WASHINGTON
Traffic Safety
COMMISSION

The Role of THC and Other Intoxicants in Fatal Crashes in Washington State

Report Prepared by:

Mary Stohr, Ph.D.
Youngki Woo, ABD Ph.D.
Dale Willits, Ph.D.
Craig Hemmens, Ph.D.

Department of Criminal Justice and Criminology
Washington State University

WTSC Report Number 2017-AG-1484

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
01/22/2018	Final Project Report	Oct. 2017 - Dec. 2018

4. TITLE AND SUBTITLE

The Role of THC and Other Intoxicants in Fatal Crashes in Washington State.

5a. CONTRACT NUMBER
2017-AG-1484

5b. GRANT NUMBER
2017-AG-1484

5c. PROGRAM ELEMENT NUMBER
n/a

6. AUTHOR(S)

Stohr, Mary, Ph.D., Woo, Youngki, ABD Ph.D., Willits, Dale, Ph.D., Hemmens, Craig, Ph.D.

5d. PROJECT NUMBER
n/a

5e. TASK NUMBER
n/a

5f. WORK UNIT NUMBER
n/a

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Washington State University
Department of Criminal Justice and Criminology
Pullman, WA

8. PERFORMING ORGANIZATION REPORT NUMBER
n/a

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Washington Traffic Safety Commission
Olympia, WA

10. SPONSOR/MONITOR'S ACRONYM(S)
WTSC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
2017-AG-1484

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release.

13. SUPPLEMENTARY NOTES
The contents of the manuscript are solely the responsibility of the authors and do not necessarily reflect the official views of the funding agency.

14. ABSTRACT

The current study employs the use of Washington State Fatality Analysis Reporting System Analytical File (WA FARS) data from 2008 to 2016 to examine the effect of cannabis involvement in fatal crashes. Of particular interest is the link between delta-9-Tetrahydrocannabinols (THC) and drivers' culpabilities and fatalities, contextual conditions of the fatal crash, and collision type. The study employs the two separate types of quantitative analyses -- logit and propensity score modeling (PSM) -- and qualitative analyses of case files.

15. SUBJECT TERMS

cannabis, marijuana, THC, fatal crashes, Washington state, culpability, propensity score modeling, logit modeling, speeding, driver errors

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Staci Hoff, Ph.D., WTSC Research Director
					19b. TELEPHONE NUMBER *(Include area code)*
None	None	None	None	59	(360) 725-9874

Final Report

The Role of THC and Other Intoxicants in Fatal Crashes in Washington State

Mary K. Stohr, Ph.D.
Principal Investigator

Youngki Woo, ABD
Co-Principal Investigator

Dale Willits, Ph.D.
Co-Principal Investigator

Craig Hemmens, J.D., Ph.D.
Co-Principal Investigator

Department of Criminal Justice and Criminology
Washington State University

This research was supported in part by the Washington Traffic Safety Commission (Grant-1484: The Role of THC and Other Intoxicants on Traffic Crashes in Washington State). The contents of the manuscript are solely the responsibility of the authors and do not necessarily reflect the official views of the funding agency.

The Role of THC and Other Intoxicants in Fatal Crashes in Washington State

Abstract

Legalization of cannabis in Washington State has led to increased use and the consequent likelihood of more intoxicated drivers. The current study employs the use of Washington State Fatality Analysis Reporting System Analytical File (WA FARS) data from 2008 to 2016 to examine the effect of cannabis involvement in fatal crashes. Of particular interest is the link between delta-9-Tetrahydrocannabinols (THC) and drivers' culpabilities and fatalities, contextual conditions of the fatal crash, and collision type. The study employs the two separate types of quantitative analyses -- logit and propensity score modeling (PSM) -- and qualitative analyses of case files. The quantitative results are mixed as the main effects and the three interaction models indicate that delta-9-THC positively and significantly predicted speeding, but negatively predicted driver errors. Only carboxy-THC consistently predicted speeding and driver errors. PSM in part confirmed these findings in that compared to clean drivers, drivers with the presence of THC only were significantly more likely to engage in speeding, but not driver errors. In addition, drivers with the presence of both alcohol and THC were significantly more likely to commit driver errors and engage in speeding than clean drivers. The qualitative crash report analysis indicates that there is a moderately strong relationship between culpability and these fatal crashes for those drivers who tested positive for delta-9-THC. These results suggest, as some portions of the logit and PSM analyses did, that marijuana consumption may be associated with fatal crashes.

FINAL REPORT

The Role of THC and Other Intoxicants

in Fatal Crashes in Washington State

SECTION 1: INTRODUCTION

History

In 1998 Washington voters approved a medical marijuana law (I-692) and in 2003 in Seattle and in 2011 in Tacoma, two of Washington's most populous cities, voters passed initiatives that required that officers regard possession of marijuana as a low priority for enforcement. Upon its passage in 2012, the citizen-sponsored initiative, I-502, in Washington mandated that the state would "license and regulate marijuana production, distribution, and possession for persons over twenty-one; remove state-law criminal and civil penalties for activities that it authorizes; tax marijuana sales; and earmark marijuana-related revenues." Commercialization of cannabis sales did not occur until July 2014, however. Among other concerns regarding these initiatives and commercialization, opponents worried that it would heighten marijuana or cannabis use by minors and would increase the incidence of drug-impaired driving (Ellison, 2012). Although alcohol-related DUIs remain the most prevalent, the number of people engaged in drugged driving is reportedly increasing in some states such as Washington.

Traffic Crashes

In 2015 there were 35,092 motor-vehicle deaths in the United States (the latest figures available from the National Highway Traffic Safety Administration [NHTSA], 2016a, p. 2). NHTSA estimates that about 29% of these fatalities involved alcohol impaired driving (they provide no figures estimating any involvement of marijuana in this report) (NHTSA, 2016b, p.10). Alcohol impaired drivers are defined by NHTSA as those who have a .08 grams per deciliter (g/dL) or higher blood alcohol concentration (BAC), though the mere fact of such impairment does not mean it was the cause of the

crash or fatality. However, in 63% of the crashes with a fatality involving alcohol, at least one driver had a BAC of .08 or higher (NHTSA, 2016c, p. 1). The cost of these deaths in 2015, coupled with injuries and property damage from motor-vehicle crashes, is estimated to be $412 billion for victims and communities (National Safety Council, 2016, p. 1).

Despite the seriousness of these incidents the 2015 figure of 35,092 represents an absolute decrease from nine years previously (2006, 42,708). Moreover, there has been a fatality rate decrease (per 100,000 licensed drivers) from 23.21 in 1994 to 15.26 in 2014 (the 2015 figures represent a 7% increase over 2014, however) (NHTSA, 2015, p. 1; NHTSA, 2016, p. 1).

