.5	9.4	43.1	2,498	
Police-reported alcohol					
Yes	71.2	13.8	15.0	572	
No / not reported	34.0	4.9	61.0	1,648	<0.001
Unknown (reported as "unknown")	66.6	14.9	18.5	811	
Police-reported drugs					
Yes	96.0	1.6	2.4	126	
No / not reported	47.7	9.6	42.7	2,902	<0.001
Unknown (reported as "unknown")	66.7	0.0	33.3	3	

	Drug test type				
	Blood	Other/ unknown	None	Total	*P*
		Row %		N	
Blood Alcohol Concentration (mg/dL)					
0	84.3	13.9	1.8	1,154	
0.01 – 0.07	75.5	13.3	11.2	98	<0.001
0.08+	75.5	17.6	6.9	596	
Unknown / not tested	0.9	0.3	98.8	1,183	
Vehicle type					
Car / light truck	48.2	8.3	43.5	2,405	
Large truck / bus	42.9	3.7	53.4	191	<0.001
Motorcycle	65.2	19.8	15.0	374	
Vehicle age (years)					
0-5	43.6	9.4	46.9	637	
6-10	48.6	10.8	40.6	870	<0.001
11-15	48.0	10.2	41.8	687	
16+	59.0	6.9	34.1	800	
Driving errors reported					
Yes	63.5	8.5	28.0	739	<0.001
No	45.3	9.5	45.2	2,292	
Left scene (hit and run)					
Yes	30.6	1.0	68.4	98	<0.001
No	50.4	9.5	40.1	2,933	
Time of day					
6:00-9:59 AM	47.2	7.0	45.8	371	
10:00AM-3:59 PM	42.5	7.8	49.6	842	
4:00-7:59 PM	48.8	9.0	42.2	754	<0.001
8:00-11:59 PM	51.8	11.1	37.1	542	
Midnight-5:59 AM	62.7	11.4	25.8	507	
Crash location					
Rural	46.3	7.6	46.1	1,409	<0.001
Urban	52.7	10.7	36.6	1,610	
Road type					
Interstate	43.5	10.4	46.1	347	
Principal arterial	46.2	7.4	46.4	1,039	<0.001
Collector / local street/road	53.4	10.7	35.9	1,513	
Crash Type					
Single-vehicle road departure	66.6	16.9	16.4	815	
Single vehicle other	40.0	1.9	58.0	417	<0.001
Multiple-vehicle	44.4	7.4	48.2	1,799	
Pedestrian involved					
Yes	36.7	0.0	63.3	362	<0.001
No	51.5	10.5	38.0	2,669	
Investigating agency					
Washington State Patrol	50.4	9.6	40.0	1,640	
County Sheriff	53.6	10.6	35.8	659	0.010
City or Municipal Police	44.7	7.5	47.8	707	

Data: Washington Traffic Safety Commission, 2010 - 2014. Drug test type Blood includes drivers given multiple types of drug tests if at least one was a blood test.

P-value is from χ^2 test of whether drug test type varied by row variable.

Table 2. Number and proportion of drivers in fatal crashes who were positive for THC based on blood toxicological test results and multiple imputation of missing values, Washington, 2010 – 2014.

