Marijuana Use, Alcohol Use, and Driving in Washington State

Emerging Issues With Poly-Drug Use on Washington Roadways

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Table of Contents

Table of Tables

Table of Figures

Glossary

Fatality Analysis Reporting System (FARS) – A national database funded by the National Highway Traffic Safety Administration (NHTSA) containing a census of all fatal traffic crashes occurring in the U.S. Washington State FARS is supplemented with information from toxicology reports, death records, coroner reports, EMS information, vehicle registration, and driver licensing information.

THC – Acronym for Tetrahydrocannabinols. For purposes of this report, the use of THC specifically refers to delta-9-THC, the psychoactive chemical entering the blood and brain immediately after marijuana smoking/consumption.

Carboxy-THC/Hydroxy-THC – The metabolites of delta-9-THC; this metabolite may be detected for up to 30 days after consumption.

Cannabinoids – A class of chemical compounds contained in marijuana. For purposes of this report, cannabinoids are an encompassing term to include any toxicology outcome related to marijuana (THC or carboxy-THC undistinguished).

Marijuana ng/ml of Blood – The unit of measurement used to describe the level of THC and/or carboxy-THC contained in a person's blood.

Other Drugs – Other drugs found in drivers involved in fatal crashes are from discrete drug families including narcotic analgesics, hallucinogens, depressants, stimulants, inhalants, and Phencyclidines (PCP). This report does not include alcohol when referring to other drugs. Detailed THC information was derived from toxicology reports. Descriptions of other drugs in this report relied on existing FARS drug coding.

Poly-Drug Drivers – Drivers involved in fatal crashes that are positive for alcohol and one or more other drugs, or two or more drugs that are not alcohol as confirmed by toxicology testing.

Blood Alcohol Concentration (BAC), Alcohol Greater Than/Equal to BAC .08 – The unit of measurement used to describe the level of alcohol contained in a person's blood; the measurement describes the percent of a person's blood that is alcohol. Alcohol greater than/equal to BAC .08 refers to a driver at or in excess of the per se limit.

Weighted Surveys – Data collected from survey respondents that represent a sample of a larger population are weighted for analysis so that the results better represent the larger population rather than just the sample of respondents.

Report Summary

This report provides select updated fatal crash information originally presented in Washington Traffic Safety Commission's report *Driver Toxicology Testing and the Involvement of Marijuana in Fatal Crashes, 2010-2014*[1] (October 2015). Since that report was published, poly-drug drivers involved in fatal crashes have increased significantly and is described more thoroughly in the present report. For the first time, this report also includes compilations of analyses of Washington's Roadside Self-Report Marijuana Survey, and questions from the Behavioral Risk Factor Surveillance and Healthy Youth Surveys. The following is a summary of key observations from these various data sources.

- Driver impairment due to alcohol and/or drugs is the number one contributing factor in Washington fatal crashes and is involved in nearly half of all traffic fatalities. Poly-drug drivers (combinations of alcohol and drugs or multiple drugs) is now the most common type of impairment among drivers in fatal crashes.

- Among drivers involved in fatal crashes 2008-2016 who were blood tested for intoxicants, 61 percent were positive for alcohol and/or drugs.

- Among drivers in fatal crashes 2008-2016 that tested positive for alcohol or drugs, 44 percent tested positive for two or more substances (poly-drug drivers). The most common substance in poly-drug drivers is alcohol, followed by THC. Alcohol and THC combined is the most common poly-drug combination.

- Although research-based estimates of the risks posed by THC have varied greatly, all studies included in this report agree that combining alcohol and THC will only further inflate the level of impairment and crash risk. The deadly consequences of combining these two impairing substances and driving are already apparent in Washington fatal crash data.

- For the first time in 2012, poly-drug drivers became the most prevalent type of impaired drivers involved in fatal crashes. Since 2012, the number of poly-drug drivers involved in fatal crashes have increased an average of 15 percent every year.

- By 2016, the number of poly-drug drivers were more than double the number of alcohol-only drivers and five times higher than the number of THC-only drivers involved in fatal crashes.

- According to the biological results of Washington's Roadside Survey, nearly one in five daytime drivers may be under the influence of marijuana, up from less than one in 10 drivers prior to the implementation of marijuana retail sales.

[1] Available at http://wtsc.wa.gov/

- According to Washington's Roadside Self-Report Marijuana Survey:

    - 39.1 percent of drivers who have used marijuana in the previous year admit to driving within three hours of marijuana use. This is similar to the results from Washington's Behavioral Risk Factor Surveillance Survey (33.5 percent).
    - More than half (53 percent) of drivers ages 15-20 believe marijuana use made their driving better. This is a significantly higher rate than drivers ages 21-25 (13.7 percent) and drivers ages 26-35 (17.4 percent).
    - Among drivers who have used marijuana in the past year, only 36.6 percent believe that it is very likely or likely that marijuana impairs a person's ability to drive safely if used within two hours of driving, compared to 77 percent of drivers who have not used marijuana in the previous year.
    - 53.5 percent of drivers who have used marijuana in the past year believe it is very likely or likely to be arrested for impaired driving after using marijuana within two hours of driving, versus 70.2 percent of drivers who have not used marijuana in the previous year.

- According to Washington's Behavioral Risk Factor Surveillance Survey, drivers who admit to driving within three hours of marijuana use in the previous year are also more likely to:
    - Drive after having perhaps too much to drink (14.5 percent).
    - Not always wear a seatbelt (15.2 percent).
    - Binge drink (45.1 percent).

- According to Washington's Healthy Youth Survey:
    - One in four 12th graders, one in six 10th graders, and one in ten 8th graders report riding in a vehicle with a driver who had been using marijuana.
    - Slightly more than 16 percent of 12th graders and 9 percent of 10th graders who have used marijuana admitted to, at least once, driving a vehicle within three hours of using marijuana.

- From 2008-2016, 76 drivers ages 16-18 involved in fatal crashes tested positive for alcohol and/or drugs. One in four of these young drivers were positive for multiple substances (poly-drug drivers).

- While driving under the influence of alcohol remains a significant issue, the interplay of drugged driving must be equally considered if we are ever to reach our goal of zero fatalities and serious injuries on Washington roadways. This complex issue will require government, non-profit, corporate, and community response to reverse a rapidly increasing trend.

Background and Literature Review

On November 6, 2012, Washington voters approved Initiative 502 legalizing recreational use of marijuana. In July 2014, the first recreational marijuana stores opened. Initiative 502 included the establishment of a blood per se level of 5ng/ml for driving under the influence of marijuana. In Washington State, marijuana's involvement in fatal crashes had been tracked for decades based on the availability of toxicology results of fatal crash involved drivers and mainly as part of the bigger drugged driving issue. After legalizing and making marijuana readily available, it was vital to understand what the impact would be on traffic safety and impaired driving. Even before recreational use was made legal, marijuana was second to alcohol as the most frequently detected drug among fatal crash involved drivers and that continues to be true after legalization. In fatal crashes, the frequent co-occurrence of marijuana with other substances known to cause driver impairment, such as alcohol, is a contributing factor in the rising poly-drug issue.

Performance and Other Effects of Combining Marijuana and Alcohol

Driver impairment due to alcohol and drugs is the number one contributing factor in Washington fatal crashes and is involved in nearly half of all traffic fatalities in the state. The single most prevalent substance found in drivers in fatal crashes remains alcohol, but drugged driving (positive for any drugs) has surpassed alcohol impaired driving in recent years. After alcohol, the most prevalent drug is marijuana, which is more likely to be paired with alcohol than to appear as a single impairing substance among fatal crash-involved drivers. While the crash risk posed by alcohol is fairly well understood, it is critically important that we come to a better understanding of how THC and alcohol combine to increase crash risk in drivers.

The impairing effects of alcohol on motor vehicle drivers have been well documented. Scientific measurement of this impact began in 1935, when Richard Holcomb of the Northwestern Traffic Safety Institute began a case-control study in Illinois to compare alcohol-involved drivers in injury crashes with a random sample of drivers not involved in crashes (Holcomb, 1938). Since that study was published, crash risk estimates associated with driver BAC have evolved to a high degree of refinement (Peck et al., 2008). However, the same cannot be said about crash risk estimates for drivers with THC blood levels.

Numerous studies from the 1980s, 1990s, and early 2000s concluded that consuming marijuana alone resulted in trivial or no significant impacts to crash risk, largely because the data they used included drivers testing positive for THC, the primary psychoactive ingredient in marijuana, but also drivers testing positive for only carboxy-THC, the inactive metabolite of THC. Thus, unknown numbers of drivers without active THC in their blood were identified as cannabis or marijuana positive, so the lower risks they posed were mixed with those of higher risk THC positive drivers. A number of these studies relied on urine tests to identify marijuana positive drivers, which is a test that does not distinguish THC from carboxy-THC and does not provide a drug level. FARS data is also an unreliable source of marijuana information because it does not distinguish between THC and carboxy-THC. Therefore, a number of older studies aiming to measure THC's impact on crash risk arrived at flawed conclusions (Ramaekers et al., 2004).

More recently, however, awareness of the data problem has resulted in studies taking better care to use data based only on drivers testing positive for THC. As a result, much more realistic risk estimates regarding cannabis impairment have appeared. In 2012, two separate published meta-studies (Asbridge et al., 2012, Li et al., 2012) relied on studies using better-quality data and each concluded that crash risk roughly doubles for drivers with active THC in their blood (compared to THC-free drivers). The consistency of findings in these two studies has yielded a more confident awareness of the crash risk posed by THC involved driving, especially within the first two or three hours after using.

Nonetheless, the wide range of risk estimates attributed to THC only drivers has continued to puzzle researchers. Moreover, the number of well-constructed studies yielding reliable estimates of the risks posed by THC and alcohol in combination is quite small. The following section provides a summary of results from these few studies of the combined effects of THC and alcohol.

Crash Risk Estimates: Culpability, Case-Control, and Case-Crossover Studies

The five risk studies included here were of three basic study designs. Three of them (Biecheler et al., 2008, Drummer et al., 2004, Longo et al., 2000) employed versions of culpability analysis (sometimes referred to as responsibility analysis) in which a rigorous review is conducted of involved factors, including potentially mitigating factors in each crash. Involved drivers are then labeled as culpable, non-culpable, or partially culpable for contributing to the crash. This last group of drivers was generally excluded from the analyses. The assumption underlying culpability analysis is that “if drugs are contributing to crash causation, it would be expected that they would be overrepresented in the culpable or responsible group” (Robertson & Drummer, 1994, p. 243). All three studies presented odds-ratios (OR) for culpable drivers in the THC-only, alcohol-only, and THC with alcohol conditions.

One of the two remaining studies (Pulido et al., 2011) used a case-crossover design in which the subjects participated in interviews, and then completed follow-up interviews one year later. The study’s authors tested the association between driver self-reported marijuana consumption during the hour before crashing, alcohol consumption during the two hours prior to crashing, and involvement in a crash resulting in non-fatal injury to the driver. A related association was also tested for the combination of alcohol with marijuana in which relative-risk (RR) estimates were derived. This study was referenced in a recent comprehensive review of research regarding the impacts of marijuana on driving performance (Hartman & Huestis, 2013). The last of the five studies was of a case-control investigation in which 321 drivers under age 27 were treated in the emergency room for a non-fatal crash injury; controls were 310 licensed drivers also treated in the emergency room for injuries unrelated to traffic (Mura et al., 2003).

The risk estimates in these studies are quite variable, ranging from an OR of 1.8 for drivers with a blood-THC level of 2 ng/mL, to a RR of 5.8 for self-reported cannabis use during the hour before suffering a crash injury. Likewise, estimates for combined THC and alcohol ranged from an OR of 4.6 to an OR of 17.4. The results and other details of these studies are summarized in Table 1.

Table 1: Studies Estimating THC Risk, Alone and in Combination with Alcohol

Study and Country	Design/Type	Target Measure	Cases / Controls	THC and Alcohol Levels	OR/RR (THC only)	OR/RR (Alc only)	OR/RR (THC+Alc)	Risk Increase w/ Alcohol
Pulido et al., 2011 **Spain**	Case-Crossover	Driver RR of suffering a non-fatal crash injury while drug and alcohol-free free or after self-reported drug / alcohol use	Out of 503 young drivers who completed the study, 68 young drivers who suffered a non-fatal crash injury requiring medical care were cases *and* controls	Self-reported cannabis use w/in 1 hr Self-reported alcohol use w/in 2 hrs	5.8 (2.4 - 14)	N/A	10.9 (1.3 - 88)	1.88
Biecheler et al., 2008 **France**	Culpability Index (simple ratio: culpables / controls)	OR of a culpable driver in a fatal crash testing positive for drugs or alcohol (e.g., at specific blood levels)	Out of 9,998 drivers with known culpability and drug/ alcohol results; culpable drivers were cases and non-culpable drivers were controls	THC ≥1 ng/mL Alc ≥.05 mg/L	2.3	9.4	14.1	6.13
Drummer et al., 2004 **Australia**	Culpability	OR of a culpable driver killed in a crash testing positive for drugs or alcohol (e.g., at specific blood levels)	Out of 3,398 fatally-injured drivers, culpable drivers were cases and non-culpable drivers were controls	THC >0 ng/mL ≥5 ng/mL Alc ≥.05 mg/L	2.7 (1.02 - 7.0) 6.6 (1.5 - 28)	6 (4.0 - 9.1)	17.4	6.44

95% Confidence intervals shown in parentheses when available. RR=Relative Risk OR=Odds Ratio Alc=Alcohol

Study and Country	Design/Type	Target Measure	Cases / Controls	THC and Alcohol Levels	OR/RR (THC only)	OR/RR (Alc only)	OR/RR (THC+Alc)	Risk Increase w/ Alcohol
Mura et al., 2003 **France**	Case-Control	Injured driver OR of testing positive for THC / alcohol related to injury in non-fatal crashes	*Cases:* 321 drivers (<age 27) treated in ER after non-fatal crashes *Controls:* 310 licensed drivers (<age 27) treated in ER for non-crash causes	THC >1 ng/mg Alc ≥.05 mg/L	2.5 (1.5 - 4.2)	3.8 (2.1 - 6.8)	4.6 (2.0 - 10.7)	1.84
Longo et al., 2000 **Australia**	Culpability	OR of a culpable driver in a fatal crash testing positive for drugs or alcohol (e.g., at specific blood levels)	Out of 2,500 drivers injured in crashes, culpable drivers were cases and non-culpable drivers were controls	THC ≤ 2 ng/mL THC >2 ng/mL Alc ≥0	0.5 1.8	4.8	6.2	3.44

95% Confidence intervals shown in parentheses when available. RR=Relative Risk OR=Odds Ratio Alc=Alcohol

Laboratory/Simulator Studies

A great advantage of simulator studies is that they yield precise estimates derived from controlled research conditions, such as ongoing alcohol and drug levels during a series of performance trials. Simulator studies often reveal the specific human skills and abilities compromised by impairing substances. The psychomotor and neurocognitive faculties comprising the core of competencies vital to the driving task are highly vulnerable to impairment.

The standard deviation of lane position (SDLP) is an exquisitely sensitive measure of the driver's ability to gauge and maintain consistent control of a vehicle's position and trajectory in the roadway. Other critical skills tests are the divided attention test (DAT), which measures the subject's ability to process and coordinate multiple information streams within the same time frame. All of these inputs must be registered and prioritized in time to make needed adjustments to one's vehicle operation in order to maintain generally safe travel. Critical tracking (CT) represents the human ability to remain focused on important visual objects moving about in the visual field – and making ongoing adjustments accordingly. Other important measures used in laboratory and simulator studies include lateral acceleration (the ability to adjust vehicle speed and steering wheel in order to safely control turning), time-out-of-lane (another measure of lateral control), reaction time (usually assessed by the stop-signal test), and working memory (a neurocognitive function measured by specific memory tests).

The results and other details of a sample of these studies is summarized in Table 2.

Table 2: Laboratory Studies Measuring Driving Performance as Impacted by THC and Alcohol

Study and Country	**Design/Type (included laboratory and driving components)**	**Target Measures**	**Subjects**	**Findings**
Desrosiers et al., 2015 **USA, France, Netherlands**	Double-blind, placebo-controlled, balanced-block design	Performance on CT, DA, SS, WM, RT tests	14 frequent ($\geq$4x/week) and 11 infrequent (<2x/week) cannabis users (8 males, 4 females)	THC only: THC alone induced performance deficits in CT, DA, LC, and SS tests in both groups but particularly for occasional users.
Ramaekers et al., 2009 **Netherlands & Germany**	Double-blind, placebo-controlled, mixed-model design	Performance on CT, DA, SS, RT tests	12 occasional and 12 heavy cannabis users (8 males, 4 females)	THC only: THC alone induced performance deficits in CT, DA, CF, and SS tests in occasional users, but CT and DA were not impacted in heavy users.