THC, Traffic Crashes and the Difficulties Associated with Testing

The difficulty in determining whether drivers are THC-positive is that in many cases where the driver in a crash is suspected of being drug impaired he/she is not tested or tested soon enough to be deemed so by per se law. There are currently no breathalyzers or other technology available for the ready and inexpensive testing for the presence of THC at roadside– though there are a few in development around the country -- and that means that many drivers involved in a crash who are suspected of THC impairment may not be tested for it (Lovrich, Christensen & Routh, 2016); Doing so would require attainment of a search warrant to do a blood test by a skilled professional either at a local jail or at a medical facility.

Even in the case of fatalities, drug and alcohol tests may not be administered. For instance, in preliminary research on this latter point by the Washington Traffic Safety Commission over five years (2010-2014) the researchers determined that of the 2,926 drivers involved in fatal crashes, only 60.6% were tested for both alcohol and drugs (WTSC, 2016, p. 2). They also found that "the frequency of drivers in fatal crashes that tested positive for THC alone or in combination with alcohol or other drugs was highest in 2014 (75 drivers) compared to the previous four year average (36 drivers)"(WTSC, 2014, p. 2). In contrast, "the frequency of drivers with alcohol greater than/equal to BAC .08 and no other drugs was lowest in 2014 (51 drivers) compared to the previous four year average (98 drivers)."

This Study

The objective of the current study is to use a mixed-methods approach to examine the causal relationship between Tetrahydrocannabinols (THC) and fatal crash incidents in the State of Washington. The data for this project come from the Washington State Fatality Analysis Reporting System (WA FARS), which includes detailed toxicology outcomes for drivers blood tested for intoxicants. For the quantitative aspects of the project, we examined 2008-2016 FARS data which has been previously coded and quantified by the Washington Traffic Safety Commission (WTSC). The WTSC has previously used most of this data (2010-2014) in a descriptive report on the involvement of marijuana in fatal crashes (WTSC, 2016C, 2016). We extended the original analysis in the current project utilizing a variety of techniques designed to better address causal inference. We also analyzed three study outcomes -- 1) drivers' culpability; 2) driver fatalities, and; (3) contextual circumstances of fatal crashes – to determine if the presence of THC had any effect on the crash outcomes.

Our findings indicate that there is reason to be concerned about the use of THC by drivers in Washington State. In both of the quantitative analyses we conducted for this study we found that the presence of THC in drivers involved in fatal crashes was associated with speeding (though not necessarily driver errors) and the qualitative analyses of the crash report yielded a moderately strong relationship between culpability and these fatal crashes for those drivers who tested positive for delta-9-THC. However, we cannot determine with these data, or any data, if the use of THC by drivers has increased post legalization.

SECTION 2: LITERATURE REVIEW

Marijuana Use by Drivers

Of illicit drugs in the United States cannabis is consumed most (Washington Traffic Safety Commission, 2016). It is also one of the most common of non-alcoholic drugs to be detected in drivers involved in fatal and nonfatal crashes nationally and internationally (Brady & Li, 2012; 2014; Farrell, Kerrigan, and Logan 2007, 2013; Romano & Pollini, 2013; Washington Traffic Safety Commission, 2016; Woratanarata et al., 2009). Though this is not always true internationally (Zhuo, Cang, Yan, Bu,

Shen, 2010). In a study of drivers in fatal crashes from 1999-2010, Brady and Li (2014, p. 1) found that the prevalence of cannabinol in drug tests almost tripled from 4.2% in 1999 to 12.2% in 2010. Dubois, Mullen, Weaver and Bedard (2015, p. 94) noted after studying fatal crashes and alcohol and cannabis that "Over the past two decades, the prevalence of THC and alcohol in car drivers involved in a fatal crash has increased approximately five-fold from below 2% in 1991 to above 10% in 2008." Research on high school seniors would confirm such increases as it has been found that increased prevalence of use of cannabis was not detected in a study of high school seniors use in the early half of the 2000s, but was in the latter half (O'Malley & Johnson 2007; O'Malley & Johnson, 2013).

The Meta-Analyses: Cannabis, Driving, Fatalities and Crashes

In a meta-analytic study of the effect of alcohol, marijuana and alcohol and marijuana on traffic fatalities, Bates and Blakely (1999) found that alcohol intake increased fatalities in all studies, the combination of cannabis and alcohol increased the likelihood of a fatal crash, but not to a great degree, but the *presence of cannabis in the drivers did not increase the odds of a fatal crash in most studies.* The authors admit that the latter finding may be related to the *inclusion of drivers with only carboxy-THC* in their blood, or drivers who had ingested cannabis but whose *psychoactive effects had worn off*, in some of the studies.

Surveys that established recent use of cannabis by directly measuring THC in blood showed that THC positives, particularly at higher doses, are about three to seven times more likely to be responsible for their crash as compared to drivers that had not used drugs or alcohol. Together these epidemiological data suggests that recent use of cannabis may increase crash risk, whereas past use of cannabis does not (Ramaekers, Berghaus, van Laar, Drummer, 2004, p. 109).

Two meta-studies reached similar conclusions regarding the motor vehicle crash risk presented by THC. In a meta-analysis involving nine studies the researchers found that driving under the influence of cannabis was associated with greater odds of crashes and fatalities (Asbridge, Hayden & Carwright, 2012). Similarly, in a meta-analysis of nine studies another set of researchers (Li, Brady, DiMaggio, Lusardi, Tzong & Li, 2012) also found that marijuana use as measured by presence of THC in the urine or blood, based on self-reporting of use, significantly increased the risk that a driver would be involved

in a motor vehicle crash. While the study by Li and his colleagues (2012) included data from studies that relied either on urine or blood samples confirming the presence of carboxy-THC alone, the meta-analysis by Asbridge and his colleagues (2012) included data from studies that only relied on blood samples confirming the presence of active metabolites of THC (Washington Traffic Safety Commission, 2016). After a meta-analysis including the re-analysis of other meta-analysis, and involving 21 observational studies, Rogeberg and Elvik (2016, p. 1348) found that "Acute cannabis intoxication is associated with a statistically significant increase in motor vehicle crash risk. The increase is of low to medium magnitude."

Other Studies of the Cannabis Effect on Driving

In a study of drug use and fatal crash assessment in the United States the researchers found that the presence of cannabis in the blood increased the odds of a fatal crash, but less so than other drugs categories assessed (i.e. narcotics, stimulants, depressants) (Li, Brady & Chen, 2013). They also found that the combination of drugs and alcohol was the most lethal in terms of fatalities.

