Marijuana use and driving in Washington State: Risk perceptions and behaviors before and after implementation of retail sales

Angela H. Eichelberger
Research, Insurance Institute for Highway Safety, Ruckersville, Virginia

ABSTRACT
Objective: Washington is among the first states to legalize recreational use of marijuana. This study examined marijuana use and risk perceptions before and after retail sales of recreational marijuana began in July 2014, the relationship between risk perceptions and marijuana use, and the relationship between self-reported marijuana use and drug test results.

Methods: Roadside surveys were conducted in 3 waves: June 2014, the month before retail sales of marijuana began; 5–6 months later (November–December 2014); and 1 year later (June 2015). A total of 2,355 drivers completed a marijuana questionnaire about their past and current marijuana use and perceived risks associated with driving after using marijuana. Data collection also included biological specimens (oral fluid and/or blood for marijuana testing and breath for alcohol testing). Drivers who tested positive for delta-9-tetrahydrocannabinol or 11-hydroxy-delta-9-tetrahydrocannabinol in oral fluid or blood were defined as THC-positive.

Results: The proportion of drivers who reported recent marijuana use was similar across the 3 surveys. However, the proportion of THC-positive daytime drivers increased from 8% before retail sales to 23% 6 months after retail sales; this proportion did not change among nighttime drivers (19 and 20%). Drivers’ perceived risk of impairment by marijuana and perceived risk of being arrested for marijuana-impaired driving were similar before and after retail sales. The odds of being THC-positive were 40% lower among drivers who perceived that marijuana was very likely to impair driving, compared to other drivers. Drivers’ perceived risk of being arrested for marijuana-impaired driving was not predictive of THC-positive driving.

Conclusions: The prevalence of daytime THC-positive drivers increased substantially a few months after retail sales of marijuana were legal. Daytime and nighttime prevalence of THC-positive drivers was similar after retail sales. This pattern differs from that typically found for alcohol use, which is consistently higher among drivers at nighttime, compared to daytime. Reports of marijuana use were not always consistent with drug test results, which suggests that comparisons of self-reported marijuana use before and after legalization could be biased. This study examined marijuana use and risk perceptions over the course of 1 year. However, law changes may influence cultural norms gradually over a longer period of time. Future studies should continue to monitor marijuana use over time, as well as identify ways to determine whether drivers are impaired by marijuana.

Introduction
Washington is among the first states to legalize recreational use of marijuana. In 2012, voters in Washington and Colorado approved ballot initiatives to legalize personal use of marijuana for adults 21 and older. Similar laws were passed in 2014 in Alaska and Oregon and in 2016 in California, Maine, Massachusetts, and Nevada. Each of these states had already legalized marijuana for medical use prior to legalizing it for recreational use. These law changes raise many questions about the impact of marijuana legalization on health and traffic safety. Research on the impact of the law changes has begun to emerge using data from Washington, Colorado, and Oregon.

Two studies have looked at the association between recreational marijuana laws and crashes in the United States. One study examined changes in fatal crash rates in Colorado and Washington before and after recreational marijuana laws were passed, relative to several southern states that did not legalize marijuana (Aydelotte et al. 2017). Although there was an increase in fatal crashes in Colorado and Washington relative to the control states, this difference was not statistically significant. Another study examined insurance data before and after sales of marijuana for recreational use began in Colorado, Oregon, and Washington (Highway Loss Data Institute 2017). The study found significantly larger increases in collision claim rates in each of these states after retail sales of marijuana were in effect.
compared with nearby states that did not change their marijuana laws over the same time period. Overall, legalized marijuana sales were associated with a 3% increase in collision claim frequencies in the 3 states after accounting for differences in insured driver population, insured vehicle fleet, urban vs. rural exposure, unemployment, weather, and seasonality.