Abbreviations - CT: critical tracking; DA: divided-attention; WM: working memory; RT: reaction time; SS: stop-signal; SDLP: standard deviation of lane position; LA: lateral acceleration; LD: lane departure; CF: cognitive function; LC: loss of control

Study and Country	Design/Type (included laboratory and driving components)	Target Measures	Subjects	Findings
Hartman et al., 2015 **USA**	Six-way crossover in which each subject participated in placebo and low- and high-THC/Alcohol conditions	Effects of THC and alcohol on SDLP, LA, and LD	Self-reported cannabis users: 13 males and 5 females between 21 and 37 years of age	Low-level THC alone significantly affected SDLP only, but alcohol-only impacted all three measures. Combining low-dose alcohol (0.05 BAC) with 5 ng/mL THC resulted in impairment similar to that of 0.08 BAC alcohol. Results did not confirm a true interaction between THC and alcohol.
Ramaekers et al., 2011 **Netherlands & Germany**	Double-blind, placebo-controlled, three-way design	Performance on CT, DA, RT, SS tests	Heavy cannabis users (daily): 15 males and 6 females between 19 and 38 years of age	Heavy users did not show performance deficits with THC alone on CT, SS, and CF tests, but DA, LC, and RT were impacted. However, alcohol alone resulted in significant decrements in CT, DA, RT, and SS tests. Data modeling also revealed THC-alcohol interaction (and greater performance deficits) for combined THC and alcohol.
Ramaekers et al., 2000 **Netherlands**	Six-way crossover in which each subject participated in placebo and low- and high-THC/Alcohol conditions	Performance on CT, DA, RT, SS, LD tests	Current alcohol (1X/wk) and cannabis (1X/mo) users: 9 males and 9 females between 20 and 28 years of age	Both THC and alcohol alone each significantly affected SDLP though less for THC than alcohol. Combining alcohol and THC resulted in severe loss of CT performance and sizeable rises in SDLP. Even at low THC levels, alcohol at the 0.05 BAC level resulted in deficits typically observed in drivers with a BAC of 0.09.

Abbreviations - CT: critical tracking; DA: divided-attention; WM: working memory; RT: reaction time; SS: stop-signal; SDLP: standard deviation of lane position; LA: lateral acceleration; LD: lane departure; CF: cognitive function; LC: loss of control

Simply converting the findings from laboratory and simulator studies to on-road driving performance effects has resulted in unwarranted conclusions. Nonetheless, these studies have given researchers the chance to understand the effects of both smoking and ingesting marijuana in a careful, dose-related manner, and also to predict how driving performance is likely to be altered (smoking results in elevated plasma-THC levels within seconds and maximum values within 15 minutes, whereas ingestion results in lower maximum values that peak in around 1 hour). All of these capabilities are even more strongly compromised by the added presence of alcohol. Even low doses of THC in combination with a 0.04% BAC produced road-tracking impairment to a degree similar to a BAC of 0.09% (Hartman & Huestis, 2013). Likewise, chronic and heavy users of marijuana, who often show reduced performance deficits owing to drug tolerance, become seriously degraded after drinking alcohol. In part, this reversal occurs because alcohol erases the ability of even strongly habituated marijuana users to compensate for their performance decrements.

A link between THC blood levels and impairment may never be developed comparable to the relationship that exists for alcohol. Alcohol and marijuana are very distinct in terms of chemical makeup, body metabolism, and psychomotor impairment and therefore should not be compared. Strategies implemented to reduce alcohol impaired driving are not likely to have the same impact on reducing drugged drivers. More research and information are needed before researchers can definitely understand the link between marijuana use and increased crash risk.

Research Complications

There is currently wide variability of risk estimates related to THC and THC combined with alcohol. Crash risks among THC positive drivers remain variable owing to an array of factors, e.g., individual human responses to THC vary tremendously and regular users become tolerant to drug effects over time. Age and gender themselves are potential confounding variables, since adolescents are highly sensitive to potential rewards and thus more susceptible to the dangers of dependency and addiction, and women produce lower levels of gastric alcohol dehydrogenase and so wind up with higher BAC levels resulting from a given dose of alcohol than men do (Baraona et al., 2001).

Risk estimates also widely vary due to study design differences. For instance, culpability studies typically underestimate the risks posed by drugs and alcohol because even non-culpable drivers involved in fatal crashes are more likely to engage in risky behaviors than controls who have never been involved in crashes. Sample size differences are also likely sources of variability and some study designs are better able to control for potential confounders than other designs. Other significant research limitations include lack of complete and reliable data, differences in toxicological blood testing methods and sensitivity, and the vast variety of marijuana potency and consumption methods. Research studies relying on simulator and controlled dose designs are limited because the flower marijuana used in those studies (ranging from 3-8% THC concentration) is not representative to the flower product available in legal recreational use states (ranging from 10-30% THC concentration).

Conclusions

Although research-based estimates of the risks posed by THC have varied greatly, all studies included in this review agree that giving alcohol to drivers who are already compromised by THC will only further inflate the level of that risk. The epidemiologic studies reviewed here estimate that drinking to a BAC level of 0.05% will increase the driver risk of crashing (and of being responsible for a crash) by a factor of between 1.84 and 6.44. One additional recent research finding by Hartman et al., 2015(b), is that the presence of alcohol increases blood levels of both carboxy-THC and hydroxy-THC, the metabolites of THC. The authors of that study have proposed that their finding may serve to clarify the reasons for alcohol's disabling impact on THC-positive subjects. Ultimately, there are still many unknowns regarding the interaction between THC and alcohol and crash risk, but the deadly consequences of combining these two impairing substances and driving are already apparent in Washington fatal crash data.

Alcohol, Marijuana, and Other Drugs in Fatal Crash-Involved Drivers

The Revised Code of Washington 46.52.065 requires that “a blood sample be taken from all drivers and all pedestrians who are killed in any traffic [crash] where the death occurred within four hours” for analysis by the state toxicologist “to determine the concentration of alcohol and, where feasible, the presence of drugs or other toxic substances.” This statute has led to statewide testing rates for deceased drivers of almost 90 percent. Failure to test a deceased driver most often results from either a long-time lag between crash and death or from some other barrier to obtaining a viable sample for testing. Unfortunately, a similar law does not exist for surviving drivers involved in fatal crashes. Therefore, testing rates among this group are much lower and rely on the reasonable suspicion of impairment by the investigating law enforcement parties.

Washington State has a centralized toxicology laboratory. This means that all drivers suspected of driving under the influence (DUI), either in traffic or as part of a crash investigation where a blood/specimen was collected, are tested by the Washington State Patrol (WSP) Toxicology Lab. The WSP Toxicology Lab’s reporting thresholds for THC have varied in the past from one to two nanograms per milliliter of blood (ng/mL). On January 1, 2013, the WSP Toxicology Lab reset the THC reporting threshold to one ng/mL and began conducting full panel (alcohol and drug) tests on all traffic crash blood sample submissions. Prior to this date, the Lab tested blood for the presence of alcohol first. Only if blood alcohol concentrations were under 0.10, the Lab then conducted drug testing. In addition, full panel alcohol and drug testing was only performed when a driver was involved in vehicular homicide/assault and/or underwent a Drug Recognition Expert examination. The Lab change to full panel testing after 2013 had a minor impact on the data used in this report (Table 4). Drivers with only alcohol screening were therefore excluded.

Table 3: Toxicology Testing of Surviving and Deceased Drivers in Fatal Crashes, 2008-2016

2008-2016	Any Toxicology Testing	No Toxicology Testing	Total Drivers in Fatal Crashes	% Tested
Surviving Drivers	1,085	2,090	3,175	34.2%
Deceased Drivers	2,465	270	2,735	90.1%
Total Drivers	**3,550**	**2,360**	**5,910**	**60.1%**

Toxicology Testing of Drivers in Fatal Crashes

In Washington State between 2008 and 2016, a total of 5,910 drivers were involved in fatal crashes. Overall testing rates of drivers involved in fatal crashes remained stable 2008-2013, and then declined in 2014. From 2008-2013, the average testing rate was 63.2 percent. From 2014-2016, the average testing rate of drivers involved in fatal crashes declined to 54.8 percent. Tables 4 and 5 describe the type, frequency, and outcomes of toxicology tests among drivers involved in fatal crashes.

Table 4: Toxicology Testing of Drivers in Fatal Crashes by Year

	Alcohol Test ONLY	Drug Test ONLY	Alcohol and Drug Test	Not Tested	% Tested	Total Drivers
2008	30	5	402	275	61.4%	712
2009	37	0	369	227	64.1%	633
2010	22	1	377	219	64.6%	619
2011	36	0	344	226	62.7%	606
2012	21	0	345	225	61.9%	591
2013	7	0	373	212	64.2%	592
2014	5	1	342	275	55.9%	623
2015	12	0	396	359	53.2%	767
2016[2]	9	0	416	342	55.4%	767
Total	**179**	**7**	**3,364**	**2360**	**60.1%**	**5,910**

Table 5: Toxicology Outcomes of Drivers in Fatal Crashes by Year

	Total Drivers	Alcohol and Drug Test	Positive for Alcohol or Drugs	% of Tested Drivers Positive	% of Total Drivers Positive
2008	712	402	252	62.7%	35.4%
2009	633	369	236	64.0%	37.3%
2010	619	377	231	61.3%	37.3%
2011	606	344	191	55.5%	31.5%
2012	591	345	196	56.8%	33.2%
2013	592	373	225	60.3%	38.0%
2014	623	342	225	65.8%	36.1%
2015	767	396	248	62.6%	32.3%
2016[2]	767	416	269	64.7%	35.1%
Total	**5,910**	**3,364**	**2,073**	**61.6%**	**35.1%**

For the remainder of this report, only drivers that were tested for both alcohol and drugs are included.

Toxicology Outcomes of Drivers in Fatal Crashes

From 2008-2016, more than one-third of drivers in fatal crashes were positive for alcohol or drugs. During this time period, drivers in fatal crashes testing positive for both alcohol and drugs or multiple drugs (poly-drug drivers) have increased. Table 6 categorizes fatal crash involved drivers into mutually exclusive groups (meaning each driver is counted in only one category), based on alcohol and drug outcomes.

[2] At the time of this analysis, data for 2016 was still preliminary but complete.

Table 6: Categorization of Drivers in Fatal Crashes Testing Positive for Alcohol or Drugs, 2008-2016

TEST STATUS	Driver Category 1	Sample	Driver Category 2	Sample	Driver Category 3	Sample
Not Tested	**Not Tested**	**2,360**	Not Tested	2,360	Not Tested	2,360
Tested - Negative	**No Drugs, No Alcohol**	**1,288**	No Drugs, No Alcohol	1,288	No Drugs, No Alcohol	1,288
Tested – Positive (2,073) Excluding Alcohol Test Only (179), Drug Test Only (7), Tested with Unknown Results (3)	**Alcohol Only**	**671**	**Alcohol Only <.079**	**96**	Alcohol Only <.079	96
			Alcohol Only ≥.08	**575**	Alcohol Only ≥.08	575
	Cannabinoids Only	**188**	**THC Only**	**118**	THC Only	118
			Carboxy-THC Only	**70**	Carboxy-THC Only	70
	Cannabinoids + Alcohol Only	**275**	**THC + Alcohol**	**187**	**THC + Alcohol <.079**	**25**
					THC + Alcohol ≥.08	**162**
			Carboxy-THC + Alcohol	**88**	Carboxy-THC + Alcohol	88
	Cannabinoids + Drugs + Alcohol	**103**	**THC + Drugs + Alcohol**	**66**	**THC + Drugs + Alcohol <.079**	**14**
					THC + Drugs + Alcohol ≥.08	**52**
			Carboxy-THC + Drugs + Alcohol	**37**	Carboxy-THC + Drugs + Alcohol	37
	Cannabinoids + Drugs Only	**132**	**THC + Drugs**	**76**	THC + Drugs	76
			Carboxy-THC + Drugs	**56**	Carboxy-THC + Drugs	56
	Other Drugs Only	**502**	Other Drugs Only	502	Other Drugs Only	502
	Other Drugs + Alcohol Only	**202**	Other Drugs + Alcohol Only	202	Other Drugs + Alcohol Only	202
Total Driver Sample, 2008-2016						**5,910**

The remainder of this section focuses on poly-drug drivers (drugs and alcohol or multiple drugs), with comparisons to alcohol-only and THC-only drivers. For purposes of this report, carboxy-THC is excluded from the remainder of this report since carboxy-THC does not always indicate recent marijuana use.

The Rising Incidence of Poly-Drug Drivers in Fatal Crashes

The frequency of poly-drug drivers in fatal crashes has increased at a steady rate over the past several years. The number of drivers testing positive for multiple substances reached the highest point in history in 2013, and that number has increased every year since, reaching unprecedented levels. Most poly-drug drivers combine alcohol with another drug. From 2008-2016, 44 percent of fatal crash-involved drivers testing positive for substances were poly-drug drivers.

Figure 1: Recent Increases in Poly-Drug Drivers in Fatal Crashes

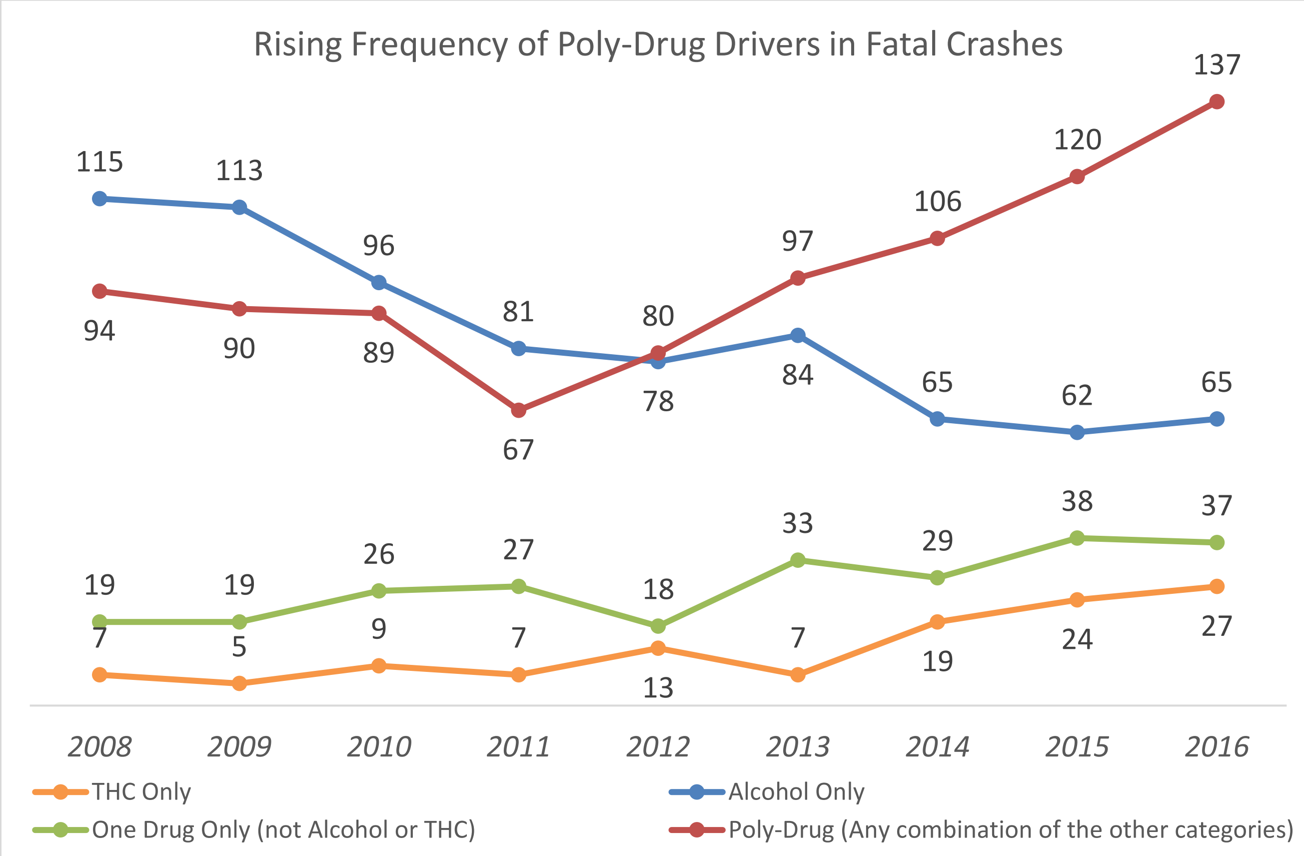
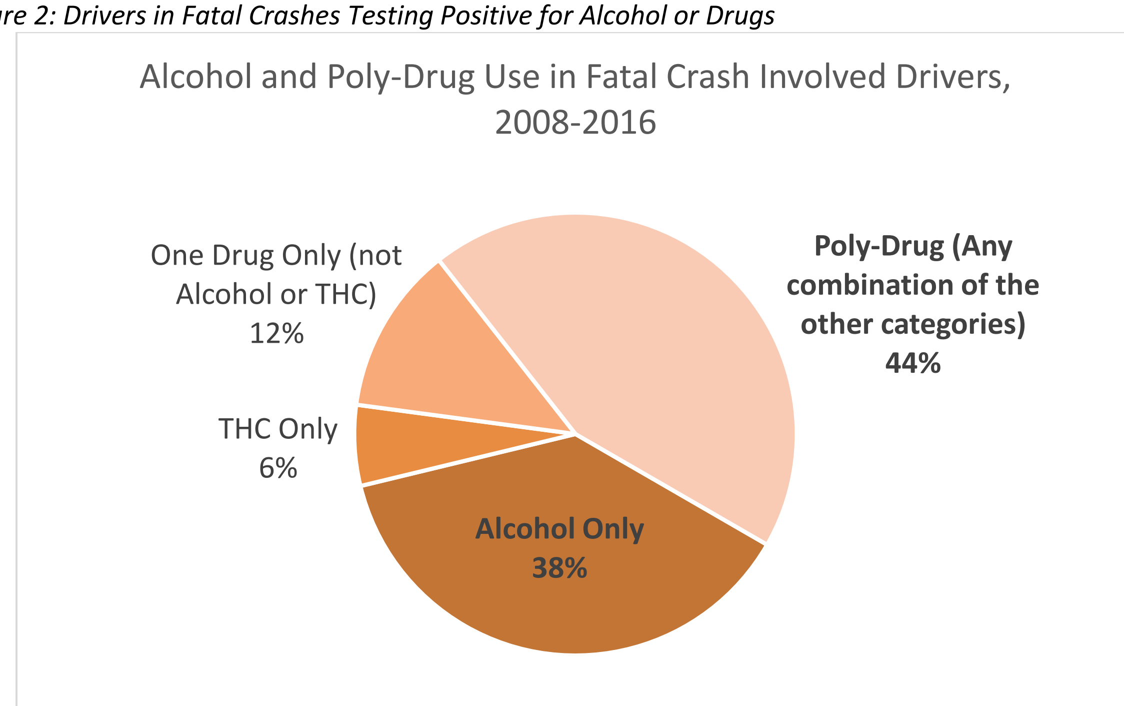
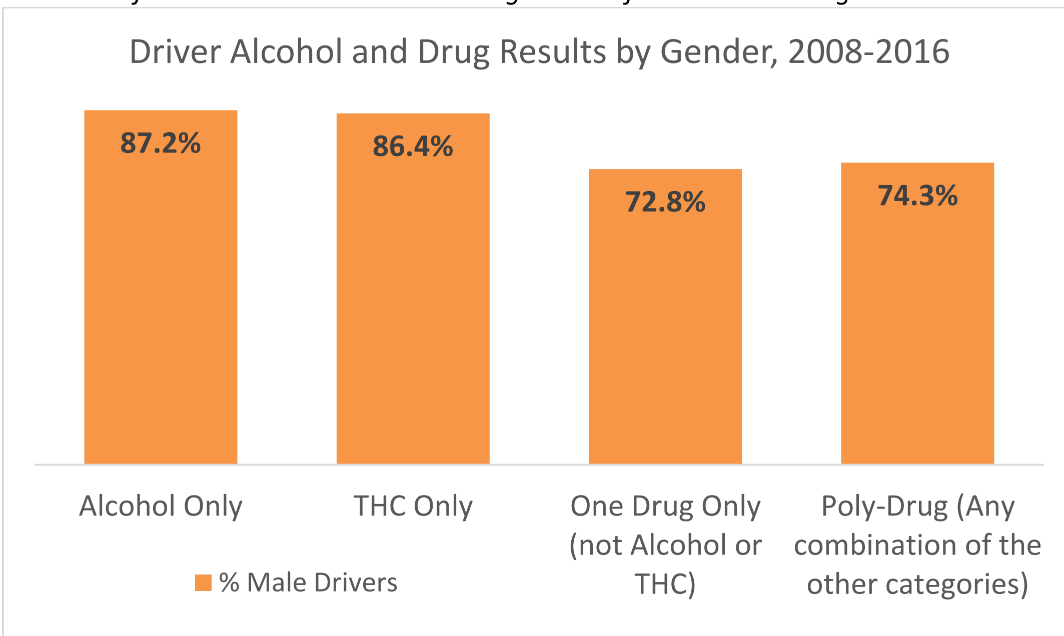