	Blood toxicological test results known				All drivers	
	Yes[a]		No[b]			
	Number of Drivers	Tested THC-positive N (%)	Number of Drivers	Imputed THC-positive N (%)	Number of Drivers	Tested+Imputed THC-positive N (%; 95% CI)
All	1,470	213 (14.5)	1,561	90 (5.8)	3,031	303 (10.0; 8.7 – 11.3)
Year						
2010	273	35 (12.8)	346	18 (5.2)	619	53 (8.5; 6.0 – 11.1)
2011	239	32 (13.4)	367	16 (4.3)	606	48 (7.9; 5.3 – 10.4)
2012	279	35 (12.5)	312	13 (4.1)	591	48 (8.1; 5.5 – 10.6)
2013	344	37 (10.8)	248	12 (4.8)	592	49 (8.3; 5.7 – 10.9)
2014	335	74 (22.1)	288	32 (11.0)	623	106 (17.0; 13.1 – 20.8)
Survival status						
Died	943	151 (16.0)	471	22 (4.6)	1,414	173 (12.2; 10.4 – 14.0)
Survived	527	62 (11.8)	1,090	68 (6.3)	1,617	130 (8.1; 6.3 – 9.8)
Age (years)						
16-17	41	2 (4.9)	34	3 (7.6)	75	5 (6.1; 0 – 13.0)
18-20	120	35 (29.2)	92	8 (8.8)	212	43 (20.3; 14.4 – 26.2)
21-24	169	33 (19.5)	160	10 (6.1)	329	43 (13.0; 9.2 – 16.8)
25-34	289	63 (21.8)	291	20 (6.7)	580	83 (14.2; 10.9 – 17.6)
35-49	332	43 (13.0)	382	22 (5.8)	714	65 (9.1; 6.8 – 11.5)
50-64	324	31 (9.6)	378	13 (3.5)	702	44 (6.3; 4.3 – 8.3)
65+	191	6 (3.1)	184	4 (2.3)	375	10 (2.7; 0.9 – 4.5)
Sex						
Female	330	32 (9.7)	424	17 (4.0)	754	49 (6.5; 4.2 – 8.8)
Male	1,140	181 (15.9)	1,104	63 (5.7)	2,244	244 (10.9; 9.3 – 12.5)
Drivers license status						
Valid	1,202	144 (12.0)	1,399	66 (4.7)	2,601	210 (8.1; 7.0 – 9.6)
Unlicensed	42	7 (16.7)	27	1 (5.2)	69	8 (12.2; 2.7 – 25.4)
Suspended/Revoked	211	59 (28.0)	81	11 (13.3)	292	70 (23.9; 19.6 – 30.4)
Alcohol detected						
Yes	505	120 (23.8)	189	13 (7.0)	694	133 (19.2; 16.2 – 22.2)
No	955	91 (9.5)	199	9 (4.7)	1,154	100 (8.7; 7.0 – 10.4)
Unknown / not tested	10	2 (20.0)	1,173	67 (5.7)	1,183	69 (5.9; 3.7 – 8.1)
Other drugs detected						
Yes	402	60 (14.9)	17	6 (35.9)	419	66 (15.8; 12.1 – 19.4)
No	1,068	153 (14.3)	21	5 (24.8)	1,089	158 (14.5; 12.4 – 16.6)
Unknown / not tested	0	0	1,523	79 (5.2)	1,523	79 (5.2; 3.3 – 7.0)
Left scene (hit and run)						
Yes	30	9 (30.0)	68	18 (26.5)	98	27 (27.6; 13.9 – 41.2)
No	1,440	204 (14.2)	1,493	72 (4.8)	2,933	276 (9.4; 8.2 – 10.7)
Vehicle type						
Car / light truck	1,128	177 (15.7)	1,277	71 (5.5)	2,405	248 (10.3; 8.8 – 11.7)
Large truck / bus	80	1 (1.3)	111	3 (2.9)	191	4 (2.2; -1 – 4.9)
Motorcycle	242	33 (13.6)	132	6 (4.8)	374	39 (10.5; 7.3 – 13.7)
Vehicle age (years)						
0-5	275	28 (10.2)	362	13 (3.7)	637	41 (6.5; 4.5 – 8.5)
6-15	739	92 (11.2)	818	41 (4.4)	1,557	133 (8.5; 7.0 – 10.0)
16+	451	93 (20.6)	349	27 (7.9)	800	120 (15.1; 11.9 – 18.2)
Day of week						
Monday-Friday	1,025	140 (13.7)	1,059	57 (5.4)	2,084	197 (9.5; 7.8 – 11.1)
Saturday-Sunday	445	73 (16.4)	502	33 (6.5)	947	106 (11.2; 8.9 – 13.5)
Time of day						
6:00-9:59 AM	173	14 (8.1)	198	8 (4.1)	371	22 (6.0; 2.7 – 9.2)
10:00AM-3:59 PM	351	37 (10.5)	491	18 (3.7)	842	55 (6.6; 4.7 – 8.4)
4:00-7:59 PM	360	45 (12.5)	394	23 (5.8)	754	68 (9.0; 6.7 – 11.3)
8:00-11:59 PM	274	49 (17.9)	268	19 (7.2)	542	68 (12.6; 8.6 – 16.6)
Midnight-5:59 AM	304	67 (22.0)	203	21 (10.3)	507	88 (17.3; 13.5 – 21.2)
Crash type						
Single-vehicle road departure	525	105 (20.0)	290	21 (7.1)	815	126 (15.4; 12.7 – 18.1)
Single-vehicle other	165	19 (11.5)	252	22 (8.8)	417	41 (9.9; 6.2 – 13.5)
Multiple-vehicle crash	780	89 (11.4)	1,019	47 (4.6)	1,799	136 (7.6; 6.0 – 9.1)