In a double-blind and placebo-controlled driving simulator study of younger drivers impaired by different levels of alcohol and THC, the researchers found that performance was most impaired when drivers had imbibed both alcohol and THC (Downey, King, Papafotiou, Swann, Ogden, Boorman & Stough, 2013). They also noted that THC is higher in the blood when consumed with alcohol and that regular THC consumers were most impaired in their driving and had higher THC levels in their blood. Once again the most dangerous combination in these and other studies as far as car crashes and fatalities went was that of alcohol and cannabis or other drugs (e.g. see Gjerde, Christophersen, Normann, & Mørland, 2011; Gjerde, Normann, Christophersen, Samuelsen & Mørland, 2011).

In a study of French injured drivers and their controls in 2000-2001 the presence of alcohol and THC singly was much higher among the injured drivers, but the difference was not statistically significant for THC (Mura et al., 2003). When this study was repeated three years later the researchers found a marked increase in the presence of cannabinoids in drivers less than 30 years old (in the blood of 39% of the drivers) (Mura et al., 2006). In a Swedish study of drivers involved in crashes and their controls, the presence of cannabis alone in the blood or urine of the driver again was not determined to

increase the odds of motor vehicle crashes, though the presence of alcohol and multiple drugs was more likely to increase those odds (Movig et al., 2004).

Marijuana use might be associated with other types of injuries, however. In a study of injuries resulting in hospitalizations, Gerberich, Sidney, Braun, Tekawa, Tolen & Guesenberry (2003) found that marijuana use is associated with a greater number of such injuries.

Cannabinoid Prevalence in Crashes after Medical Marijuana Legalization

In a time series analysis of 12 U.S. states' fatal crash data (1992-2009) pre and post medical marijuana legalization Masten and Guenzburger (2014) found that increases were detected in only three states: California, Hawaii and Washington. Moreover, these increases occurred only one time rather than represented a trend. The researchers speculated that this finding indicated that the drug was reaching the population of patients it was intended for and was not having the effect of increasing the number of new users. The researchers recommend some standardization in drug testing nationally to ensure that assessments of use and involvement in crashes are valid; as they admit that these findings could be skewed by the variability of testing between and among the states over time. Notably, they found that only about 25% of drivers who were fatally-injured in motor vehicle crashes from 1992-2009 were tested for drugs (Masten & Guenzburger, 2014, p. 39).

In a separate study of fatal crashes pre and post legalization of medical marijuana (1994-2011) in Colorado, Salomonsen-Sautel, Min and Sakai (2014) found that there were increases in marijuana-positive drivers in fatal crashes post legalization. This change in the trend occurred in mid-2009 and since the study only lasted until 2011 it was not clear if it would continue.

In another study of California drivers by Pollini, Romano, Johnson and Lacey (2015) the researchers examined FARS data and roadside surveys post decriminalization of marijuana. They found that the prevalence of use by drivers did not increase generally, but that there was an increase in the presence of cannabinoids in fatally injured drivers.

Finally, in a study by Santella-Tenorio and his colleagues (2016, p. e1) of U.S. traffic fatalities from 1985-2014, pre and post the passage of medical marijuana laws (MML) in some states, the researchers found that MMLs and the presence of dispensaries "were associated with reductions in

traffic fatalities," especially among those 25-44. This association, however, was disrupted at certain time periods in some states indicating some mitigation by state-local factors.

Characteristics of DUI Drivers and Circumstances of Crashes

The research indicates that Driving Under the Influence (DUI) of drugs or alcohol is not an activity reserved for just one age or gender group. According to the latest report by the Substance Abuse Mental Health Services Administration (SAMHSA), who deploys national self-report surveys on drug use and health, DUIs are committed by very young and by very old drivers and by males and females alike. However, they are much more common for younger and male drivers (Lipari, Hughes and Bose, 2016). Based on 2014 data, DUI offenses for alcohol were highest among drivers who were 21 to 29. While DUI for illicit drugs peaked between the ages of 20 and 23 (Lipari et al., 2016, p. 3). For alcohol related DUIs, illicit drug and alcohol and illicit drug drivers, the number of females was about half of the number of males in each of those categories. The female DUI drivers, for the most part, paralleled the males in their age peaks and drop-offs of DUI for alcohol or drugs, though younger males (16-20) were more likely to drive under the influence of illicit drugs and illicit drugs and alcohol than were younger females (Lipari et al., 2016, p. 5).

The SAMSHA researchers had found that DUIs in 2014 were lower than in the early 2000s, but had stabilized and were similar in estimates of percentages for those who had driven under the influence for 2011 through 2013, for both males and females (Lipari, 2016, p. 8). They speculated that prevention messages and preventative steps, especially those that targeted young males may be having an effect in reducing DUIs. However, there is no empirical evidence that one of the most popular anti-drug programs in schools in the United States, the DARE (Drug Abuse Desistance Education) Program that was and still is administered by police officers in schools had any long term effect on attitudes towards, or use of, drugs (e.g. see West and O'Neal, 2004; Pan and Bai, 2009).

Of course, in addition to the characteristics of the driver, the circumstances of the crash are likely to play a role in determining the probability of a crash. For instance, in a comparison study of fatality rates in various states and high-income countries, Kahane (2016) found that younger and less experienced males on a motorcycle, driving on rural roads in warmer climates were more likely to be

involved in a crash than other types of drivers in other types of circumstances. As in the United States, when alcohol is added to this mix, the risk of a crash and injury or death increases sharply (Kahane, 2016; NHTSA, 2016a; Romano & Pollini, 2013). In a review of self-reported dangerous driving (such as risky, aggressive and negative emotional driving), coupled with driving simulator data, and an examination of actual crashes, Richer and Bergeron (2009) found an association between driving under the influence of cannabis and risky driving and negative emotional driving.

In a study involving the use of FARS 1998-2010 data, Romano and Pollini (2013) found that drug involved crashes happened throughout the day, though this depended on the drug class to some extent, but that when alcohol was involved it was more likely that a crash would occur at night. As has been found in other studies, alcohol involved crashes were much more common than those related to drug-impaired driving. Notably a number of states' fatal crashes were excluded from this analysis as they did not meet the criteria that 80% of the fatally injured drivers in single vehicle crashes had a known drug test and died at the scene of the crash (Romano & Pollini, 2013, p. 1431). But of the 16,942 fatal crashes analyzed for this study, they found that younger and male drivers were more likely to have cannabinol prevalence, than others, and cannabinol involved fatal crashes were more likely to occur at night. In a similar analysis of virtually the same data set Brady and Li (2012, p. 104) noted that over half of the fatalities in car crashes in the United States for 2005-2009 involved drivers who had been using alcohol or drugs and that almost 20% had been using poly-drugs (including cannabinols).