Figure 2: Drivers in Fatal Crashes Testing Positive for Alcohol or Drugs



Males have always been the dominate gender among drivers involved in fatal crashes. This is also true among drivers in fatal crashes testing positive for drugs or alcohol. While still predominately male, drivers positive for other drugs (not THC or alcohol) or poly-drugs have a higher proportion of female drivers than alcohol-only or THC-only drivers. Among the other drugs and poly-drug drivers, one in four are female.

Figure 3: Gender of Drivers in Fatal Crashes Testing Positive for Alcohol or Drugs

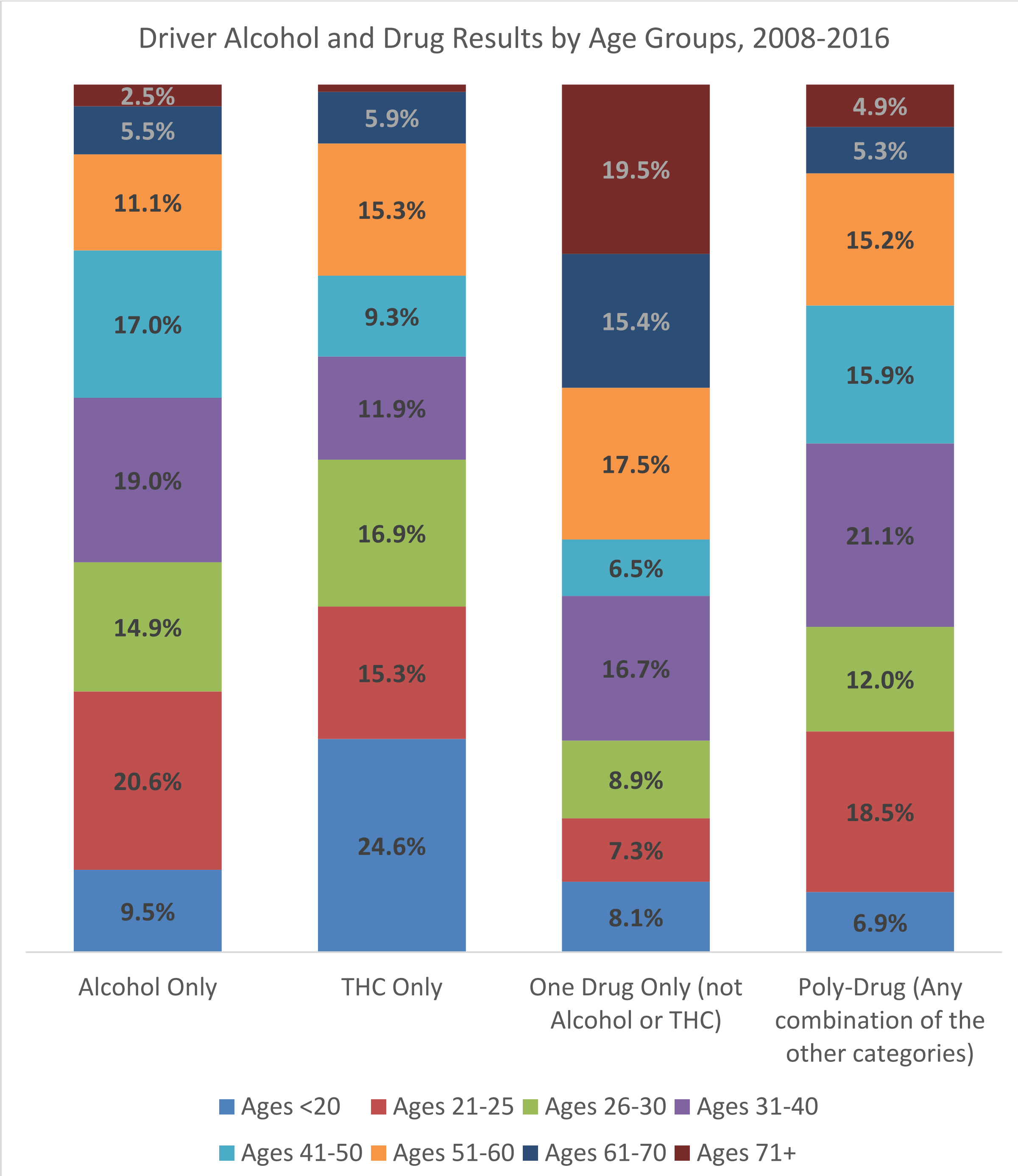


The figure on the following page shows age group comparisons. Other-drug and poly-drug drivers also span age groups more evenly than alcohol-only or THC-only drivers. Among THC-only drivers in fatal crashes, more than half (56.8 percent) were age 30 or younger. Similarly, 45 percent of alcohol-only drivers were age 30 or younger. The dominate age group for THC-only were drivers ages 20 and younger, comprising nearly a quarter of all THC-only drivers. For alcohol-only, the dominate age group was ages 21-25 comprising over 20 percent.

For drivers testing positive for other drugs-only, only one in four are ages 30 or younger. The dominate age group for other drugs-only are drivers ages 71 and older, comprising one in five other-drug drivers. Drivers that do not test positive for THC or alcohol, but do test positive for another drug, and only one other drug, are likely prescription drug users. Given the older dominate age in this group, it is possible that the majority of these drivers are taking prescription drugs. However, it is unknown if the prescriptions are impairing or are being abused. What we do know is that this population is not mixing drugs.

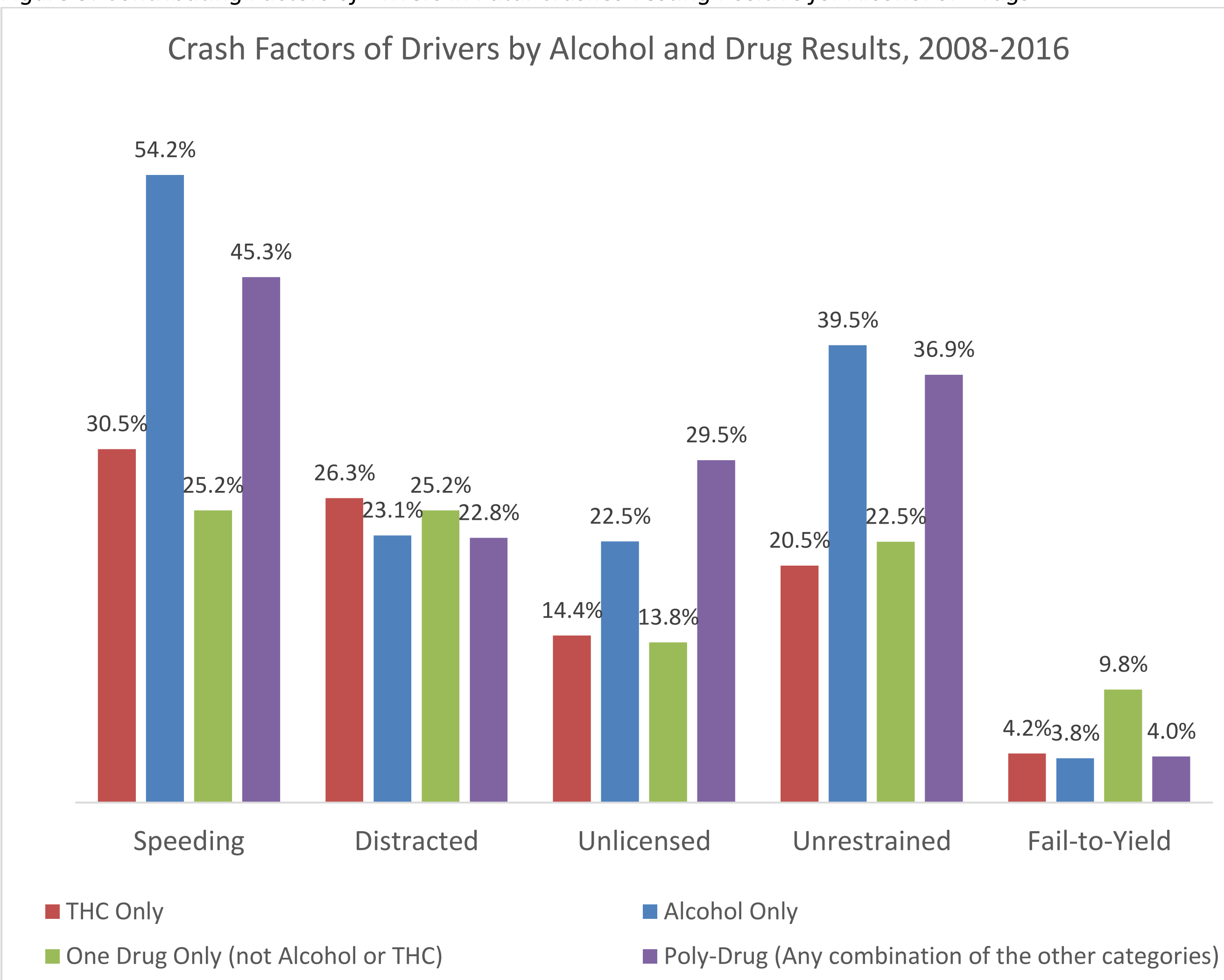
Among poly-drug users, 37 percent are age 30 or younger. The younger (age 20 or younger) and older (age 61 or older) poly-drug drivers are the minority ages in this driver group, whereas every age group in between are more equally represented than in the other driver categories. One in five poly-drug drivers were ages 31-40, similar to alcohol-only drivers.

Figure 4: Age of Drivers in Fatal Crashes Testing Positive for Alcohol or Drugs



Alcohol is the deadliest substance involved in fatal crashes. Drivers under the influence of alcohol, alone or in combination with other drugs, emerge as the most high-risk drivers ultimately being involved in fatal crashes. More than half of alcohol-only drivers were speeding, followed by 45 percent of poly-drug drivers. These two driver groups also had the highest rates of not using a seatbelt. Interestingly, nearly one out of three THC-only drivers were speeding, and had the highest rate of distraction at 26 percent. Poly-drug users had the highest rate of not having a valid license at the time of the fatal crash.

Figure 5: Contributing Factors of Drivers in Fatal Crashes Testing Positive for Alcohol or Drugs



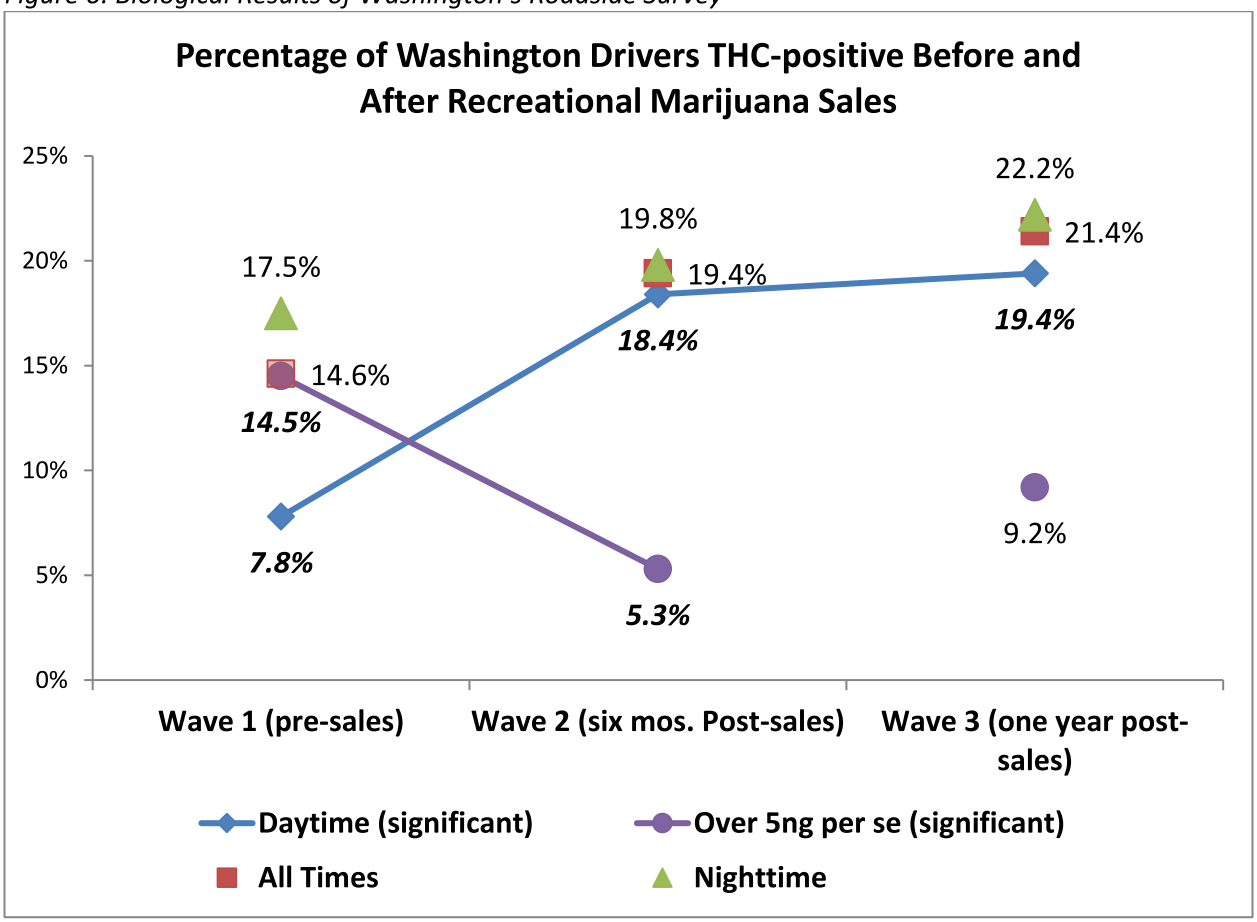
Drug and/or alcohol positive drivers involved in fatal crashes commit more driver errors than 'clean' drivers involved in fatal crashes. These drivers are also more likely to be the only vehicle in the crash. Although alcohol often emerges and the most dangerous of drugs involved in fatal crashes, THC and other drugs, including prescription drugs, also pose significant risk. The increasing trend of poly-drug drivers in fatal crashes is certainly cause for concern as drug combinations, especially with alcohol, may amplify impairment.