Data: Washington Traffic Safety Commission, 2010 – 2014. THC values were imputed 10 times when driver was not tested or test results were unknown; results reflect averages from 10 imputed values for each driver. Drivers with missing values of row variables were excluded from rows where relevant. Row and column totals may not add to grand total and percents in table may differ from percents calculated by hand from counts shown in table due to rounding of averages of imputed values.

a. THC-positive based on detection of THC concentration of 1 ng/mL or greater in sample of blood.

b. Includes 38 drivers subject to blood toxicology test but with results indeterminate for THC due to reporting issues (27 positive for unspecified cannabinoids; 11 negative at 2 ng/mL threshold but positive for carboxy-THC).

Table 3. Drivers with THC concentrations equal to or greater than 5 ng/mL as a proportion of all drivers involved in fatal crashes and as a proportion of all THC-positive drivers involved in fatal crashes, by year and survival status, Washington, 2010 – 2014.

			THC ≥ 5 ng/mL		
	Total drivers	Number THC-positive	N	% of all drivers (95% CI)	% of THC+ drivers (95% CI)
All drivers	3,031	303	164	5.4 (4.4 – 6.4)	54.1 (46.5 – 61.8)
Survival status					
Died	1,414	173	117	8.3 (6.7 – 9.8)	67.6 (59.9 – 75.2)
Survived	1,617	130	47	2.9 (1.8 – 4.1)	36.3 (23.2 – 49.6)
Year					
2010	619	53	32	5.2 (3.0 – 7.3)	60.3 (40.8 – 79.9)
2011	606	48	26	4.3 (2.5 – 6.0)	54.2 (38.4 – 70.2)
2012	591	48	29	4.9 (3.0 – 6.9)	61.2 (43.5 – 79.3)
2013	592	49	25	4.1 (2.4 – 5.9)	50.0 (34.2 – 65.9)
2014	623	106	53	8.4 (5.7 – 11.2)	49.7 (37.3 – 62.2)
Year (Died)					
2010	291	32	25	8.7 (5.2 – 12.1)	78.1 (62.0 – 94.2)
2011	291	29	19	6.6 (3.6 – 9.6)	67.4 (47.4 – 87.3)
2012	272	27	19	6.8 (3.8 – 9.9)	68.6 (49.2 – 88.2)
2013	271	26	15	5.5 (2.7 – 8.4)	58.1 (38.1 – 78.1)
2014	289	59	39	13.4 (9.3 – 17.4)	65.5 (53.0 – 78.0)
Year (Survived)					
2010	328	21	7	2.0 (0 – 4.3)	32.2 (0 – 65.5)
2011	315	19	7	2.1 (0.2 – 4.1)	34.7 (8.2 – 61.6)
2012	319	21	11	3.3 (0.8 – 5.8)	51.5 (22.2 – 81.1)
2013	321	23	10	3.0 (0.7 – 5.2)	40.9 (15.7 – 66.5)
2014	334	47	14	4.2 (0.5 – 7.8)	29.8 (7.1 – 52.1)