Marijuana Perceptions and Use by Youth in Washington and Colorado

Use of marijuana by young drivers is particularly pernicious and is likely to grow in those states such as Washington who have legalized its recreational use (Asbridge, Poulin & Donato, 2005; Fergusson, Horwood, Boden, 2008; Center for the Study of Health and Risk Behavior, 2015). Couple this with the findings in more than one study which indicate that use of cannabis may be increasing by high school seniors. In more than a decade of tracking the use of marijuana by high school seniors in Washington state, through the use of the Healthy Youth Survey from 2004 to 2014, fewer regarded use as a risk, more reported use in the last 30 days and more reported using or being in the car with a driver who had used marijuana (Banta-Green, 2016; Healthy Youth Survey, 2015). The latest report, however,

indicates that use stabilized in 2015 and appeared to decrease slightly by 2016, though the perceived risk from regular use of it by 8th graders decreased and remains low by many Washington state teenagers (Healthy Youth Survey, 2016). Notably 51% of 12th graders who had used cannabis in the last 30 days had also driven within three hours of using at least once (Healthy Youth Survey, 2016, p.1).

Recent research related to this point, however, indicates that in the two states who legalized recreational marijuana first, Washington and Colorado, adolescents' view of the dangerousness of marijuana and increased use varied. Cerda and her colleagues (2016) analyzed data from the national and annual cross-sectional Monitoring the Future survey of students in 8th, 10th, and 12th grades from 2010 to 2015. They found that in Washington perceived harmfulness of marijuana decreased more than in states that did not legalize, after legalization. And that reported use of marijuana increased for 8th and 10th graders before, but even more after, legalization in Washington State, but it decreased in states that did not legalize during this time period. In contrast, Colorado youth did not express statistically significant differences from youth in non-legal states about perceived harmfulness or about usage of marijuana.

The research on alcohol intoxication of drivers has uniformly indicated that intoxication by a driver of a motor vehicle is more likely to result in a crash with injuries or fatalities, than no ingestion of alcohol. However, the effect of cannabis use by drivers on crashes or fatalities is less clear (Bates & Blakely, 1999).

DRE Officers

A determination of intoxication by alcohol and by drugs is first made by officers on the scene of a crash. In each state there are specially trained Drug Recognition Expert or DRE officers who are best equipped to make this determination. The DRE program was established by the National Highway Traffic Safety Administration (NHTSA) in 1988 and is managed by the International Association of Chiefs of Police (IACP). DRE officers are trained to assess the driver, interview witnesses and to review the circumstances of the crash. Their role is critical as they assess the symptoms of any drug or alcohol use and any impairment of the driver (Farrell, Kerrigan, and Logan, 2007; Lovrich et al., 2016). Should they make a determination of drugged driving, a search warrant is applied for and the driver's blood or

urine is then taken to determine the level of their intoxication (whether blood or urine is collected is determined by local statute and law enforcement practice). After a study of DRE impairment exams and cases Hartman and her colleagues (2016) concluded that the blood test in cannabis cases should be administered as quickly as possible and that psychophysical and eye exams were the best cannabis-impairment indicators though the 5 ng/L as an indicator of impairment was a of limited value.

Since passage of I-502 in Washington State virtually all commissioned officers in the Washington State Patrol have received ARIDE (Advanced Roadside Impaired Driving Enforcement) training (Lovrich et al., 2016). The WSP Academy embeds a week of ARIDE training into their training curriculum and includes an explanation of the role that DRE officers have in interacting with regular patrol officers in the assessment of DUI driving.

Per se Requirements

The research on the impairing effect of THC when present in the bloodstream or urine of drivers is not yet fully established in the research or the law (Farrell, Kerrigan, Logan, 2007; Logan et al., 2013; Logan, Kacinko, Beirness, 2016). In a recent state appellate court decision in Arizona the judge ruled that a driver with a medical marijuana card and who had 26.9 ng/ml of the marijuana metabolite THC in his blood when tested after being stopped by the police, could not just be deemed intoxicated or drugged because the medical science about the level of THC needed to impair a driver was not determined in state law or settled among medical practitioners (*Ishak v. McClennen, 2016*). Moreover, as it is known that carboxy-THC lingers in the blood stream days or even weeks after it is ingested, thus delineating a generic level of intoxication is complicated at this juncture (Bates & Blakely, 1999; Farrell, Kerrigan, Logan, 2007).

In a survey of U.S. laboratories involved in the analysis of crash and arrest data, Logan and his colleagues (2013, p. 554) found that there is not yet widespread agreement on the need to test for drugs, including cannabinoids, when the BAC for alcohol impairment exceeds 0.08 g/ 100 mL in the blood or g/210 L in breath as at that point the person is legally impaired and can be charged. Yet not testing leaves a gap in our knowledge the researchers claimed.

In a separate study Logan, Kacinko and Beirness (2016) found that there was not enough evidence to establish thresholds for THC impairment as they found minimal differences in impairment between those with THC concentrations below and above 5.00 ng/mL. They concluded that "a quantitative threshold for *per se* laws for THC following cannabis use cannot be scientifically supported" (Logan et al., 2016, p. 3).

Slater, Castle, Logan and Hingson (2016) examined the FARS data and the testing practices across the states. They too complained that caution needs to be exercised when examining this data as differences in how drugged driving is quantified across jurisdictions and states persist. They argue for standardization and mandatory testing policies. They conclude that more research on drug concentration levels that result in driving skills impairment is needed.

As of May 2016, only five states (Montana, Nevada, Ohio, Pennsylvania and Washington) had set per se limits for THC and among those states the level of intoxication varied from 1.00 ng/mL to 5.00 ng/mL (Capron, 2016, p. 9). In Colorado, the presence of THC in blood above 5ng/ml "gives rise to permissible inference that the defendant was under the influence of one or more drugs" (House Bill 13-1325, p.1-2). Notably, in their survey of 42 laboratories in 24 states, with a 71% return rate, of the extant science on per se limits for cannabinoids, Farrell, Kerrigan, and Logan (2007, p. 1,215) found that the mode was 5.00 ng/mL, but that the range for detection to confirm the presence of the drug in urine or blood is 2-50.00 ng/mL. In *Ishak v. McClennen* the driver, Ishak, had over a 26.00 ng/mL reading.