Washington's Roadside Surveys 2014-2015

In partnership with NHTSA and the Pacific Institute for Research and Evaluation (PIRE), a roadside survey modeling the National Roadside Survey (NRS) was conducted in Washington State. The survey collected biological (blood and oral fluid) samples and self-report survey information from drivers randomly selected from active traffic flow. This information was collected in three waves; one month prior to retail sales, six months following retail sales (the opening of the first retail store for recreational purchases), and twelve months following retail sales. More information about this effort and the full results of the analysis of the biological samples can be found by reviewing Ramirez et al. (2016).

Figure 6 was developed from information presented in Ramirez et al. (2016). After marijuana retail stores opened there were significant increases in daytime prevalence of THC-positive drivers on Washington roadways. According to the biological survey, nearly one in five daytime drivers may be under the influence of marijuana, up from less than one in ten drivers prior to retail sales. The number of drivers exceeding the five ng/mL marijuana per se limit significantly decreased six months after retail sales began, but this effect was gone by 12 months post-sales. There were no other significant differences between waves.

Figure 6: Biological Results of Washington's Roadside Survey

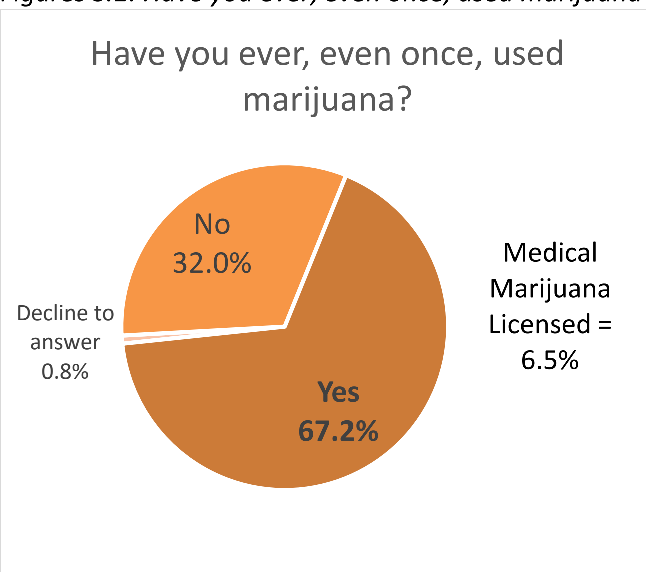


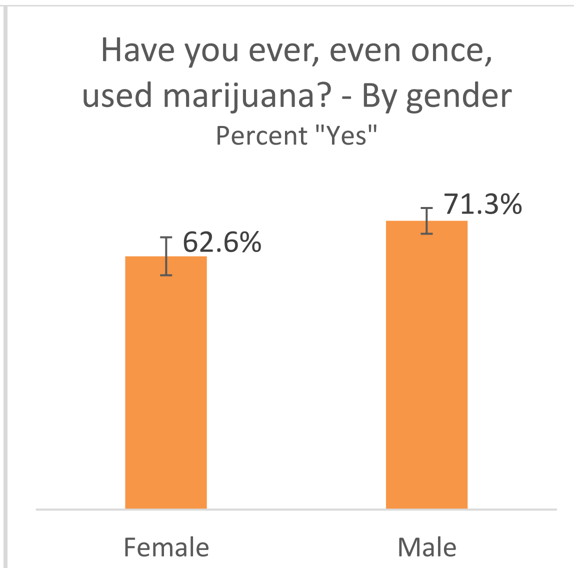
Self-report Marijuana Survey

The Washington Traffic Safety Commission, in partnership with analysts from PIRE, the AAA Foundation for Traffic Safety, and the Insurance Institute for Highway Safety, analyzed the self-report marijuana survey information collected as part of the roadside survey. The full marijuana survey is available in Appendix B. Analyses of this survey were not included in the Ramirez et al. (2016) report. This team of analysts applied a post-stratification weighting adjustment to the design weights calculated for analysis of the biological specimens. The weight adjustment was based on Washington licensed driver demographics for age and gender. This adjustment provided greater generalizability to the licensed driver population in Washington. This weighting method is described fully in Appendix C.

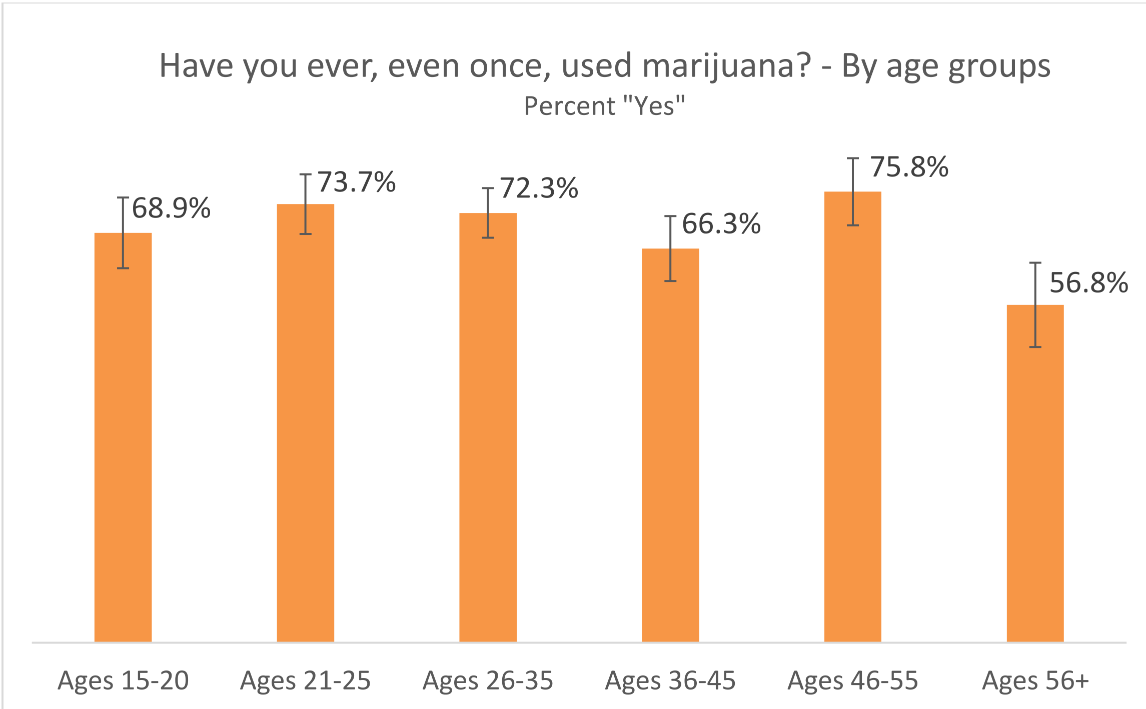
Initial analyses of the self-report survey did not reveal any significant changes in self-reported information by wave. Therefore, the data was combined into a single sample with sufficient sample sizes to perform demographic analyses. Those results are presented in this section. The following figures show the weighted responses to the self-report marijuana survey collected as part of Washington's roadside survey. Only noteworthy outcomes by age, gender, and education level are presented.

Figures S.1: Have you ever, even once, used marijuana?





The majority of people self-reported that they have tried marijuana at least once. A higher majority (71.3 percent) of males have tried marijuana compared to 62.6 percent of the females. The charts on the following page show persons aged older than 56 have the lowest majority of lifetime use (56.8 percent), whereas the age group 46-55 has the highest (75.8 percent). Majority of lifetime use also decreases with higher education status, although these differences are not significant.


Have you ever, even once, used marijuana? - By age groups
Percent "Yes"
68.9%
73.7%
72.3%
66.3%
75.8%
56.8%
Ages 15-20
Ages 21-25
Ages 26-35
Ages 36-45
Ages 46-55
Ages 56+

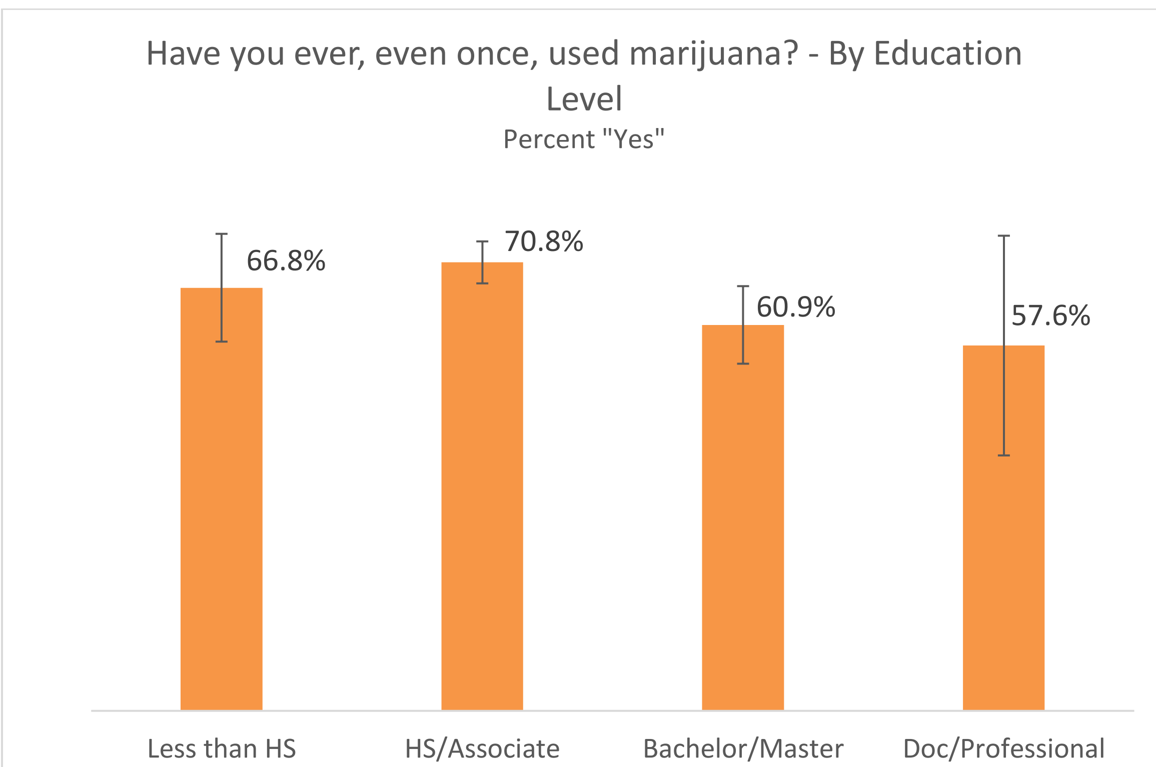
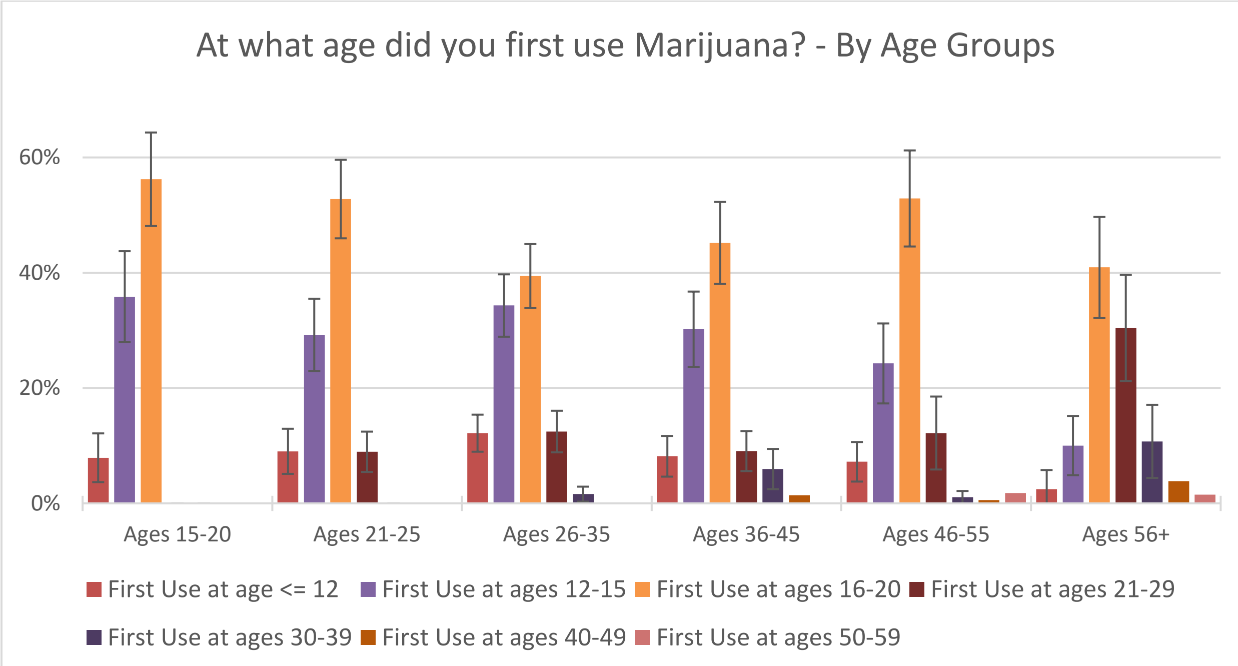
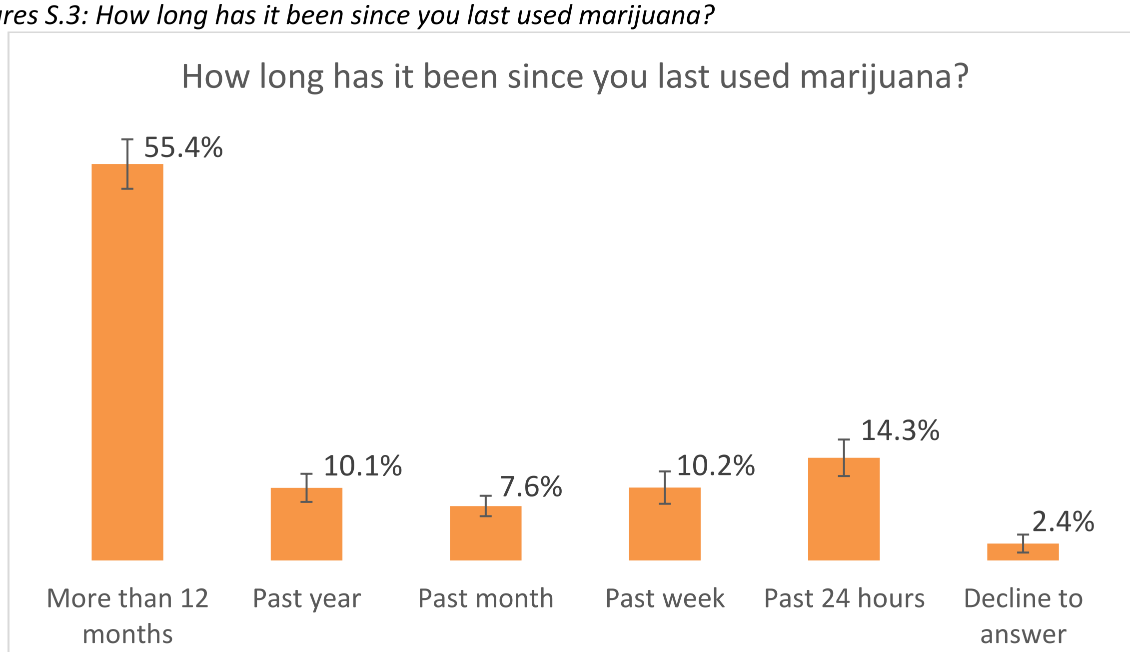

Have you ever, even once, used marijuana? - By Education Level
Percent "Yes"
66.8%
70.8%
60.9%
57.6%
Less than HS
HS/Associate
Bachelor/Master
Doc/Professional

Figure S.2: At what age did you first use marijuana?