There is some evidence that marijuana use has recently increased in Washington. One study examined marijuana use among drivers involved in fatal crashes (Tefft et al. 2016). The proportion of marijuana-positive drivers in fatal crashes changed little from 2010 to late 2013, but an upward trend in marijuana-positive drivers began in late 2013, about 9 months after possession of marijuana was legal. The proportion of marijuana-positive drivers involved in fatal crashes increased from 8% in 2013 to 17% in 2014. A roadside survey of drivers who did not crash examined marijuana prevalence in drivers before and after retail sales went into effect in July 2014 (Ramirez et al. 2016). Among weekend nighttime drivers, 18% were marijuana-positive in June 2014, before retail marijuana sales were effective, and 22% were marijuana-positive 1 year later. This change was not statistically significant. Over the same period, the percentage of marijuana-positive drivers increased significantly from 8% to 19% among daytime (Friday) drivers.

It is not clear whether trends in marijuana use in Washington are attributable to recreational marijuana laws or other factors. Marijuana use is increasing nationally, and changes in states that have legalized marijuana may be part of a larger national trend (Center for Behavioral Health Statistics and Quality 2015, 2017; Kelley-Baker et al. 2017). Nationally, self-reported past-month marijuana use among people ages 12 and older was about 6% from 2002 to 2008 and then gradually increased to 9% in 2016 (Center for Behavioral Health Statistics and Quality 2015, 2017). From 2002 to 2016, past-month marijuana use declined among ages 12–17 (8 to 6%) but increased among ages 18–25 (17 to 23%) and ages 26 and older (4 to 7%). In national roadside surveys, the proportion of nighttime weekend drivers who were positive for marijuana increased from 9% in 2007 to 13% in 2013–2014 (Kelley-Baker et al. 2017).

There are various pathways by which marijuana legalization might influence behavior. One way is by increasing access to marijuana products through retail sales. Another less direct way to influence behavior is by changing perceptions of the substance. Legalization may affect how people think about marijuana and may lessen an individual’s perceived risk. These changes in risk perceptions may be important to the extent that they influence behavior. A meta-analysis of several experimental studies, including a study of driving behavior, found that heightened risk appraisals were often related to safer behaviors (Sheeran et al. 2014).

Prior research has reported drug test results from Washington roadside data (Ramirez et al. 2016), but results on risk perceptions and self-reported marijuana use have not been previously reported for this data set. Self-report data provide additional details (e.g., frequency of use) that cannot be obtained from drug test results. Furthermore, marijuana use, a behavior that some see as controversial, may be underreported, which has implications for the appropriateness of using self-report data to estimate the prevalence of drug use among drivers. Thus, the objectives of the current study are to examine changes in marijuana use and perceptions of risk before and after implementation of retail sales of recreational marijuana in Washington, the relationship between risk perceptions and marijuana use, and the relationship between self-reported marijuana use and drug test results.

Methods

Data collection

The study analyzed existing data from Washington roadside surveys, which were sponsored NHTSA and partially funded by the Insurance Institute for Highway Safety. The research protocol was reviewed and approved by an institutional review board for the protection of participants. Roadside surveys were conducted by researchers at the Pacific Institute for Research and Evaluation in 3 waves. The first survey occurred in June 2014, the month before retail sales of marijuana began (July 8, 2014), and the second and third surveys occurred 5–6 months later (November–December 2014) and 1 year later (June 2015). Each survey included one Friday daytime session (either 9:30 a.m. to 11:30 a.m. or 1:30 p.m. to 3:30 p.m.) and 4 nighttime weekend sessions (10 p.m. to midnight and 1 a.m. to 3 a.m. on Friday and Saturday nights) in 6 counties in Washington.

Researchers invited randomly selected passenger vehicle drivers at either a stoplight or a stop sign to turn in to the data collection location for information about participating in a voluntary, paid research study. Drivers were offered $10 for an oral fluid sample and $50 for a blood sample. Eligible drivers included those aged 16 and older. Drivers were asked questions to screen out those who had already participated in the study. Informed consent was obtained for all participants. The institutional review board waived requirements for parental consent for drivers aged 16–17 to participate in all aspects of the study, except the collection of blood specimens, which was limited to participants aged 18 and older. Potential participants were given information about the study and could leave or end participation at any time.

An interview with drivers gathered demographic information, and drivers were asked to complete a questionnaire about their past and current marijuana use and risk perceptions about marijuana use before driving. To measure risk perceptions, drivers were asked to rate the likelihood of marijuana impairing a person’s ability to drive safely if used within 2 h of driving and the likelihood of a person being arrested for impaired driving after using marijuana within 2 h of driving.