Capron (2016, p.17-19) lists the difficulties that police and prosecutors face in evidence collection, charging and prosecuting a case involving THC post legalization in Washington state:

- Under 5.00 ng/mL cases, prosecutors must review police video
- Over 5.00 ng/mL cases usually involve more impairment so it is easier to charge
- Many DUI's are resolved by plea agreements when under the per se level even with signs of impairment and poor performance on field sobriety tests
- Exigent circumstances cases are usually thrown out
- Must get a warrant prior to blood draw even though evidence is being lost

- Modified the DRE protocol to obtain the blood draw before the evaluation (evaluation usually takes 1 hour)
- Other certified DRE's forgo the evaluation and just get the blood
- Warrant process had to be sped up given the rapid loss of THC over time
- Possession is the lowest priority and rarely enforced
- Prosecutors office extremely hesitant to charge any marijuana related crimes, except major grow

Washington State Patrol Experience with Legalization

In a recent (2016) analysis of Washington State Patrol data on cannabis and driving by Banta-Green, Rowhani-Rahbar, Ebel, Andris and Qiu, and supported by the AAA Foundation for Traffic Safety, the authors conducted interviews of key actors (law enforcement, prosecutors and toxicology laboratory staff) and examined archival data on DUI arrests, law enforcement staffing and training from 2005 to 2014. They found that the number of troopers with specialized training ("Advanced Roadside Impaired Driving Enforcement") to detect THC impairment by drivers rose from 109 in 2009 to 669 in 2013 (Banta-Green et al., 2016, p. 1). They also noted that after the United State Supreme Court decision *Missouri v. McNeely* in April 2013 that required a warrant for DUI-related blood tests, the number of DUI-related arrests decreased.

In addition, the researchers found that the number of DUI and collisions cases tested by toxicology for THC, and excluding alcohol positive cases, rose from 20 to 30% during this time period; as did the median blood level detected (from 4.00 ng/mL in 2005 to 5.6 ng/mL in 2014) (Banta-Green et al., 2016, p. 2). Among drivers who were involved in a collision and were subsequently tested for THC, 15% came up positive, some along with another substance such as alcohol or another drug. Overall, 7% met or exceeded the *per se* level of THC (Banta-Green, 2016, p. 2). And among those suspected of being drug or alcohol impaired, but not involved in a collision, 37% tested positive for THC only (26% of these) or along with another drug or alcohol (11%) (Banta-Green, 2016, p. 2). Fully 20% of these 37% had a THC level that met or exceeded the *per se* limit of 5.00 ng/mL.

The researchers noted that the median time to draw blood in the THC cases was 139 minutes, but 165 for all cases. Notably, those found to have carboxy-THC in their blood also tended to have longer times to draw it (175 minutes) (Banta-Green, 2016, p. 2). They found that the THC level dropped as much as 5ng/mL per every two hours. Therefore, of those who were tested under 120 minutes, 26% had a THC level that met or exceeded the *per se* limit, whereas of those tested after two hours, only 10% met or exceeded 5.00 ng/mL (Banta-Green, 2016, p.2). The authors concluded, as had Capron (2016), that drawing blood expeditiously in THC suspected DUI cases if one hopes to document drugged driving at or above the *per se* limit is crucial.

These findings indicate that THC-involved driving is relatively common, appears to be increasing and is likely underestimated given the generally protracted time until a blood specimen is obtained. Evaluating the impact of protracted time until blood testing is complicated by the lack of available standardized law enforcement data on the time of testing. These findings highlight the challenges in enforcing drugged driving laws, particularly with a *per se* component, in the absence of point-of-contact testing modalities and in the presence of logistical delays in obtaining blood specimens (Banta-Green et al., 2016, p. 3).

Summary of the Literature

There is extensive research on the involvement of cannabis in drugged driving. Cannabis use alone when recent, and particularly when coupled with alcohol, can impair drivers. In some states, including Washington State, after legalization of medical marijuana in 1998 the presence of cannabinoids in the blood of drivers in fatal crashes increased, though it is not clear if this finding from the late 1990s was a trend or if it reflected the increased propensity to test for THC at the time.

There is recent research that indicates young people in Washington State are less likely to perceive that marijuana use is harmful and they are more likely to use marijuana than in the past. Use of cannabis by high school seniors is up, but has stabilized in recent surveys. Couple these findings with the knowledge that young and male drivers are much more likely to be involved in fatal crashes and are much more likely to be consumers of cannabis and there is reason for concern by policymakers.

There may also be an association between cannabis use and risky and negative emotional driving that is associated with actual crashes. Also studies of traffic crashes indicate that cannabis impaired driving is not restricted just to night time driving, but occurs throughout the day, unlike alcohol impaired driving which is much more common at nighttime.

Several states in reaction to the decriminalization and legalization of medical and recreational marijuana, and because of concerns about increased use and subsequent greater numbers of drugged drivers on the roads, have increased training of DRE officers. But because the *per se* requirements for intoxication are being challenged in courts and by research, the difficulty in establishing legal per se intoxication, even when a DRE officer is present, has increased. Moreover, the search warrant requirement for blood draws tends to delay testing, resulting in reduced chances of validating a DRE officer's determination of drugged driving and greater difficulty in obtaining a DUI prosecution or conviction.

SECTION 3: EVALUATION DESIGN, METHODS AND RESULTS

Analytic Strategy

The objective of the current study is to use a mixed-methods approach to examine the causal relationship between Tetrahydrocannabinols (THC) and fatal crash incidents in the State of Washington. The data for this project come from the Washington State Fatality Analysis Reporting System (WA FARS). For the quantitative aspects of the project, we examined 2008-2016 FARS data which has been previously coded and quantified by the Washington Traffic Safety Commission (WTSC). The WTSC has previously used most of this data (2010-2014) in a descriptive report on the involvement of marijuana in fatal crashes (WTSC, 2016). We extended the original analysis in the current project utilizing a variety of techniques designed to better address causal inference. For the qualitative aspects of this research we systematically coded and analyzed a subset of the original fatal crash reports utilizing a qualitative comparative approach in which the case control comparisons are informed by our quantitative results.

Data Sets

These data from the Washington State Fatality Analysis Reporting System Analytical File (WA FARS) provide information on all fatal crashes in the State of Washington and are organized into person and incident-level records. Unlike the NHTSA FARS, the WA FARS includes specified THC results (delta-9 versus THC metabolites) and blood levels, for all drivers in fatal crashes who were blood tested for drugs. NHTSA FARS can only be used to identify the presence of unspecified cannabinoids and does not include drug levels (Berning & Smither, 2014). The WA FARS also differs from NHTSA FARS in that the latter does not include statistically imputed alcohol results (see Subramanian, 2002).

For the purposes of these analyses, the fatal driver is the unit of analysis and we merge data about the incident with data about the driver. WA FARS data from January 2008 to December 2016 are used, as this is the period of time in which driver THC information is included in the data. This resulted in a total of 10,155 individuals involved in fatal crashes. Among these individuals, 5,931 drivers were involved in fatal crashes, of which 2,421 were blood tested for intoxicants.