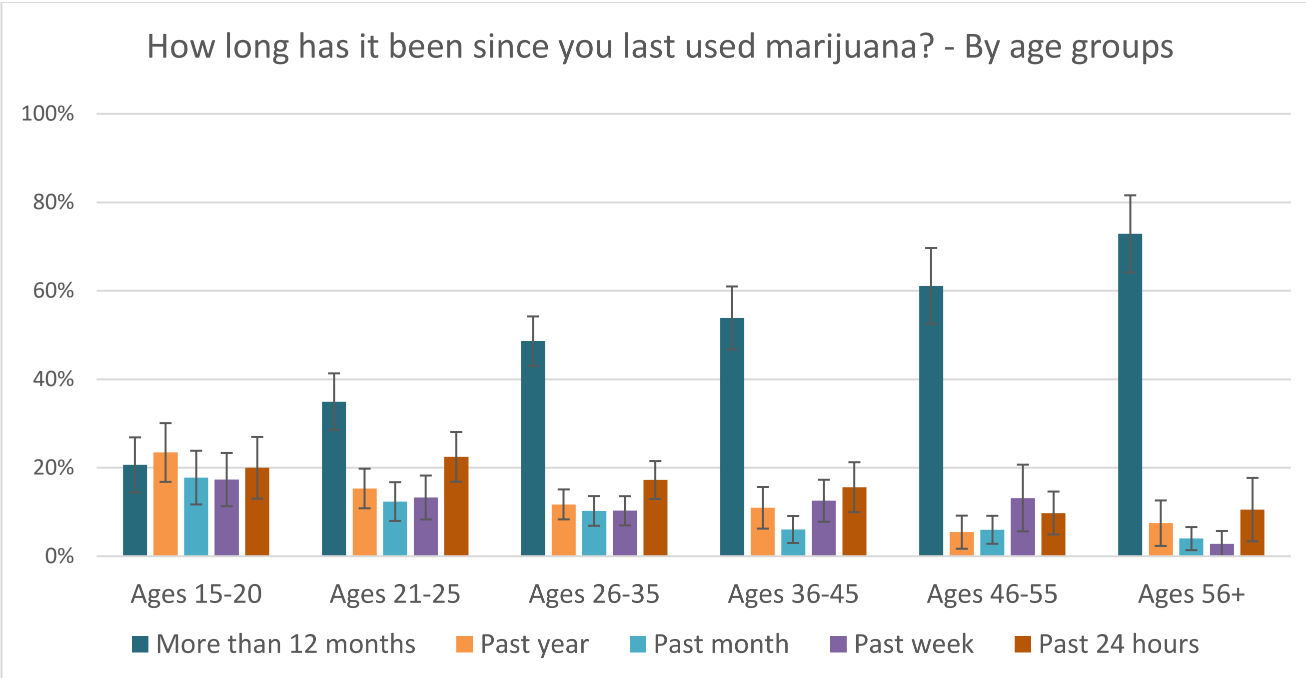


Among all age groups, the most common age of first use was ages 16-20. Among people who have used marijuana younger than age 56, a smaller but significant proportion reported age of first use was ages 12-15. Age of first use is largely consistent between generations. Based on this survey, it appears that few middle-aged and older persons used marijuana for the first time as a result of legalization.

Figures S.3: How long has it been since you last used marijuana?

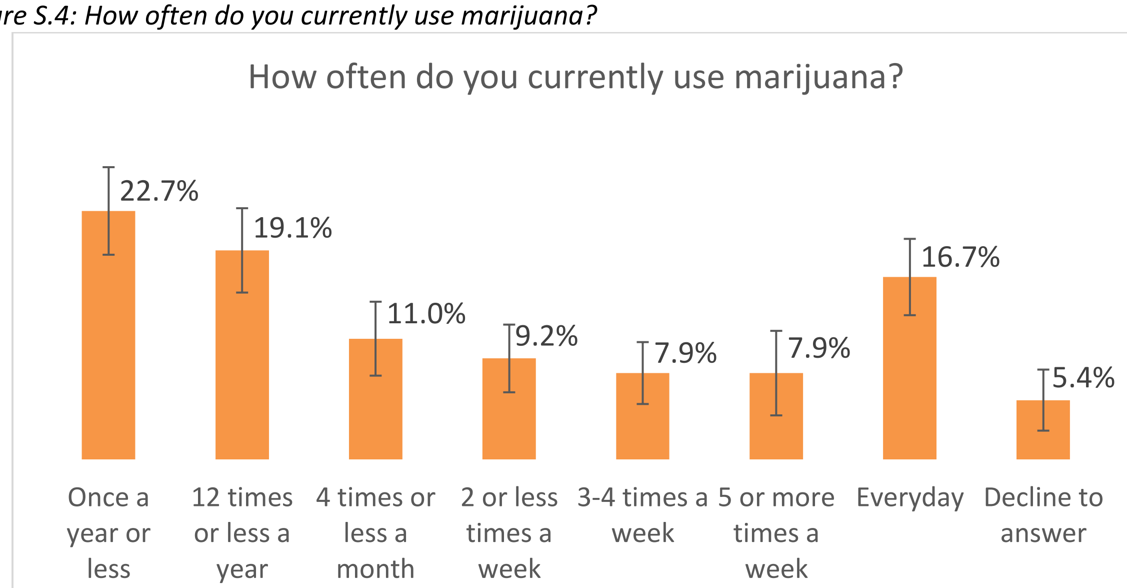


The majority of persons who have ever used marijuana have not used it in the previous year. However, nearly 15 percent of lifetime users report using marijuana in the previous day. The older age groups were more likely to report not using marijuana in the previous year, whereas the age groups 15-25 reported the highest rates of use in the previous 24 hours.



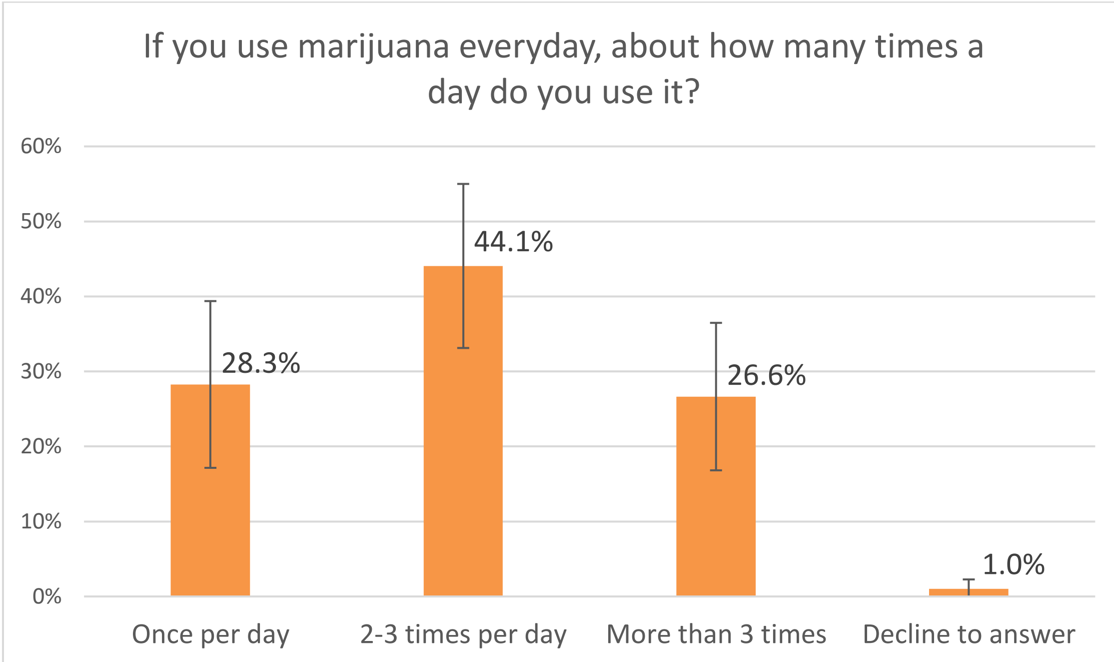
The remainder of this section only includes persons who have used marijuana at least once in the previous year.

Figure S.4: How often do you currently use marijuana?



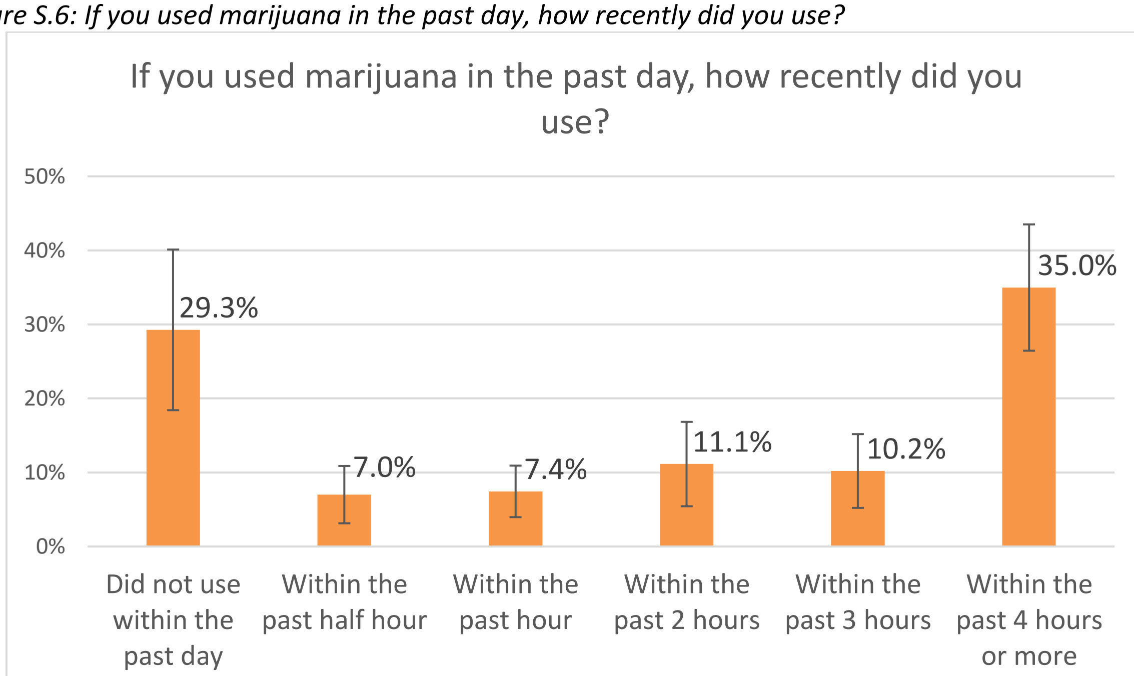
The majority of marijuana users could be considered casual users. Just over 40 percent of marijuana users report using marijuana once a month or less. However, the next highest group are every day users, or chronic users; 16.7 percent reported using marijuana daily.

Figure S.5: If you use marijuana every day, about how many times a day do you use it?



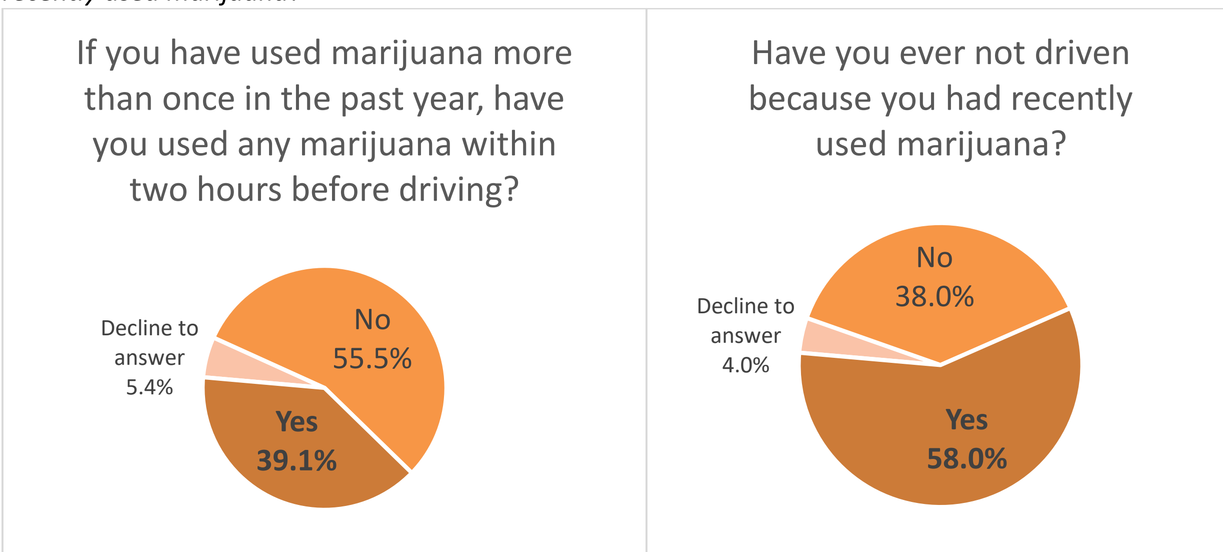
Among daily users of marijuana, the majority (44.1 percent) reported using it two to three times per day. An additional 28.3 percent report using marijuana only once a day and another 26.6 percent report using marijuana more than three times every day.

Figure S.6: If you used marijuana in the past day, how recently did you use?

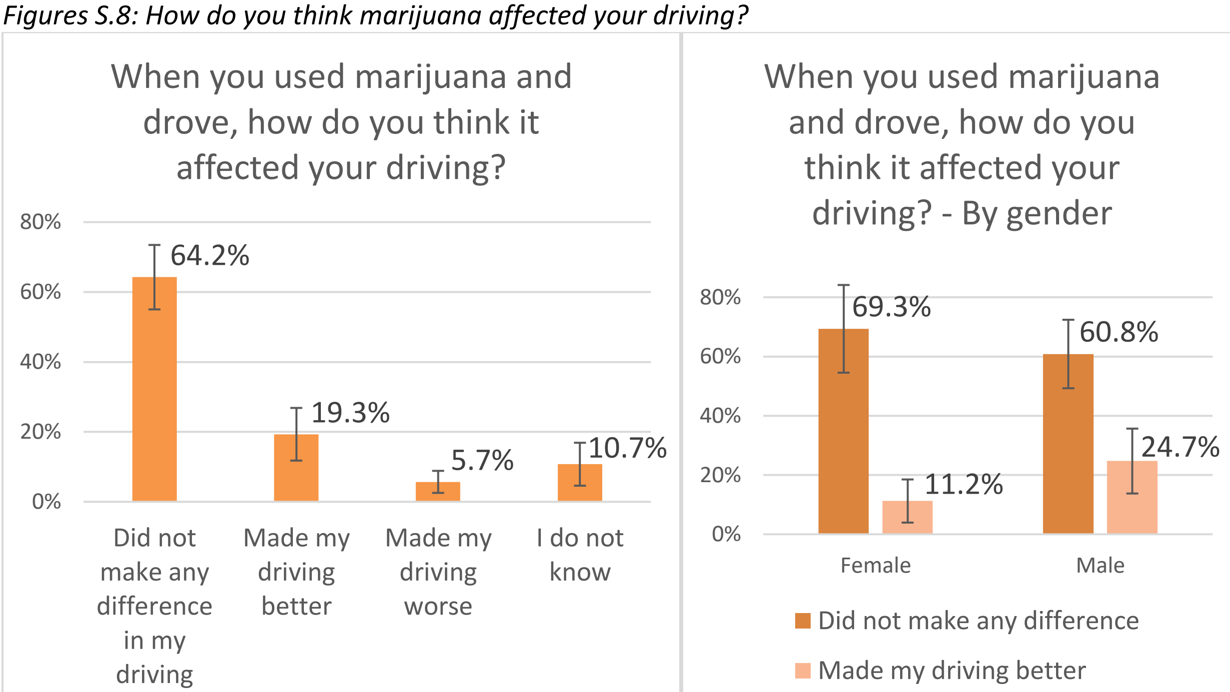


The majority of respondents reported not using marijuana in the previous four hours (64.3 percent). However, nearly 36 percent of daily users reported using within the previous three hours (including use in the past half hour, hour, two hours, and three hours in Figure S.6). All respondents were recruited from the roadside, meaning they were all driving just before participating in the survey. Alarmingly, 7 percent reported use in the previous half hour, indicating some may have even been using marijuana while driving. In fact, 39.1 percent of drivers admitted to driving within three hours of using marijuana at least once in the previous year. Despite this admission, 58 percent of drivers also admit not driving due to recent marijuana use.

Figures S.7: Have you used marijuana within two hours before driving? Not driven because you had recently used marijuana?



Figures S.8: How do you think marijuana affected your driving?



Among marijuana users admitting to driving within three hours of marijuana use, two out of three did not think the marijuana use made any difference in their driving. One in five drivers actually reported that they thought marijuana use made their driving better. One in four men felt marijuana use made them better drivers, compared to just over one in ten women. As shown in the chart below, novice drivers ages 15-20 hold the majority opinion that marijuana use made their driving better. The frequency of this opinion declined significantly among age groups greater than age 21.