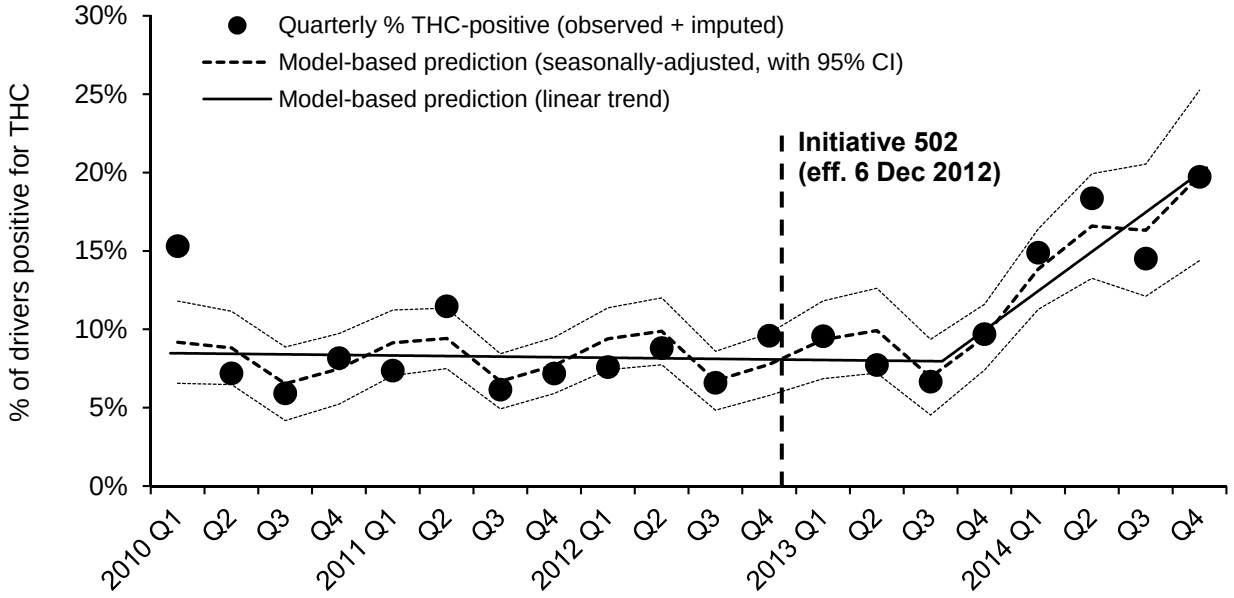
Data: Washington Traffic Safety Commission, 2010 – 2014.
Based on results of blood toxicological tests. Results imputed 10 times when driver was not tested or test results were unknown; results reflect averages from 10 imputed values for each driver. Row and column totals may not add to grand total and percents in table may differ from percents calculated by hand from counts shown in table due to rounding of averages of imputed values.
THC-positive and THC+ denote THC concentration of 1 ng/mL or greater.

Table 4. Presence of alcohol and other drugs among THC-positive drivers involved in fatal crashes, by year and survival status, Washington, 2010 – 2014.

	Total THC-positive Drivers	Other substances present							
		None (THC only)		Alcohol		Other drugs		Alcohol and other drugs	
		N (Row %)							
All drivers	303	103	(34.0)	118	(39.0)	50	(16.5)	32	(10.5)
Survival status									
Died	173	42	(24.1)	76	(44.2)	35	(20.2)	20	(11.5)
Survived	130	61	(47.0)	42	(32.2)	15	(11.6)	12	(9.1)
Year									
2010	53	16	(30.1)	23	(43.7)	9	(17.2)	5	(9.1)
2011	48	14	(29.5)	22	(46.0)	6	(11.9)	6	(12.6)
2012	48	20	(42.8)	15	(32.3)	8	(17.2)	4	(7.8)
2013	49	14	(27.6)	22	(44.3)	7	(14.7)	7	(13.5)
2014	106	39	(37.0)	36	(34.2)	20	(18.8)	11	(10.0)
Year (Died)									
2010	32	6	(17.9)	15	(46.6)	7	(21.6)	5	(13.9)
2011	29	6	(20.4)	14	(49.1)	4	(15.1)	4	(15.4)
2012	27	8	(30.3)	11	(39.1)	5	(19.2)	3	(11.4)
2013	26	6	(23.6)	11	(42.6)	5	(19.4)	4	(14.3)
2014	59	16	(26.8)	26	(43.5)	13	(22.8)	4	(7.0)
Year (Survived)									
2010	21	11	(52.7)	8	(39.0)	2	(10.2)	0	(1.5)
2011	19	8	(43.0)	8	(41.5)	1	(7.3)	2	(8.3)
2012	21	12	(59.2)	5	(23.3)	3	(14.6)	1	(2.9)
2013	23	7	(31.9)	11	(46.1)	2	(9.5)	3	(12.5)
2014	47	23	(49.9)	11	(22.5)	6	(13.7)	7	(13.9)