First Set of Analyses

Driver Error Outcome Variables

The WA FARS data has information about fatal crashes in Washington State, including fifty-one measures that reflect driver culpabilities, like evidence of speeding, driving errors or fault. Given that many of these individual variables occurred relatively infrequently, these measures were combined into two dichotomous variables representing driver contributing circumstances: 1) speeding and 2) driver errors (identified by police). The first dependent variable, speeding was dichotomous in nature, but the other outcome, driver error, contains several sub-categories. For example, in the driver error variable, there were 34 sub-types of driving errors or fault, such as driving in an erratic reckless or negligent manner, or abrupt speed change, distracted driving, driving on the wrong side, improper lane changing, intentional illegal driving on the road shoulder, failure to yield or obey the signal, overcorrecting, and errors by external conditions (tire blowout, live animals, and cross wind). These measures were dummy coded into a dichotomous variables representing driver error.

Drug and Alcohol Variables

In addition to measures of driver errors, the WA FARS data also includes information on the presence of driver alcohol and drugs. Given that prior research has highlighted the confounded intoxication of combining cannabis and alcohol (Dubois et al., 2015; Hartman et al., 2015; Li et al., 2013), measures of both are included, as well as of other drugs in order to examine whether cannabis has an independent and/or contingent relationship with driver errors. Specifically, two dummy variables were created that indicate whether the driver tested positive for delta-9-THC at less than 5 nanograms per milliliter or 5 or more nanograms per milliliter (the per se limit in Washington state). In addition, a dummy variable measure of carboxy-THC is used in the analysis. carboxy-THC results are included in the drug tests for fatal crashes in Washington and are indicative that a person had consumed cannabis, as carboxy-THC (an inactive ingredient) can stay in the bloodstream for a significantly longer period of time (Desrosiers, Himes, Scheidweiler, Concheiro-Guisan, Gorelick, & Huestis, 2014), with some research suggesting carboxy-THC can be detected up to 30 days after consumption (Washington Traffic Safety Commission, 2016). Given that all delta-9-THC positive drivers, regardless of whether they were above or below the per se limit, also include positive results for carboxy-THC, a modified dummy variable for carboxy-THC was constructed such that it was scored a 1 if only carboxy-THC was positive. Thus, a positive result (either below or above the per se limit) for delta-9-THC indicates recent consumption and potential impairment, while a positive result for carboxy-THC may indicate non-recent consumption, though this depends on the lag in blood draw time.

In order to measure alcohol impairment, two dummy variables indicating whether the driver's blood alcohol content was greater than or equal to .08 (the legal limit in Washington state) or less than .08 were included in the models. In addition, a single dummy variable indicating whether the driver tested positive for other drugs, including narcotics, stimulants, hallucinogens, phencyclidine, inhalants, and other drugs was used as a control variable. As a robustness check, all of the models below were estimated using square root of actual THC and BAC levels. Compared to these results, however, results across all the models using dummy variables were generally better with improved goodness-of-fit of

logistic models. Thus only results from the dummy variables measures of alcohol and THC are presented in this study.

Driver Characteristic Variables

A variety of driver characteristics are included as control variables. Specifically, these include driver's age (in years), gender (where 1 equals male and female is the reference category), whether the driver was licensed (1= licensed, 0 = unlicensed), and prior traffic convictions (including previous DWIs, driver's license suspensions, and speeding conditions). Table 1 presents descriptive statistics for all of the outcome and driver characteristics variables.

TABLE 1. Outcome Measures and Driver Characteristics (N = 5,931)

Variable	Mean/%	SD	Range
Outcome Measures			
Speeding	0.25	0.43	0-1
Errors (identified by police)	0.27	0.45	0-1
Driver Characteristics			
Age (year)	42.4	18.43	9-99
9-15	0.3%		
16-25	23.3%		
26-35	19.0%		
36-45	15.3%		
46-55	16.2%		
56-65	13.4%		
Over 65	12.7%		
Gender (1 = male)	0.75	0.43	0-1
Unlicensed driver	0.13	0.33	0-1
Traffic records (during the previous three years)			
DWIs	0.03	0.17	0-1
Driver license suspensions	0.19	0.39	0-1
Speeding convictions	0.27	0.44	0-1
Other traffic convictions	0.32	0.47	0-1
Drug and Alcohol Involvement			
Alcohol positive			
BAC < .079	0.04	0.18	0-1
BAC > .080	0.19	0.39	0-1
delta-9-THC positive			
THC < 5.00	0.03	0.17	0-1
THC > 5.00	0.04	0.20	0-1
Carboxy THC positive (without delta-9-THC)	0.03	0.18	0-1
Other drugs[b] positive (except for cannabinoid)	0.12	0.33	0-1

Notes: Drivers in fatal crashes in Washington State, 2008-2016. b other drugs include narcotics, depressants, stimulants, hallucinogens, phencyclidine, inhalants, and other unknown forms of drugs.

Environmental and Contextual Variables

In addition to these driver characteristics, the WA FARS data includes a number of factors related to the context of fatal crashes. Given that weather, road, and vehicle conditions might also affect driver errors, measures of these variables are included in the models and crash specific factors as additional control variables. Descriptive statistics for these environmental factors are presented below.

TABLE 2. Environmental Contexts of Fatal Crashes (N = 5,931)

Variable	Mean/%	SD	Range
Natural Conditions			
Weather condition			
Clear	71.8%		
Cloudy	12.9%		
Rain	10.9%		
Fog/smoke	2.2%		
Snow	2.2%		
Time of crash (1 = night: 5 A.M. to 5 P.M.)	0.40	0.49	0-1
Road Conditions			
Road alignment (1 = Straight)	0.70	0.46	0-1
Road grade (1 = Level)	0.66	0.47	0-1
Intersect involved	0.27	0.44	0-1
Surface type			
Concrete	11.0%		
Asphalt	85.8%		
Others (brick, slag, stone, etc.)	3.2%		
Surface condition			
Dry	73.8%		
Wet or Water	20.3%		
Snow or Frost	4.3%		
Others (sand, dirt, mud, oil, etc.)	1.6%		
Speed limit (based on vehicle 1)	46.37	12.67	5-70
Number of traffic lanes in crash	2.46	0.93	1-5
Drivers' Vehicle Conditions			
Vehicle type			
Motorcycle	11.7%		
Medium/heavy truck	5.8%		
Passenger vehicle (sedan, SUV, van, light truck)	80.0%		
Others (bus, motorhome, NR-U etc.)	2.6%		
Other External Conditions			
Number of occupants in vehicle	1.51	0.91	1-5
Number of vehicles in crash	1.81	0.81	1-4
Number of non-motorists in crash	0.13	0.34	0-1
Lap and shoulder belt used	0.62	0.49	0-1
Heavy truck involved	0.11	0.32	0-1
Head-on involved	0.20	0.40	0-1
Traffic control device	0.14	0.35	0-1

Given that each of the outcome variables (speeding and driver errors) are measured dichotomously, a set of three logistic regression models examining main effects are presented, each with robust standard errors. As the WA FARS data includes a number of factors that might be predictive of the outcome variables (see Tables 1 and 2), a stepwise backward selection process was used to select independent variables, based on prior evidence and literature. Specifically, this process began by estimating all three regressions with all independent variables presented in Tables 1 and 2, then independent variables that were not significant at the p value less than .10 were removed, with exceptions made for variables that have previously been found to be associated with fatal crashes, including gender, time of crash, alcohol BAC test positive, and THC/other drugs positive. In order to ensure that this model selection process did not unduly affect our results, these results were compared to the full models, which were substantively similar, though slightly more cumbersome to present (results available upon request).