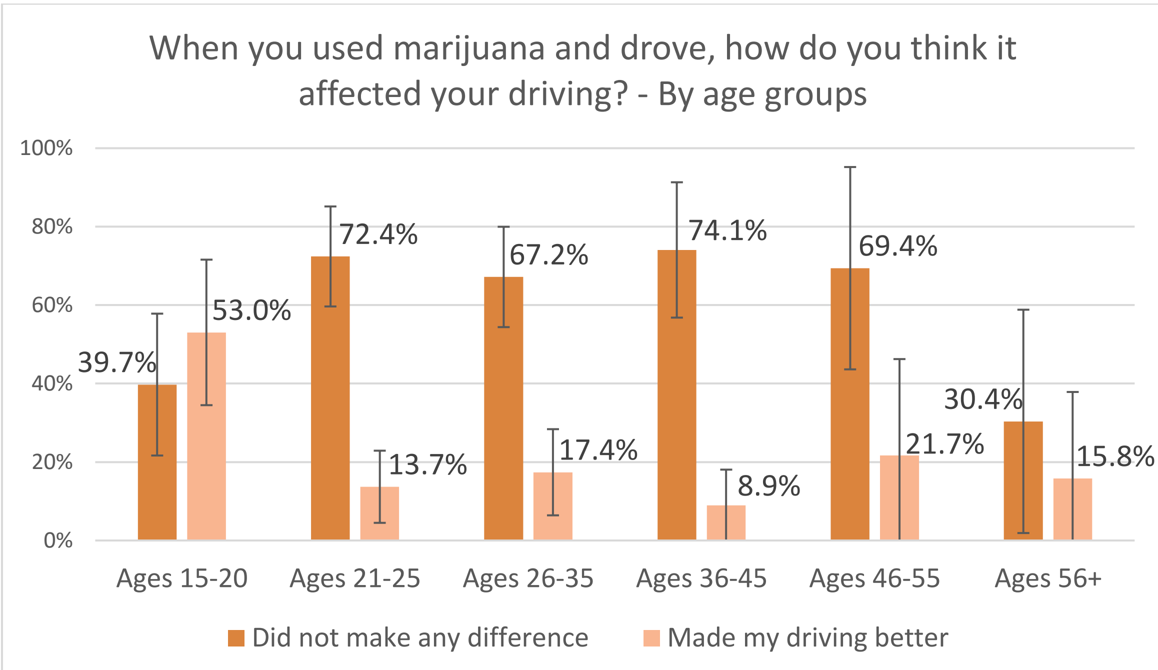
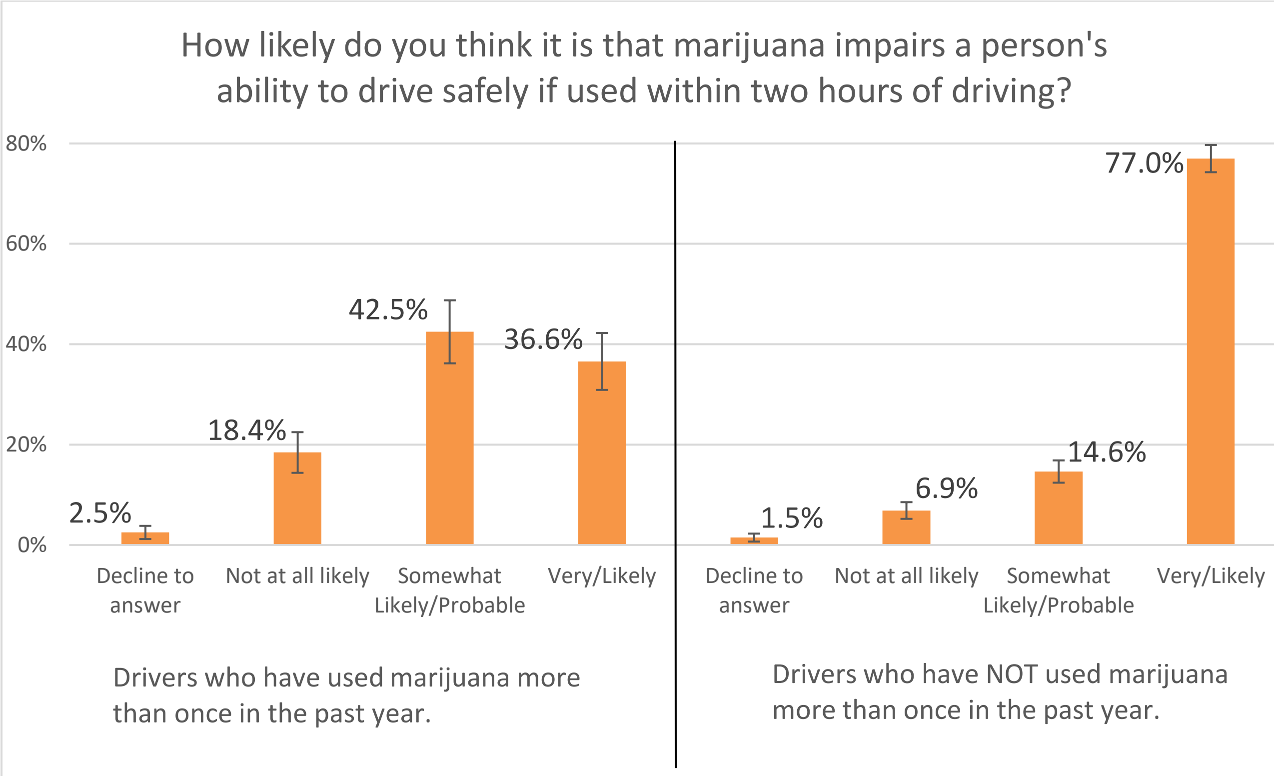
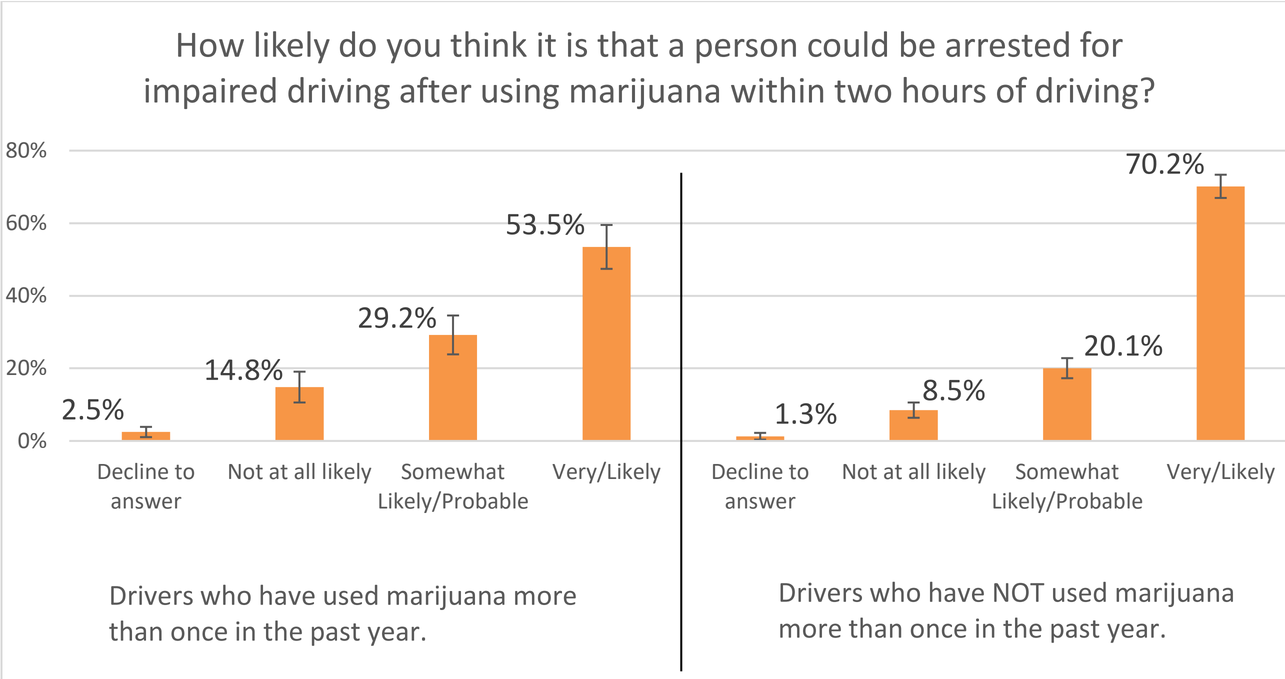


Figure S.9: How likely do you think it is that marijuana impairs a person's ability to drive safely?



There are significant differences of opinion between persons who have used marijuana in the past year and those who have not. The majority (77 percent) of persons who have not used marijuana in the previous year believe that it is very/likely that marijuana impairs a person's ability to drive safely if consumed within two hours of driving. By comparison, only 36.6 percent of drivers who have used marijuana at least once in the previous year believe it is very/likely to impair driving ability. Nearly one in five of this group do not think marijuana use impairs driving ability at all, versus only 6.9 percent of persons who have not used marijuana in the previous year.

Figure S.10: How likely do you think it is that a person could be arrested for impaired driving after using marijuana within two hours of driving?



Drivers who have not used marijuana in the previous year thought it was more likely to be arrested for impaired driving after using marijuana than drivers who have used marijuana in the previous year. Only 8.5 percent of drivers who had not used marijuana in the previous year thought it was not at all likely to be arrested for impaired driving after using marijuana, compared to 14.8 percent of previous year marijuana users.

Roadside Surveys: The Importance of Continued Data Collection

Just after Washington completed the roadside study presented here, NHTSA was prohibited by Congress to spend federal money on national roadside survey data collection efforts. NHTSA has encouraged states to conduct similar prevalence studies to measure the prevalence of drugged driving on roadways, while admitting national data will no longer be available. (Compton, 2017.)

While Washington has been fortunate to have the roadside data collected pre- and post- recreational marijuana legalization, it is unlikely we will be able to continue this effort without NHTSA's research resources and federal funding support. As a result, Washington will have to rely on other self-report survey information to continue monitoring the impact of marijuana legalization. These other surveys are presented in the following section.

Washington’s Self-Report Health Surveys

Behavioral Risk Factor Surveillance System (BRFSS)

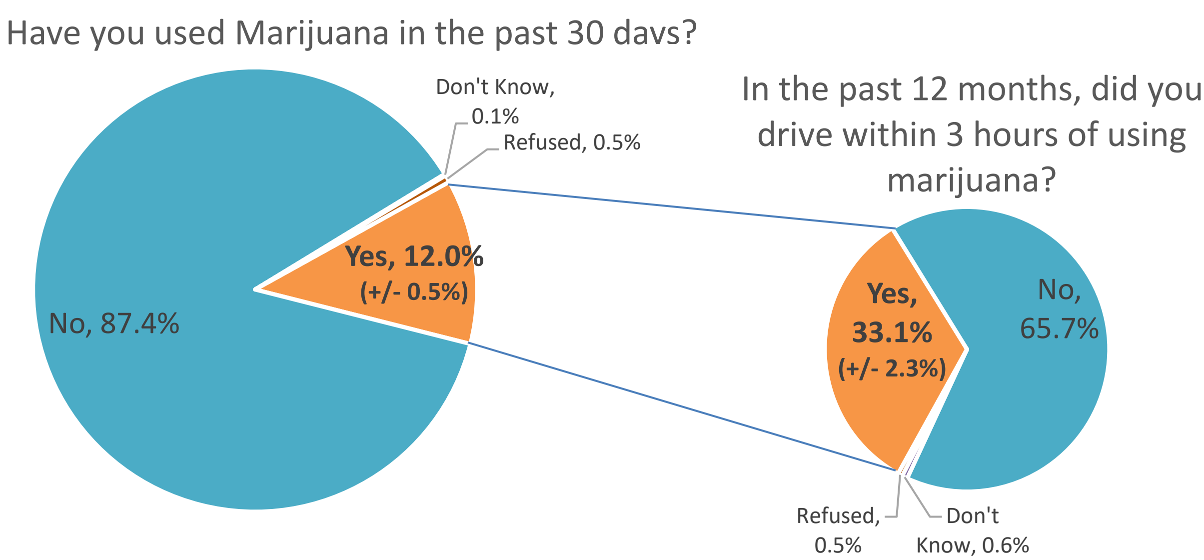
Washington’s Behavioral Risk Factor Surveillance Survey (BRFSS) is managed by the Washington Department of Health under a grant from the Centers for Disease Control and Prevention (CDC), contributing to the national survey compiled by the CDC. The Washington BRFSS provides opportunity for stakeholders to add additional questions to this survey, thereby taking advantage of large survey sample sizes, robust weighting procedures, and multiple cross-analyses with other BRFSS modules. Since 2014, the WTSC has sponsored a traffic safety module on the BRFSS survey to include a question about driving within three hours of using marijuana. If a respondent admits to using marijuana in the past 30 days, those respondents are then also asked about driving within three hours of marijuana use.

Table 7: WA BRFSS Traffic Safety Module Driving After Marijuana Use

If WA9.2 (MJPAST30) = 1 or WA9.4 (MEDMJ) = 1, continue, otherwise skip to next section		
TSMJDRV	WA13.5 Thinking about the last TWELVE months, did you ever drive within approximately three hours after using marijuana or hashish?	1 = Yes 2 = No 7 = Don't Know 9 = Refused

The following analysis combines three years of BRFSS data (2014-2016)[3] in order to provide reliable estimates of driving after marijuana use by various subgroupings, such as demographics and other high-risk behaviors. Approximately one-third of persons reporting past month marijuana use also report driving within three hours of marijuana use.

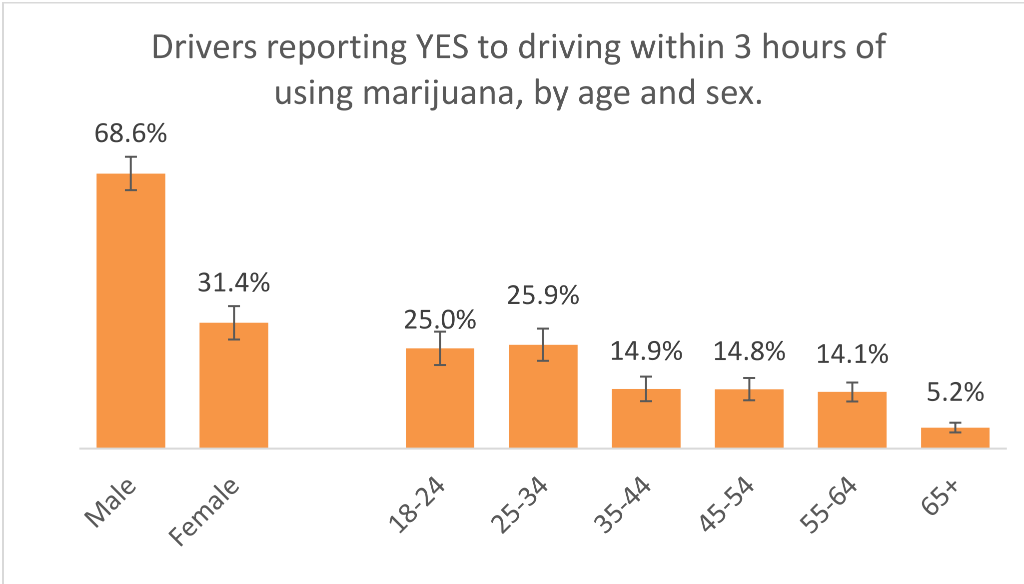
Figure B1: Driving Within 3 Hours of Marijuana Use: WA BRFSS 2014-2016



[3] Data Source: Washington State Department of Health, Center for Health Statistics, Behavioral Risk Factor Surveillance System, supported in part by the Centers for Disease Control and Prevention, Cooperative Agreement U58/SO000047-4, 3U58SO000047-03W1 (2014) U58/DP006066-01 (2015) NU58/DP006066-02-02 (2016).

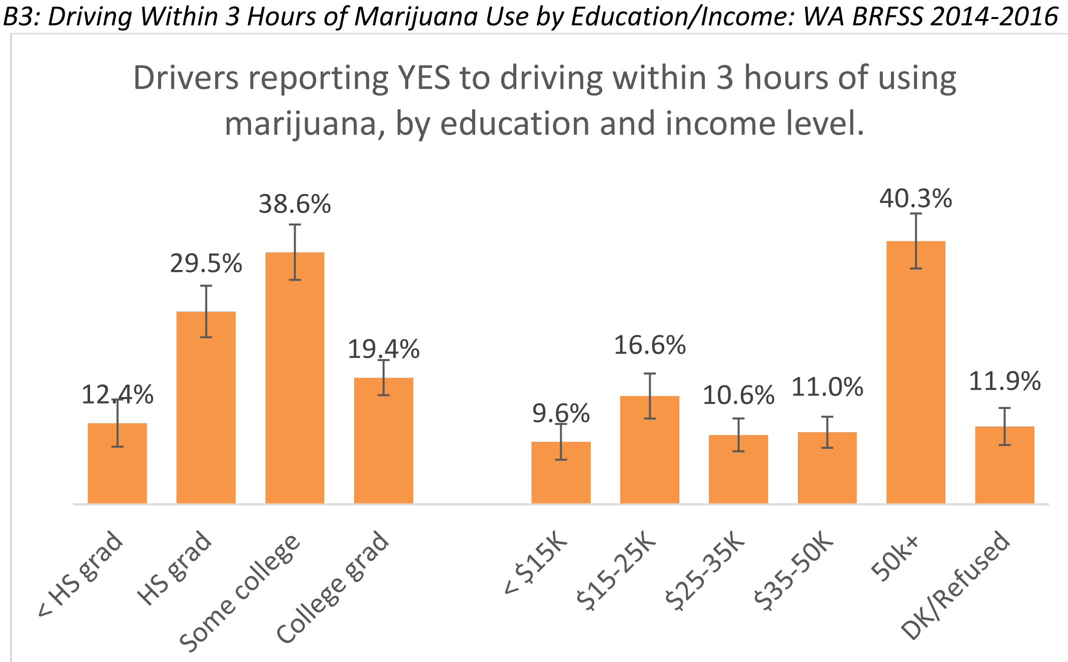
As shown in the roadside survey results, persons reporting driving after marijuana use are more frequently male and under age 35. Over half of persons reporting driving after marijuana use were ages 18-34.