Data collection also included biological specimens. Drivers were asked to provide a breath sample for alcohol testing and oral fluid and blood for drug testing. The Quantisal device was used to collect oral fluid, and a phlebotomist collected blood. All data were collected.
blood specimen that was tested for marijuana. Table 1 shows marijuana questionnaire, 2,323 gave an oral fluid and/or cooperation rate was 94%. Of those who completed the 2,510 drivers were eligible to participate, and 2,355 completed all or part of the marijuana questionnaire. Thus, the accepted alternative arrangements.

If a driver had a blood alcohol concentration greater than 0.05 g/dL or when signs of impairment were observed, when a driver had a blood alcohol concentration greater than 0.05 g/dL or when signs of impairment were observed, several alternatives were offered: Having a licensed, unimpaired occupant drive the vehicle, calling a friend or relative to pick up the driver, calling a taxi (paid for by the study), arranging for a hotel room (paid for by the study), and calling a tow truck (paid for by the study). All such drivers accepted alternative arrangements.

Overall, 2,532 vehicles entered the data location sites, 2,510 drivers were eligible to participate, and 2,355 completed all or part of the marijuana questionnaire. Thus, the cooperation rate was 94%. Of those who completed the marijuana questionnaire, 2,323 gave an oral fluid and/or blood specimen that was tested for marijuana. Table 1 shows the number of participating drivers by data collection wave.

### Weighting and analyses

The sampling procedure used a multistage sampling strategy with 4 nested sampling frames: Primary sampling units (6 of 39 counties), sampling area within county (30 one-square-mile grids randomly selected within county), specific roadway locations (one site per grid), and random selection of passing vehicles. A selection probability was calculated separately for each sampling frame, and weights were the inverse of the product of the 4 probabilities. Detailed information on sampling and weighting is reported by Ramirez and colleagues (2016). To increase the representativeness of the sample to the licensed driver population in Washington, a poststratification adjustment to the weights was applied based on the licensed driver population by age and sex. Weights were calculated separately for each data collection wave.

All responses were weighted as described in the previous paragraph, and percentages and 95% confidence intervals were computed for each variable of interest by data collection wave. Because prior research found differences in the proportions of THC-positive drivers by time of day, sex, and age (Ramirez et al. 2016), results were also analyzed by these subgroups.

Logistic regression models examined whether legalized retail sales and risk perceptions were associated with marijuana use among drivers, while controlling for demographic variables. Another logistic regression model tested whether legalized retail sales were associated with perceived risk of being impaired by marijuana. All models controlled for age, sex, race, Hispanic, education, and income. Cases with missing data were excluded from regression models. Results were considered statistically significant at the .05 level.

### Results

#### Sample characteristics

Table A1 (see online supplement) displays the characteristics of drivers who completed all or part of the marijuana questionnaire. The age, sex, race, and ethnicity distributions of respondents were similar across the 3 data collection waves. There were differences in education level and household income between the first 2 surveys and the third survey. The proportion of drivers with some college or a college degree decreased from 64 to 35%, and the proportion with an income of $50,001–75,000 decreased from 31 to 15%.

#### Responses to marijuana questions

Table A2 (see online supplement) shows drivers’ responses to the marijuana questionnaire before and after retail sales of recreational marijuana were legal. The proportion of drivers who reported ever using marijuana was similar across the 3 surveys (about 7 in 10). Among drivers who reported ever using marijuana, the age of first marijuana use was similar for each survey. Drivers’ responses to questions about marijuana use, driving after using marijuana, and perceptions of risk differed little across the 3 surveys. The percentage of drivers who said that they obtained marijuana from a licensed distributor or retailer increased significantly from 8% before retail sales to 20% 1 year later.
Legalized retail sales, risk perceptions, and marijuana use in regression models

The association of legalized retail sales with both self-reported marijuana use and drug test results was examined in separate regression models that accounted for demographic factors. Compared with before legalized retail sales, the odds of drivers reporting past-24-h marijuana use did not differ significantly 6 months later (odds ratio [OR] = 0.92; P = .66) or 1 year later (OR = 0.86; P = .44). The odds of drivers testing positive for THC were significantly greater 6 months after legalized sales (OR = 1.53; P < .01) but not 1 year later (OR = 0.94; P = .71). When risk perceptions were entered into the regression model, the odds of drivers being THC-positive were significantly lower among those who perceived that impairment by marijuana was very likely (OR = 0.60; P < .01), relative to other drivers. Perceived likelihood of arrest for marijuana-impaired driving was not a statistically significant predictor in the model (OR = 0.97; P = .82).