Next, in order to explore the possibility of an interactive relationship between THC and alcohol and other drugs, a series of interaction models were estimated for each outcome variable. These models examined the following interactions: delta-9-THC by BAC, carboxy-THC by BAC, delta-9-THC by Other Drugs, carboxy-THC by Other Drugs, BAC by Other Drugs, and three-way interactions examining delta-9-THC by BAC by Other Drugs and Caroxy-THC by BAC by Other Drugs. Following best practices with interaction modeling (Jaccard, 2001), each potential two-way interaction were first estimated in separate models. Then, all relevant two-way interactions (along with main effects) were included when three-way interactions were estimated. Lastly, to explore the probability of the relationship between drivers and substance use, a set of the same logistic regression models were applied and estimated for each outcome variable using several sub-groups of drivers, including 1) drivers who were given a drug blood test[1], 2) drivers who were given a drug test and tested positive for alcohol, and

[1] Before the use of blood test drivers alone, a preliminary analysis was completed using blood test drivers only and combined drug blood test drivers only and both blood and urine test drivers. Findings from blood test drivers alone produced better results in terms of the effects of alcohol, THC, carboxy-THC, and other drugs on each outcome variable. Consequently, other drug test type (e.g., urine, both urine and blood, unknown test type) was excluded in the analysis.

3) drivers who were given a drug test and tested positive for alcohol greater than or equal to .08. Only models with statistically significant interactions are presented to facilitate the presentation of results.

Results

Speeding Models

Results for the main effects and the three interaction models were speeding is regressed on driver characteristics, contextual factors, and drug and alcohol involvement are presented in Table 3.

TABLE 3. Logit Models of Drug and Alcohol on Speeding (n = 5,318; drivers from 2008-2016 WA FARS data)

Covariates		Main Effects Model		Interaction Model 1		Interaction Model 2		Interaction Model 3	
		Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR
Driver Characteristics									
Age		-.03(.00)	0.97***	-.03(.00)	0.97***	-.03(.00)	0.97***	-.03(.00)	0.97***
Gender (1 = male)		.41(.10)	1.51***	.40(.10)	1.49***	.41(.10)	1.50***	.41(.10)	1.50***
Prior Speeding convictions (in the past three years)		.10(.08)	1.10	.10(.08)	1.10	.10(.08)	1.10	.10(.08)	1.10
Natural Conditions									
Weather condition	*Clear (reference)*	--	--	--	--	--	--	--	--
	Cloudy	.08(.12)	1.08	.08(.12)	1.08	.07(.12)	1.08	.07(.12)	1.08
	Rain	-.34(.17)	0.71*	-.33(.17)	0.72*	-.34(.17)	0.71*	-.34(.17)	0.71*
	Fog/Smoke	.83(.29)	2.30**	.83(.29)	2.29**	.84(.29)	2.32**	.83(.29)	2.30**
	Snow	1.10(.29)	3.01***	1.12(.29)	3.06***	1.12(.29)	3.07***	1.12(.29)	3.08***
Time of crash (1 = night)		.04(.08)	1.04	.03(.08)	1.03	.03(.08)	1.03	.03(.08)	1.03
Road Conditions									
Road alignment (1 = straight)		-.74(.08)	0.48***	-.74(.08)	0.48***	-.74(.08)	0.48***	-.74(.08)	0.48***
Road grade (1 = level)		-.20(.08)	0.82*	-.20(.08)	0.82*	-.20(.08)	0.82*	-.20(.08)	0.82*
Surface condition (1 = dry)		-.67(.12)	0.51***	-.67(.12)	0.51***	-.68(.12)	0.51***	-.68(.12)	0.51***
Surface type (1 = Asphalt)		-.17(.12)	0.84	-.17(.12)	0.85	-.17(.12)	0.84	-.16(.12)	0.85
Intersection		-.44(.10)	0.64***	-.44(.10)	0.64***	-.44(.10)	0.65***	-.44(.10)	0.64***
Speed limit		-.02(.00)	0.98***	-.02(.00)	0.98***	-.03(.00)	0.98***	-.02(.00)	0.98***
Drivers' Vehicle Conditions									
Vehicle type	*Passenger vehicle (Reference)*	--	--	--	--	--	--	--	--
	Heavy truck	-.59(.23)	0.55*	-.58(.23)	0.56*	-.57(.23)	0.57*	-.57(.23)	0.57*
	Motorcycle	1.22(.12)	3.39***	1.22(.12)	3.38***	1.22(.12)	3.39***	1.21(.12)	3.37***
	Others	-.14(.34)	0.87	-.13(.34)	0.88	-.13(.34)	0.88	-.14(.34)	0.87
Other External Conditions									
Number of occupants in vehicle		.11(.04)	1.12**	.11(.04)	1.12**	.11(.04)	1.12**	.11(.04)	1.12**
Number of vehicles in crash		-.49(.06)	0.61***	-.49(.06)	0.61***	-.49(.06)	0.61***	-.49(.06)	0.61***
Drug and Alcohol Involvement									
BAC < .079		.87(.17)	2.38***	.86(.17)	2.36***	.84(.17)	2.32***	.87(.17)	2.31***
BAC > .080		1.25(.10)	3.49***	1.37(.11)	3.92***	1.35(.11)	3.86***	1.34(.11)	3.82***
THC < 5.00		.12(.21)	1.13	.11(.20)	1.11	.10(.20)	1.11	.10(.20)	1.11
THC > 5.00		.39(.17)	1.48*	.37(.17)	1.45*	.58(.19)	1.78**	.59(.19)	1.81**
Carboxy only without THC		.49(.18)	1.63**	.48(.18)	1.61**	.47(.18)	1.60*	.73(.23)	2.08**
Other drugs[a]		.60(.10)	1.82***	.77(.12)	2.15***	.82(.12)	2.27***	.87(.12)	2.39***
Interactions[b]									
BAC>.080*Other drugs		--	--	-.58(.22)	0.56**	-.55(.22)	0.58*	-.53(.22)	0.59*
THC> 5.00*Other drugs		--	--	--	--	-.81(.37)	0.44*	-.87(.37)	0.42*