Figure B2: Driving Within 3 Hours of Marijuana Use by Age/Gender: WA BRFSS 2014-2016



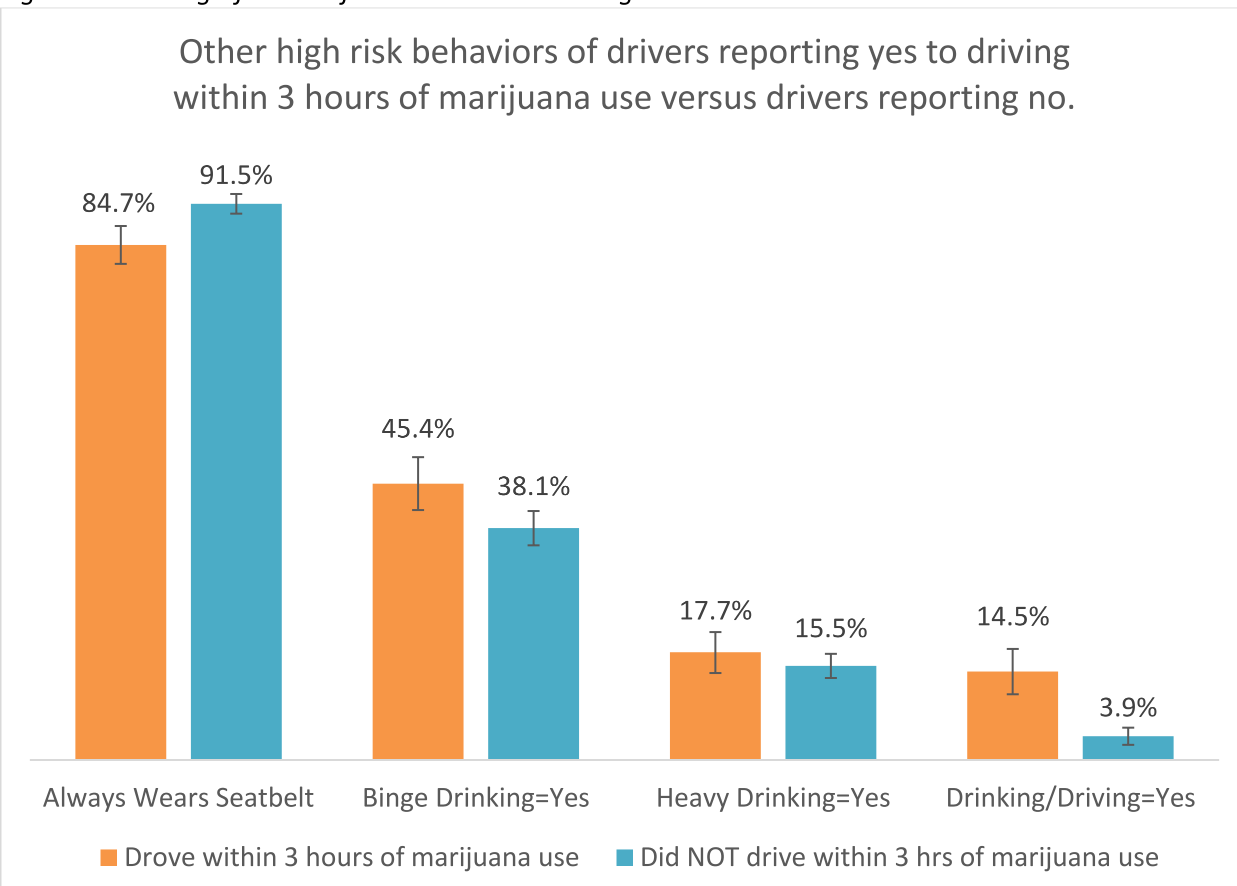
According to the BRFSS survey, the majority (58.6 percent) of persons reporting driving within three hours of using marijuana have at least some college education and 40.3 percent make more than $50,000 per year. This conflicts with the findings from the roadside self-report survey, even though those results were not significant.

Figure B3: Driving Within 3 Hours of Marijuana Use by Education/Income: WA BRFSS 2014-2016



Persons who drive within three hours of marijuana use are significantly more likely to also drink and drive compared to those who do not report driving within three hours of marijuana use. Nearly one in six drivers who report driving within three hours of marijuana use also report driving after having perhaps too much to drink, compared to less than one in twenty drivers who do not report driving within three hours of marijuana use. Fifteen percent of drivers who have driven within three hours of using marijuana report not always wearing a seatbelt, compared to only 8.5 percent of drivers who report not driving after marijuana use. Finally, persons who drive within three hours of marijuana use also have higher rates of binge drinking.

Figure B4: Driving After Marijuana Use and Other High-Risk Behaviors: WA BRFSS 2014-2016



Healthy Youth Survey (HYS)

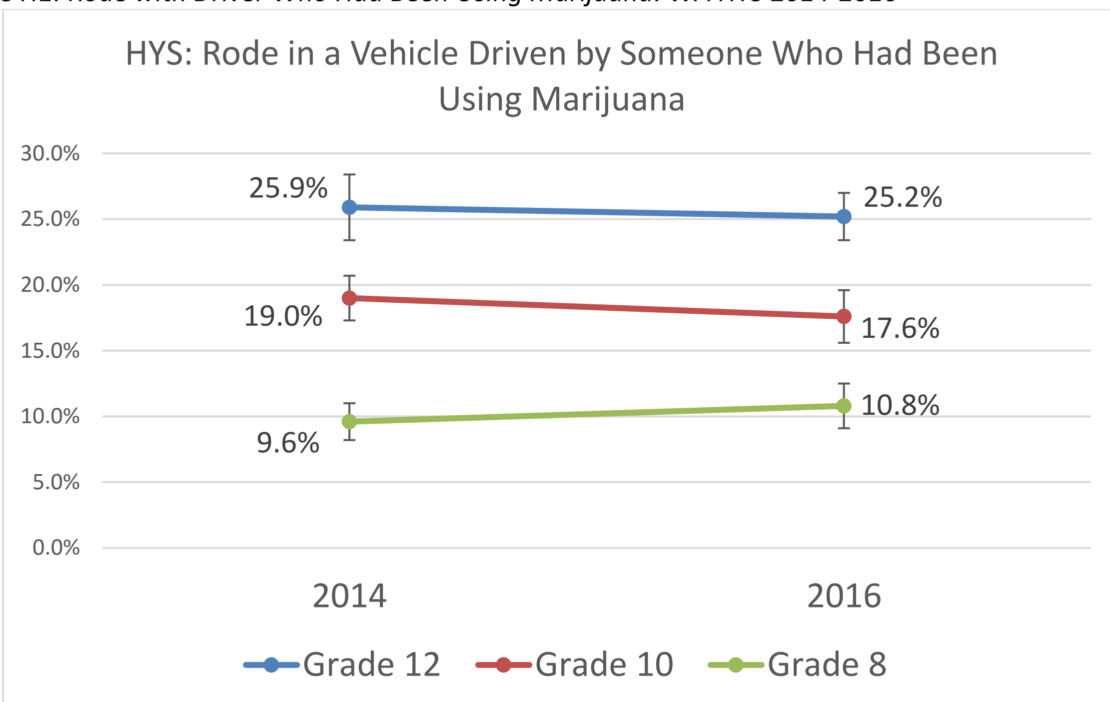
The Washington Healthy Youth Survey (HYS)[4] is a collaborative effort between the Office of Superintendent of Public Instruction, the Department of Health, the Department of Social and Health Services, and the Liquor and Cannabis Board. The Survey is financially supported by the state, and in 2016 the survey was funded by the State Dedicated Marijuana Account. The HYS is administered every other year to Washington students in grades 8, 10, and 12 during class time and measures health risk behaviors that contribute to morbidity, mortality, and social problems among youth in Washington

[4] http://www.askhys.net/Home/AboutHYS

State. In 2016, over 230,000 students from all 39 counties participated in HYS. In 2014, questions about marijuana and driving were added to the survey. The HYS marijuana and driving questions were modeled after the HYS drinking and driving questions.

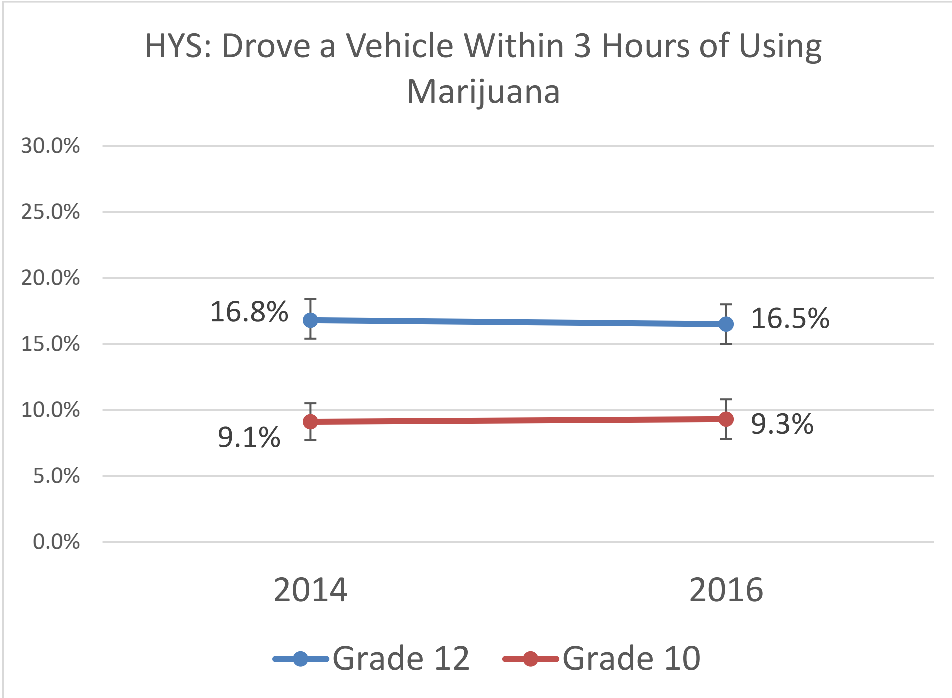
There was no significant change between 2014 and 2016 when students were asked about riding with a driver who had been using marijuana. One in four 12th graders reported having ridden with a driver who had been using marijuana. Students in 10th and 8th grades have lower rates, one in six and one in ten respectively. This difference between grades could be due simply to awareness and that 12th graders are more likely to be riding with peers.

Figure H1: Rode with Driver Who Had Been Using Marijuana: WA HYS 2014-2016



There was also no significant change from 2014 to 2016 when students were asked about driving themselves after marijuana use, but the results are alarming. One in six 12th graders report driving at least once within three hours of using marijuana. Nearly one in ten 10th graders report the same. These results are shown in Figure H2.

Figure H2: Drove a Vehicle Within 3 Hours of Marijuana Use: WA HYS 2014-2016



As shown in the self-report roadside survey, younger drivers are the least likely age group to believe that marijuana impairs driving, and even more concerning is more than half feel that marijuana use actually makes their driving better. It is important to address these misconceptions about marijuana's ability to impair driving in order to decrease the prevalence of young drivers driving after marijuana use. Novice drivers already have an increased crash risk and adding any drug or alcohol use significantly increases that risk. From 2008-2016, 76 drivers ages 16-18 were involved in fatal crashes after consuming drugs and/or alcohol (Table 8). Fifty-four of these drivers lost their lives and 22 contributed to the death of another, in some cases their own family and close friends. Poly-drug use is also an alarming trend among this novice driver population.

Table 8: Number of Drivers Ages 16-18 Involved in Fatal Crashes 2008-2016 with Drugs/Alcohol

Drug/Alcohol Status of Drivers in Fatal Crashes	Number of Drivers Ages 16-18	Driver Deceased	Driver Involved in the Death of Another Person
One Drug Only	8	5	3
Only Alcohol	32	20	12
Only THC	16	12	4
Poly-Drug	20	17	3
Total Alcohol/Drug Drivers	76	54	22

Summary and Conclusions

Poly-drug drivers, or drivers who have consumed two or more substances, have emerged as the most common type of impaired drivers involved in Washington fatal crashes in just the past five years. In 2012, and for the first time, there were more poly-drug drivers involved in fatal crashes than drivers who had consumed only alcohol, only marijuana, or only one other type of drug. Since 2012, the number of poly-drug drivers involved in fatal crashes continues to increase every year at an average rate of 15 percent per year. This alarming trend comes at a time when traffic fatalities are on the rise, jumping almost 20 percent in 2015 alone. The recent rise in traffic fatalities is most certainly due in part to an increase in poly-drug use among drivers on Washington roadways. While alcohol is still the most common substance mixed with other drugs among this high-risk group, alcohol-specific countermeasures alone will not be sufficient for impacting this emerging issue. While it is still largely unknown what role marijuana alone plays in fatal crash risk, it is clear that marijuana mixed with other substances, most commonly alcohol, is contributing to fatal crashes in Washington State.

Information from several self-report surveys indicate that not only is driving after marijuana use quite prevalent, many drivers do not believe that marijuana actually impairs driving. This misperception is especially prevalent among young drivers who also use marijuana. More than half of drivers under the age of 20 that report driving after recent marijuana use actually believe the marijuana use makes their driving better. This is an especially dangerous opinion if, for example, a driver might use marijuana to compensate for the consumption of another substance, such as alcohol, that clearly creates a driving deficit. It is these poly-drug drivers that we see more and more of in fatal crashes every year.

Funding to implement traffic safety countermeasures to combat the increase in drugged driving is limited as there are no specific federal programs addressing drugged driving like there is for alcohol driving. National fatal crash data is a limited resource for studying drugged driving trends due to the extreme variability between states in drug testing, reporting, and laboratory procedures (such as which drugs are included on common screening panels and reporting thresholds for certain drugs). Now that the National Roadside Surveys have been defunded, it will be harder than ever to track the evolution of this deadly issue. Regardless, the Washington Traffic Safety Commission, along with our many state, federal, and community partners, continue to develop innovative and new countermeasures and data collection efforts to combat drugged driving within an environment of limited resources. While alcohol driving very much remains a significant issue, the interplay of drugged driving must be equally considered if we are ever to reach our goal of zero fatalities and serious injuries on Washington roadways. This complex issue will require government, non-profit, corporate, and community response to reverse a rapidly increasing trend.

Appendix A: Reference Summaries

Asbridge M, Hayden JA, & Cartwright JL (2012). Acute cannabis consumption and motor vehicle collision risk: systematic review of observation studies and meta-analysis. *British Medical Journal*. **344**:e536.

> This systematic review and meta-analysis of nine studies (selected from a pool of just under 3,000 studies) regarding motor vehicle crash risk resulting from driver consumption of cannabis found that driving under the influence of THC was associated with roughly a doubled risk of crashing compared to controls (OR=1.92, 1.35-2.73). These studies included cohort designs, case-control designs, and cross-sectional designs.

Baraona E, Abittan CS, Dohmen K, Moretti M, Pozzato G, Chayes ZW, Shaefer C, & Lieber CS (2001). Gender differences in pharmacokinetics of alcohol. *Alcoholism: Clinical and Experimental Research*. **25**:502-507.

> This study investigated the possible source of gender differences in alcohol metabolism. It is known that "for an equal alcohol intake, women develop higher blood alcohol levels than men" and that women demonstrate "a faster rate of ethanol elimination" (502). One hour after a 'standard fatty meal' 22 male and 23 female subjects were randomly given, either orally (10% solution) or intravenously (5% solution), an alcohol dose of 300 mg/kg body weight.

Biecheler M-B, Peytavin J-F, the SAM Group, Facy F, & Martineau H (2008). SAM survey on "drugs in fatal accidents": search of substances consumed and comparison between drivers involved under the influence of alcohol or cannabis. *Traffic Injury Prevention*. **9**:11-21.

> To estimate the added culpability risk of combining alcohol with THC, this study relied on complete and accurate alcohol and drug data, as required by law, for all drivers involved in French fatal crashes. Culpability analysis and calculation of odds ratios revealed that culpable drivers (cases) were 2.3 times more likely (than controls) to have blood-THC at levels above 1 ng/mL, 9.4 times more likely to have a BAC of 0.05 or higher, and 14.1 times more likely to have combined THC with alcohol.

Compton (2017). Marijuana-Impaired Driving – A Report to Congress. U.S. Department of Transportation, Washington D.C. Report Number DOT HS 812 440.

> This report was prepared in response to a federal requirement directing the U.S. DOT to examine issues related to marijuana-impaired driving, provide a report to Congress, and in the report provide recommendations.

Desrosiers NA, Ramaekers JG, Chauchard E, Gorelick DA, & Huestis MA (2015). Smoked cannabis' psychomotor and neurocognitive effects in occasional and frequent smokers. *Journal of Analytical Toxicology*. **39**:251-261.

> This study compared tolerance to cannabis intoxication among frequent and infrequent users, as measured in laboratory and simulator testing of critical tracking (CT), divided attention (DA), and working memory (WK). Authors found 'significantly impaired psychomotor function' as late as 3.5 hours after smoking, especially for infrequent users but for frequent users as well (p. 256).

CT and DA were particularly comprised in infrequent users during the initial hour post-smoking. Minimal impact was found on WM. Overall, results confirm significant tolerance in frequent users compared to infrequent ones.

Drummer OH, Gerostamoulos J, Batziris H, Chu M, Caplehorn J, Robertson MD, & Swann P (2004). The involvement of drugs in drivers of motor vehicles killed in Australian road traffic crashes. *Accident Analysis and Prevention*. **36**:239-248.