Another regression model explored whether legalized retail sales were associated with changes in perceived likelihood of marijuana impairment. The odds of perceiving marijuana impairment as very likely did not differ significantly 6 months (OR = 1.02; P = .88) or 1 year (OR = 1.09; P = .49) after legalization.

Substance use and risk perceptions by age and sex

Table A3 (see online supplement) shows drivers’ marijuana and alcohol use and perceptions of risk by age and sex. During the first 2 surveys, drivers aged 16–34 (both males and females) were significantly more likely to report past-year marijuana use, compared to those 35 and older. Males aged 16–34 showed the largest changes in proportion of THC-positive drivers and proportion of alcohol-positive drivers before and after retail sales, compared to females and males aged 35 and older. Among males aged 16–34, the proportion of THC-positive drivers increased from 16 to 27%, and the proportion of alcohol-positive drivers decreased from 10 to 5%; however, these differences were not statistically significant.

Mean age at first marijuana use (not shown in table) did not differ significantly before and after retail sales among any of the groups. Among males aged 16–34, mean age at first marijuana use was 16 (SD = 2) for each of the surveys. Among females aged 16–34, mean first use was age 16 (SD = 3) during the first 2 surveys and age 17 (SD = 3) during the third survey. On average, males aged 35 and older reported first use at age 18 (SD = 6) during the first 2 surveys and age 19 (SD = 8) during the third survey, and females aged 35 and older reported first use at age 19 (SD = 10) during the first survey and age 21 (SD = 11) during the last 2 surveys. Perceptions of risk generally did not differ significantly by age and sex, except during the first survey. Before retail sales, females aged 35 and older were significantly more likely to think that marijuana is very likely to impair driving if used within 2 h of driving (67%) compared to males (35–48%) and younger females (36%).

Substance use by day and night

During the daytime, the proportion of THC-positive drivers increased significantly from 8% before retail sales to 23% 6 months after retail sales (see Table 2). Over the same time period, differences in self-reported use among daytime drivers were not statistically significant. During the nighttime, self-reported marijuana use and proportion of THC-positive drivers did not differ before and after retail sales. For each survey, the proportion of alcohol-positive drivers was significantly higher at night (ranging from 4 to 7%) than during the daytime (1% or less).

Self-report vs. drug test results

Table 3 displays self-reported marijuana use and perceptions of risk among THC-positive and THC-negative drivers. Among those who were THC-positive, 72% reported past-year marijuana use 1 year after retail sales were legal,
compared to 30–35% in the earlier surveys. When results are stratified by THC levels in blood (THC ≥ 5 ng/mL vs. 0 < THC < 5 ng/mL), drivers with both high and low THC levels showed similar patterns in self-reported marijuana use across the 3 surveys (not shown in table). Among drivers with high THC levels (≥ 5 ng/mL), self-reported past-year marijuana use increased from 33% (95% confidence interval [CI], 20, 45) before retail sales to 81% (95% CI, 64, 98) 1 year after retail sales. Among drivers with low THC levels, self-reported past-year marijuana use increased from 15% (95% CI, 0, 47) before retail sales to 74% (95% CI, 55, 93) 1 year after retail sales. Among THC-negative drivers, the proportion of drivers who reported past-month marijuana use decreased 1 year after retail sales were legal (from 20% in June 2014 to 12% in June 2015).

During the first 2 surveys, drivers who were THC-positive and drivers who were THC-negative were about equally likely to think that marijuana is very likely to impair driving if used within 2 h of driving (see Table 3). However, THC-positive drivers’ perceptions that marijuana is very likely to impair driving decreased significantly from 45% before retail sales to 17% 1 year after. Among THC-negative drivers, the perception that marijuana is very likely to impair driving was 52% before retail sales and 56% 1 year after. Perceptions that marijuana-impaired drivers are very likely to be arrested did not differ significantly before and after retail sales among either group of drivers.