Data: Washington Traffic Safety Commission, 2010 – 2014.
Based on results of blood toxicological tests. Results imputed 10 times when driver was not tested or test results were unknown; results reflect averages from 10 imputed values for each driver. Row and column totals may not add to grand total and percents in table may differ from percents calculated by hand from counts shown in table due to rounding of averages of imputed values.
Category *other drugs* indicates driver tested (or imputed) positive for one or more drugs other than cannabinoids, including: depressants, stimulants, narcotics, hallucinogens, inhalants, PCP, or other unspecified drug.

Figure 1. Quarterly average proportion of drivers involved in fatal crashes who were positive for THC and modeled seasonally-adjusted linear trend before and after Washington Initiative 502 took effect on 6 December 2012 legalizing recreational use of marijuana for adults aged 21 years and older, Washington, 2010 – 2014.



Data: Washington Traffic Safety Commission, 2010 – 2014.
Drivers positive for THC based on results of blood toxicological tests. Results imputed 10 times when driver was not tested or test results were unknown; results reflect averages from 10 imputed values for each driver. Model-based predictions are from binomial regression model with identity link function, indicator variables for seasons, and a linear spline with change in slope on 5 September 2013 (39 weeks after effective date of Initiative 502).

Appendix

Variables used in imputation model for THC.

- Calendar year
- Quarter (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Dec)
- Day of week (Mon-Thurs, Fri, Sat, Sun)
- Time of day (6-9:59AM, 10AM-3:59PM, 4-7:59PM, 8-11:59PM, midnight-5:59AM)
- Survival / time to death (died within 1 hour after crash, died 1-2 hours after crash, died more than 2 hours after crash, survived)
- Driver's age and sex (entered into model as age, age^2, sex, age × sex, and age^2 × sex)
- Driver's license status (valid, expired, suspended/revoked, unlicensed)
- Previous DWI convictions in past 3 years (0, 1+)
- Previous license suspensions in past 3 years (0, 1+)
- Driver's seatbelt use (yes/no)
- Any unsafe driving actions or driving errors were noted on the police report (yes/no; derived from driver-related contributing factors indicative of specific driving actions or errors)
- Driver fled from the scene of the crash (yes/no)
- Number of vehicles involved in the crash (1, 2, 3+)
- Pedestrian involved in crash (yes/no)
- Vehicle departed the roadway prior to the crash (yes/no)
- Investigating agency (State Patrol, County Sheriff, City/Municipal Police)
- Vehicle type (car/light truck, large truck or bus, motorcycle, other)
- Vehicle age (0-5 years, 6-10 years, 11-15 years, 16+ years)
- Land use (urban/rural)
- Roadway type (Interstate, principal arterial, collector or local street or road)
- Police-reported alcohol involvement (yes, no, unknown [police reported "unknown"])
- Police-reported drug involvement (yes, no, unknown [police reported "unknown"])
- Blood alcohol concentration (milligrams of alcohol per deciliter of blood)
- Carboxy-THC detected in drug test (yes/no)
- Other cannabinoids detected in drug test (yes/no)
- Other drugs besides cannabinoids or alcohol detected (yes/no)
- Type of drug test (blood, other/unknown, none)
- Laboratory threshold for detection of THC (1 mg/dL, 2 mg/dL) one month after crash date