This study of 3,398 drivers killed in Australian road crashes conducted a culpability review (see Robertson and Drummer, 1994, for a description of this procedure) and then determined the odds-ratios of finding drugs and alcohol in the blood of culpable versus non-culpable drivers.

Hartman RL, Brown TL, Milavetz G, Spurgin A, Pierce RS, Gorelick DA, Gaffney G, & Huestis MA (2015a). Cannabis effects on driving lateral control with and without alcohol. *Drug and Alcohol Dependence.***154**:25-37.

This study investigated the impact of THC on one measure of driver lateral control (SDLP) at various blood levels instead of as a dose-response effect (as in many earlier studies). At a THC blood-level of 8.2 ng/mL the authors found a substantial increase in SDLP, roughly equivalent to that observed among subjects testing at the 0.05% Breath Alcohol Concentration (BrAC) level. Combining 5 ng/mL THC with 0.05% BrAC produced SDLP increases similar to those with a BrAC of 0.08%.

Hartman RL, Brown TL, Milavetz G, Spurgin A, Gorelick DA, Gaffney G, & Huestis MA (2015b). Controlled cannabis vaporizer administration: blood and plasma cannabinoids with and without alcohol. *Clinical Chemistry.***61**:850-869.

This study scrutinized blood and plasma cannabinoid level changes in 32 adult cannabis users (≥1/every 3 months) who inhaled vaporized placebo, low-dose, or high-dose cannabis 10 minutes after drinking placebo or low-dose alcohol (0.065% peak breath alcohol). The study found that adding doses of alcohol to THC-positive subjects increases levels of 11-OH-THC, the very potent psychoactive metabolite which is intermediate between THC and carboxy-THC.

Hartman RL & Huestis MA (2013). Cannabis effects on driving skills. *Clinical Chemistry*. **59**:478-492.

This is a comprehensive review of results from epidemiologic, culpability, case-control, laboratory, and driving-simulator studies regarding the impacts of THC on human performance.

Holcomb, RL (1938). Alcohol in relation to traffic accidents. *Journal of the American Medical Association*. **111**:1076-1085.

The author's investigation represents the first case-control study of the relationship between alcohol levels and crash risk.

Li M-C, Brady JE, DiMaggio CH, Lusardi AR, Tzong KY, & Li G (2012). Marijuana use and motor vehicle crashes. *Epidemiologic Reviews*. **34**:65-72.

This systematic review and meta-analysis of nine studies (selected from a pool of just under 3,000 studies) regarding motor vehicle crash risk resulting from driver consumption of cannabis

found that driving under the influence of THC was associated with roughly a doubled risk of crashing compared to controls (OR=2.66). These studies included cohort designs, case-control designs, and cross-sectional designs.

Longo M, Hunter CE, Lokan R, White JM, & White MA (2000). The prevalence of alcohol, cannabinoids, benzodiazepines and stimulants among injured drivers and their role in driver culpability. Part2: the relationship between drug prevalence and drug concentration, and driver culpability. *Accident Analysis and Prevention*. **32**: 623-632.

This culpability study of 2,500 drivers injured in Australian crashes found that drivers testing positive for THC (up to 2 ng/mL) had a lower odds ratio (OR) of being culpable than drug-free drivers. Drivers with THC levels of 2.1 ng/mL and above showed an OR of 1.8. Alcohol-only drivers had a culpability OR of 4.8, whereas drivers who combined THC with alcohol showed an OR of 6.2. Thus, the low culpability of THC-only drivers was greatly inflated by the presence of alcohol.

Mura P, Kintz P, Ludes B, Gaulier JM, Marquet P, Martin-Dupont S, Vincent F, Kaddour A, Goullé JP, Nouveau J, Moulsma M, Tilhet-Coartet S, & Pourrat O (2003). Comparison of the prevalence of alcohol, cannabis and other drugs between 900 injured drivers and 900 control subjects: results of a French collaborative study. *Forensic Science International*. **133**:79-85.

This case-control study examined drivers $\geq$ 18 years of age treated in emergency rooms (ERs) in France. Cases consisted of 321 drivers ages 18-27 admitted to ERs with non-fatal crash injuries and controls consisted of licensed drivers (also ages 18-27) admitted to ERs with non-fatal injuries sustained for other causes. The blood of both cases and controls were tested for THC (>1 ng/mg) and alcohol (>.05 mg/L).

Peck RC, Gebers MA, Voas RB, & Romano E (2008). The relationship between blood alcohol concentration (BAC), age, and crash risk. *Journal of Safety Research*. **39**:311-319.

This study reanalyzed data originally collected and reported in the 2005 Long Beach-Fort Lauderdale study of crash risk arising from different levels of driver alcohol impairment at different BAC levels. The authors used conditional logistic regression analysis, a method sensitive to variable interactions, in this specific case to that between age and BAC in producing crash risk. Notably, the study found that drivers under age 21 with a BAC of 0.08 are 4.5 times more likely to crash than drivers ages 21 and over at the same BAC level. That risk ratio increases to 9.6 for a BAC of 0.12 – and to 20.3 at 0.16.

Pulido J, Barrio G, Lardelli P, Bravo MJ, Espelt MTBA, & De la Fuente L (2011). Cannabis use and traffic injuries. *Epidemiology.* 22:609-610.

This study recruited subjects from a population of young regular cocaine users in three large Spanish cities. The authors obtained baseline data and follow-up questionnaires for a sample of 503 subjects. For their cannabis study, researchers used a case-crossover design to examine the relationship between driver cannabis intoxication and the risk of a traffic-related injury during the two hours after use. The “self-matching” feature of this study design offered “complete adjustment for all confounders that remain stable over time," such as personality traits, driving ability, physical limitations, or the presence of other drugs. Thus, this design represented an improvement over earlier observational studies that were only partly successful in controlling for confounders. The 68 subjects who reported sustaining injuries after driving a motor vehicle became the core subjects for this study. The results showed a relative-risk (RR) of 5.8 during the first hour after cannabis use among subjects who had ingested cannabis but were free of other drugs or alcohol (compared to the control period for the same drivers, in which they were free of all psychoactive substances), which rose to 10.9 for subjects who had ingested alcohol as well as cannabis. The RR for both groups dropped to 2.2 and 1.9, respectively, during the second hour of this study. Thus, combining alcohol with cannabis resulted in an 88 percent increase in the risk of sustaining an injury while driving.

Ramaekers JG, Theunissen EL, De Brouwer M, Toennes SW, Moeller MR, & Kauert G (2011). Tolerance and cross-tolerance to neurocognitive effects of THC and alcohol in heavy cannabis users. *Psychopharmacology*. **214**:391-401.

This double-blind, placebo-controlled study investigated the hypothesis, based largely on numerous animal studies, that heavy cannabis users develop cross-tolerance to the impairing effects of alcohol. The authors administered critical tracking (CT), divided attention (DA), stop-signal (SS), and Tower of London (CF) tests to 21 daily cannabis users over a seven-hour period, during which the subjects drank alcohol in placebo, low-level, and high-level concentrations. The authors hypothesized, based on animal testing data, that cannabis users who are highly tolerant to the effects of THC may also be cross-tolerant to the effects of alcohol. However, while the study found that THC generally did not affect neurocognitive performance in heavy users, alcohol strongly affected it. Moreover, combining alcohol with THC resulted in diminished performance on DA test compared to alcohol alone conditions.

Ramaekers JG, Kauert G, van Ruitenbeek P, Theunissen EL, Toennes SW, & Moeller MR (2009). Neurocognitive performance during acute THC intoxication in heavy and occasional cannabis users. *Journal of Psychopharmacology*.**23**:266-277.

This study used a double-blind, placebo-controlled, mixed-model design to quantify the relationship between tolerance (in experienced users) to THC and the apparent reduction in the observed degree of performance deficit. It also confirmed that THC alone generated performance deficits for occasional users in critical tracking, divided attention capability, reaction time, and cognitive function. By contrast, neither CT nor DA capabilities were compromised by the same doses in heavy users.

Ramaekers JG, Berghaus G, van Laar M, & Drummer OH (2004). Dose related risk of motor vehicle crashes after cannabis use. *Drug and Alcohol Dependence*.**73**:109-119.

This study reviewed earlier studies and found that all those relying on carboxy-THC as a measure of driver impairment (e.g., based on urine-testing) found odds-ratios of about 1.0 and below, thereby driving the erroneous conclusion that cannabis is not impairing.

Ramaekers JG, Robbe HWJ, & O'Hanlon JF (2000). Marijuana, alcohol, and actual driving performance. *Human Psychopharmacology*. **15**:551-558.

> In this study the authors tested 18 participants (9 males and 9 females between 20 and 28 years of age in six different THC and alcohol conditions. The study found that alcohol and THC alone caused significant SDLP increases, though the size of the deficit caused by THC was much than that created by alcohol. Moreover, combining THC and alcohol led to a 'severe' loss of critical tracking ability. Combining low-levels of THC with alcohol sufficient to create a BAC 0.05 led to impairment deficits generally observed in drivers with a BAC level of 0.09%.

Ramirez A, Berning, A, Carr K, Scherer M, Lacey JH, Kelley-Baker, T, & Fisher DA (2016). Marijuana, other drugs, and alcohol use by drivers in Washington State (Report No. DOT HS 812 299). Washington, DC: National Highway Traffic Safety Administration.

> National roadside surveys have been conducted nearly every decade since the 1970s. The Washington State roadside study used a similar research design and tested biological samples for more than 70 over-the-counter, prescription, and illegal drugs that may impair driving. The main objective of this study was to examine whether the percent of drivers positive for marijuana increased after sales of the drug became available in July 2014. The study found a statistically significantly increase in daytime prevalence of THC-positive drivers between the six months prior to retail sales (7.8 percent) and the 12 months following retail sales (18.9 percent).

Robertson MD & Drummer OH (1994). Responsibility analysis: a methodology to study the effects of drugs in driving. *Accident Analysis and Prevention*. **26**:243-247.

> The authors describe a formal method for assigning responsibility (often called culpability in more recent studies) to drivers involved in injury and fatality crashes through a close examination of eight separate factors involved (including mitigating ones). This particular study is based on the assumption that "if drugs are contributing to accident causation, it would be expected that they would be overrepresented in the culpable or responsible group" (243).

Appendix B: Roadside Survey Self-Report Marijuana Survey

The following questions ask about marijuana, driving, and laws regarding marijuana. In this voluntary survey when we say "marijuana" we are including cannabis and hashish as well as any product that has marijuana in it (including foods and beverages). When we ask about "using" marijuana we include smoking, eating, or any other way you might consume or ingest it. All your answers are anonymous and confidential. This survey is for research purposes only. You may skip any question and stop participating at any time.

1. **Have you ever, even once, used marijuana?**

   ☐ Yes ☐ No ☐ Decline to answer

   If Yes, when did you first use marijuana?

   ______ Age ☐ Decline to answer

   (If No or **Decline to answer,** please **skip to item #10**)

2. **How long has it been since you last used marijuana?**

   ☐ Past 24 hours → **see "If past 24 hours" below**
   ☐ Past week
   ☐ Past month
   ☐ Past year
   ☐ More than 12 months → **Skip to item #8**
   ☐ Decline to answer

   If in the past 24 hours – If used in the past day, how recently did you use?

   ☐ Within the past ½ hour (30 minutes)
   ☐ Within the past hour
   ☐ Within the past 2 hours
   ☐ Within the past 3 hours
   ☐ Within the past 4 hours or more
   ☐ Did not use within the past day

3. **How often do you currently use marijuana?**

   ☐ Everyday → **see "If every day" below**
   ☐ 5 or more times a week
   ☐ 3-4 times a week
   ☐ 2 or less times a week
   ☐ 4 times or less a month
   ☐ 12 times or less a year
   ☐ Once a year or less → **Skip to item #8**
   ☐ Decline to answer

   If every day, on days you use marijuana, about how many times a day do you use it? (select one)

   ☐ Once per day
   ☐ 2-3 times per day
   ☐ More than 3 times per day
   ☐ Decline to answer

4. **In the past year, have you used any marijuana within two hours before driving?**
   ☐ Yes
   ☐ No → **Skip to item#7**
   ☐ Decline to answer
5. **When you used marijuana and drove, how do you think it affected your driving?**
   ☐ Made my driving better
   ☐ Made my driving worse
   ☐ Didn't make any difference in my driving
   ☐ I don't know
   ☐ Decline to answer
6. **Have you used any marijuana TODAY that you think may affect your driving?**
   ☐ Yes ☐ No ☐ Decline to answer
7. **Have you ever NOT driven because you had recently used marijuana?**
   ☐ Yes ☐ No ☐ Decline to answer
8. **How do you usually get your marijuana?**
   ☐ Licensed distributor/retailer ☐ Other: ________ ___________
   ☐ Grow my own
   ☐ Friend ☐ Decline to answer
9. **Where was the last place you used marijuana?**
   ☐ My home ☐ Car
   ☐ Friends home ☐ Other __________________
   ☐ School/Dorm ☐ Don't remember
   ☐ Bar/Club ☐ Declined to answer
   ☐ Park/Other public place
10. **Are you currently authorized /licensed to purchase medical marijuana?**
   ☐ Yes ☐ No ☐ Decline to answer

   If Yes, have you used your authorization /license to purchase marijuana?
   ☐ Yes ☐ No ☐ Decline to answer

   If Yes, you are authorized/ licensed, what year did you receive your permit?
   Year: ____________ ☐ Decline to answer
11. **How likely do you think it is that marijuana impairs a person's ability to drive safely if used within two hours of driving?**
   ☐ Very likely ☐ Not at all likely
   ☐ Likely ☐ Decline to answer
   ☐ Somewhat likely
12. **How likely do you think it is that a person could be arrested for impaired driving after using marijuana within two hours of driving?**
   ☐ Very likely ☐ Not at all likely
   ☐ Likely ☐ Decline to answer
   ☐ Somewhat likely

Appendix C: Post-stratification Weighting Methodology

The Washington roadside survey followed the same sampling method from the 2007 and 2013-2014 National Roadside Surveys. The sampling procedure is a multistage sampling strategy employing four nested sampling frames:

- Primary Sampling Units (PSUs) = 6 of 39 counties selected
- Random selection of 1-mile^2 grids = 30 grids per county selected
- Semi-random selection of survey sites within grids (1 site per grid, 1 site per PSU) = 6 sites
- Random selection of vehicles at the survey site

The above method was used across all three waves. Some sites were used between different waves, but not all. At each of the six sites, five two-hour data collection periods commenced during each wave.

From the roadside survey data provided by NHTSA and PIRE, every observation within a specified site/time had the same weight, indicating the weight as a design (site-level) weight rather than a respondent (person-level) weight. The 2007 NRS methodology identifies PSU population density, number of fatal crashes, number of injury crashes, and select socioeconomic conditions as site selection factors. It is unclear based on the available materials if these factors are also used in deriving the design weights, or if the design weights are just simply selection probabilities based on total PSUs and total observed vehicle counts during data collection. As reported in the 2007 NRS Drug Results report, the probability of selection within each of the four nested sampling frames was known; therefore the weight was the inverse of the product of the four probabilities.

Assuming the Washington roadside survey weights are also the inverse of the product of the four sampling probabilities, then a post-stratification adjustment based on the licensed driver population by age and gender may increase the representativeness of the sample to the Washington licensed driver population for the self-report survey analysis.

Licensed Driver Population information was provided by the Department of Licensing (DOL) for calendar year 2014 and included counts by age, gender and county. The driver and passenger demographic data was initially grouped by age using self-reported driver age. However, 98 records were missing self-reported driver age, therefore age was regrouped to follow the categorization of the surveyor-reported age groups (five age groups). Self-reported age was used first, and if missing then the surveyor-reported age group was used. For records missing both the age variables, age was considered UNK. There were 16 records missing either gender, or both age variables. Since there were only 16 records out of 2,532 missing the post-stratification age/gender information, the adjustment factor was set to one, which resulted in no adjustment to the design weight for these records.

Using the DOL information, licensed driver population proportions by age and gender were derived. These proportions are shown in the table below.

<table>
<tr><td colspan="4">Weight Adjustment DOL Driving Population Proportions by Age/Gender Groupings</td></tr>
<tr><td></td><td>Male</td><td>Female</td><td>UNK</td></tr>
<tr><td>16-20</td><td>0.026486</td><td>0.025693</td><td rowspan="5">Equal to sample proportion (post-strat adjustment = 1, no adjustment to design weight)</td></tr>
<tr><td>21-34</td><td>0.135495</td><td>0.122655</td></tr>
<tr><td>35-50</td><td>0.149209</td><td>0.134749</td></tr>
<tr><td>51-64</td><td>0.122566</td><td>0.1183</td></tr>
<tr><td>65+</td><td>0.082862</td><td>0.081986</td></tr>
<tr><td>UNK</td><td colspan="3">Equal to sample proportion (post-strat adjustment = 1, no adjustment to design weight)</td></tr>
</table>

Sample proportions by the above age and gender categories were also derived. The post-stratification (PS) weighting adjustment was calculated by dividing the DOL population age/gender proportion by the sample age/gender proportion. This result was multiplied by the design weight to derive the new post-stratification weights for self-report survey analysis.

$$PS_{Weight} = \left(\frac{Proportion_{Population}}{Proportion_{Sample}}\right) * Design_{Weight}$$