### Discussion

It is not surprising that drivers were more likely to report buying marijuana from a licensed retailer or distributor after recreational sales of marijuana were legalized in Washington. However, an important question is whether these retail sales resulted in greater marijuana use among drivers. Although self-reported marijuana use did not change among drivers after retail sales were legalized in Washington, the odds of drivers testing positive for THC increased 53% 6 months after legalized sales. This effect was largely driven by increases in THC presence among daytime drivers.

One year after retail sales were legalized, the proportion of THC-positive drivers was similar during daytime and nighttime (17 and 19%, respectively). In contrast, alcohol use among drivers differed significantly by time of day for each survey, with the proportion of alcohol-positive drivers consistently higher at nighttime (4–7%) compared to daytime (1% or less). These findings may have implications for enforcement of impaired driving laws. Dedicated alcohol-impaired driving enforcement has traditionally focused more often on nighttime hours, because alcohol-impaired driving occurs more often during these hours. However, the findings suggest that marijuana use may not necessarily follow the same patterns as alcohol use. Accordingly, marijuana-impaired driving enforcement may need to include daytime patrols.

Drivers’ perceived risk of impairment by marijuana and perceived risk of being arrested for marijuana-impaired driving did not change before and after retail sales were legalized. However, the perception that marijuana is very likely to impair driving was associated with 40% lower odds of being THC-positive. This finding suggests that risk perceptions, specifically perceptions of impairment risk, may be related to willingness to drive after using marijuana. These risk perceptions are a potential target for educational campaigns.

Reports of marijuana use were not always consistent with drug test results. In the first 2 surveys, only 30–35% of THC-positive drivers reported past-year marijuana use, whereas 72% reported past-year marijuana use a year after retail sales were legal. It is unclear whether willingness to report marijuana use was related to legalization or some other factor, because the change did not occur until 1 year after sales were legal. If people are more willing to report marijuana use as a result of legalization, comparisons of self-report data before and after legalization could be biased.

### Table 3. Drivers’ self-reported marijuana use, alcohol use, and perceptions of risk, by whether drivers were THC-positive (weighted percentages and 95% confidence intervals).a

| Variable                                      | THC-positive | THC-negative |
|-----------------------------------------------|--------------|--------------|
| | June 2014 | November–December 2014 | June 2015 | June 2014 | November–December 2014 | June 2015 |
| Self-reported last marijuana useb | N = 127 | N = 126 | N = 149 | N = 752 | N = 516 | N = 653 |
| Past 3 h | 3 [1, 6] | 3 [0, 6] | 11 [11, 27] | 3 [1, 5] | 4 [2, 5] | 1 [0, 1] |
| Past 24 h | 8 [12, 12] | 11 [5, 17] | 40 [28, 52] | 11 [6, 15] | 10 [7, 12] | 2 [0, 4] |
| Past week | 20 [10, 31] | 17 [30, 24] | 65 [52, 77] | 15 [10, 19] | 17 [14, 21] | 7 [4, 11] |
| Past month | 25 [15, 36] | 25 [16, 34] | 71 [58, 83] | 20 [15, 25] | 22 [18, 27] | 12 [8, 16] |
| Past year | 30 [19, 41] | 35 [26, 45] | 72 [60, 85] | 29 [24, 34] | 29 [24, 33] | 16 [13, 20] |
| > 1 year ago or never | 67 [55, 78] | 64 [54, 74] | 15 [7, 24] | 69 [64, 75] | 68 [63, 73] | 82 [78, 86] |
| Breath results | N = 125 | N = 126 | N = 147 | N = 746 | N = 514 | N = 642 |
| Alcohol-positive | 1 [1, 12] | 1 [0, 3] | 5 [1, 10] | 4 [2, 6] | 4 [2, 5] | 4 [1, 6] |
| Perceptions of risk | | | | | |
| Marijuana very likely to impair driving | N = 127 | N = 126 | N = 148 | N = 751 | N = 516 | N = 653 |
| if used within 2 h of driving | 45 [32, 57] | 51 [40, 62] | 17 [8, 26] | 52 [46, 58] | 49 [43, 54] | 56 [50, 61] |
| Drivers very likely to be arrested for impaired driving | N = 127 | N = 126 | N = 148 | N = 750 | N = 516 | N = 653 |
| if marijuana used within 2 h of driving | 33 [22, 44] | 36 [26, 47] | 28 [18, 39] | 40 [34, 45] | 40 [34, 45] | 43 [37, 49] |

aNot applicable. THC-positive is defined as a positive test for THC and/or the active metabolite hydroxy-THC in blood and/or oral fluid.
bPercentages sum to more than 100% due to some categories being cumulative (e.g., “past week” includes “past 24 h”).
The proportion of THC-positive drivers in the current roadside survey of drivers (15–21%) was similar to the proportion found in a study of Washington drivers involved in fatal crashes in 2014 (17%; Tefft et al. 2016). The study of fatal crashes identified an upward trend in marijuana-positive drivers that began in late 2013, which is several months before retail sales were legalized. Although the proportions of THC-positive drivers in the current roadside survey and in fatal crashes are consistent with each other, the 2 studies are not comparable enough to infer whether or not marijuana use had an impact on fatal crash risk. The current study examined both oral fluid and blood results for THC and hydroxy-THC, whereas the study of drivers in fatal crashes examined THC in blood only and used a higher (2 ng/mL) cutoff than in the current study (1 ng/mL). In addition, the sample of drivers who were out driving on Fridays and Saturdays is not necessarily representative of all drivers.

Males aged 16–34 showed the highest prevalence of THC-positive drivers 1 year after retail sales were legalized (27%) compared to females and males aged 35 and older. This finding is consistent with recent national studies that find the highest prevalence of marijuana use among young people and males (Eichelberger 2016; Kelley-Baker et al. 2017).

Reported past-year marijuana use in the current study was higher (26–30%) than has been found in other surveys conducted around the same time. In a 2015 telephone survey of Washington drivers aged 18 and older, 15% reported past-year marijuana use (Eichelberger 2015), and 18% of Washington adults reported past-year marijuana use in the 2014–2015 National Surveys on Drug Use and Health (Center for Behavioral Health Statistics and Quality 2016). Each of these surveys used different methods, and samples may represent different populations. For example, a majority of respondents in the roadside survey were nighttime weekend drivers, whereas the telephone survey of drivers was conducted throughout the week during daytime and early evening hours.

**Limitations**

Results that differed before and after legalization are not necessarily caused by law changes and may have been influenced by other unknown factors. Although age, sex, race, and ethnicity distributions did not vary across the 3 surveys, the third survey included a greater proportion of drivers with lower income and lower education levels compared to the first 2 surveys. The surveys are not necessarily representative of all drivers, because individuals who choose to respond to surveys may differ in their attitudes and behaviors from those who do not. The study was conducted on Fridays (daytime and nighttime) and Saturday nights, and people who drive at these times may differ from those who drive at other days and times. Another limitation is that self-report data may not always be accurate due to recall and social desirability biases, especially for behaviors such as drug use, which may be seen as undesirable.

Biological measures of marijuana use also have limitations. It cannot be determined how recently drivers may have used marijuana or whether drivers were impaired. Laboratory studies have found extreme variability among different individuals in how long THC can be detected in oral fluid (Lee et al. 2011) and in blood (Bergamaschi et al. 2013). Experimental studies have found evidence that recent marijuana use causes modest performance decrements in simulated and on-road driving (Hartman and Huestis 2013; Sewell et al. 2009). However, THC levels cannot reliably predict impairment because low levels of THC can be detected for several hours after peak impairment (Compton 2017). This may explain why some studies have not found THC-positive drivers at greater risk of crashing than THC-negative drivers (e.g., Lacey et al. 2016). More research is needed to identify ways to determine whether drivers are impaired by marijuana.

This study examined marijuana use and risk perceptions over the course of 1 year in a single state. However, law changes may influence cultural norms gradually over a longer period of time. Data show that per capita alcohol consumption in the United States increased steadily for more than a decade after prohibition was lifted (Haughwout et al. 2015). Future studies should continue to monitor marijuana use over time in multiple states that have now legalized recreational use.

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