Covariates	Main Effects Model		Interaction Model 1		Interaction Model 2		Interaction Model 3	
	Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR
Carboxy*Other drugs	--	--	--	--	--	--	-.81(.38)	0.44*
Model χ^2	1502.431***		1508.949***		1510.068***		1515.256***	
Nagelkerke R^2	.384		.385		.386		.387	

*Note: Significant interaction terms in the models are presented. OR = odds ratios. BAC = blood alcohol concentration. THC = delta-9-tetrahydrocannabinol. a other drugs include narcotics, depressants, stimulants, hallucinogens, phencyclindine, inhalants, and other unknown types of drugs. b Two interaction terms, BAC<.79*Carboxy and BAC<.79*Carboxy*Other drug were excluded due to multicollinearity as well as zero cell issue. † p <.1, *p <.05, **p <.01, ***p <.001*

The results indicate that young males, driving a motorcycle in poor weather conditions, on curvy wet roads, who test positive for alcohol, carboxy-THC or delta-9-THC or other drugs, are more likely to be speeding when involved in a fatal crash. The odds of speeding for drivers who tested positive for delta-9-THC were 48% greater than for those who did not, controlling for other factors. The presence of carboxy-THC was significantly associated with speeding, indicating that drivers who had consumed cannabis, but not so recently that they tested positive for delta-9-THC, were more likely to speed. The odds of speeding for drivers who tested positive for carboxy-THC were 63% greater than for those who did not, controlling for other factors.

Though this is a substantial increase, it falls far short of the magnitude of the effect of alcohol on speeding. Drivers who tested below the .079 limit were 138% and drivers who tested positive over the .08 BAC limit were 249% more likely to have been speeding during a fatal crash than drivers who did not, controlling for other factors. On the other hand, drivers with elevated BACs and who tested positive for other drugs were more likely to speed during a fatal crash than other drivers.

The interaction models indicate no statistically significant two- or three-way interaction between delta-9-THC and alcohol. These results suggest that drivers were no more likely to speed if they were simultaneously under the influence of alcohol. There is a statistically significant interaction between other drugs and BAC over .08 limit, delta-9-THC over the per se limit, and carboxy-THC in interaction models 1, 2, and 3. This interaction was negative, suggesting that drivers who had used cannabis recently and under the influence of psychoactive THC and tested positive for some other drug were less likely to speed, though it should be noted that the overall relationship between carboxy-THC and speeding and

other drugs and speeding remain positive. These interactions only provide modest improvements to model fit as evidenced by the small increases in Nagelkerke R^2 values.

In order to explore the possible relationship between certain types of drivers and substance use on speeding, sub-group analysis was conducted using the same logit models. Three sub-groups of drivers were identified, including drivers who were given a drug test, drivers who were given a drug test and tested positive for alcohol, and drivers who were given a drug test and tested positive for alcohol greater than or equal to .08. The results are presented in table 4.

TABLE 4. Sub-Group Analysis: Logit Models of Drug and Alcohol on Speeding

Covariates		Drug Tested Drivers (n=1,955)[b]		BAC Positive Drivers (n=664)[c]		BAC >.08 Drivers (n=555)[d]	
		Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR
Driver Characteristics							
Age		-.04(.00)	0.96***	-.05(.01)	0.95***	-.05(.01)	0.96***
Gender (1 = male)		.51(.15)	1.66**	.65(.23)	1.91**	.79(.26)	2.20**
Prior Speeding convictions (in the past three years)		-.06(.13)	0.94	-.13(.20)	0.88	-.20(.22)	0.82
Natural Conditions							
Weather condition	*Clear (reference)*	--	--	--	--	--	--
	Cloudy	.03(.19)	1.03	-.03(.27)	0.97	.15(.30)	1.16
	Rain	-.24(.28)	0.79	-.21(.44)	0.81	-.11(.49)	0.89
	Fog/Smoke	.41(.42)	1.51	.47(.70)	1.60	.39(.68)	1.48
	Snow	.47(.53)	1.60	-1.11(.95)	0.33	-1.08(.89)	0.34
Time of crash (1 = night)		.02(.13)	1.02	.21(.21)	1.23	.04(.23)	1.04
Road Conditions							
Road alignment (1 = straight)		-.84(.13)	0.43***	-.78(.20)	0.46***	-.82(.22)	0.44***
Road grade (1 = level)		-.39(.13)	0.68**	-.34(.20)	0.72†	-.25(.22)	0.78
Surface condition (1 = dry)		-.56(.21)	0.57**	-.12(.34)	0.89	-.18(.35)	0.84
Surface type (1 = Asphalt)		-.08(.18)	0.93	-.00(.27)	1.00	-.04(.29)	0.96
Intersection		-.33(.15)	0.72*	-.38(.25)	0.68	-.28(.27)	0.75
Speed limit		-.03(.01)	0.97***	-.06(.01)	0.95***	-.05(.01)	0.95***
Drivers' Vehicle Conditions							
Vehicle type	*Passenger vehicle (Reference)*	--	--	-.50(.27)	0.61†	-.12(.29)	0.89
	Heavy truck	-.09(.34)	0.92				
	Motorcycle	.98(.17)	2.66***				
	Others[a]	.00(.57)	1.00				
Other External Conditions							
Number of occupants in vehicle		.09(.07)	1.09	-.13(.10)	0.88	-.11(.11)	0.90
Number of vehicles in crash		-.23(.09)	0.79*	-.36(.13)	0.70**	-.35(.14)	0.71*
Drug and Alcohol Involvement							
BAC < .079		.82(.22)	2.28***	--	--	--	--
BAC > .080		1.18(.14)	3.25***	--	--	--	--
THC < 5.00		-.28(.23)	0.76	-.49(.28)	0.61†	-.46(.31)	0.63
THC > 5.00		.35(.18)	1.41†	.22(.27)	1.25	.24(.29)	1.28
Carboxy only without THC		.41(.21)	1.50†	.44(.34)	1.55	.38(.34)	1.46
Other drugs[a]		.41(.13)	1.51***	.29(.21)	1.33	.32(.23)	1.38
Model χ^2		589.957***		182.011***		135.105***	
Nagelkerke R^2		.386		.328		.300	

See note on following page.

*Note: No significant interaction terms in the models are found. OR = odds ratios. BAC = blood alcohol concentration. THC = delta-9-tetrahydrocannabinol. a other drugs include narcotics, depressants, stimulants, hallucinogens, phencyclidine, inhalants, and other unknown types of drugs. b 2,159 drivers who were **blood tested** for drugs. c 750 drivers who were blood tested for drugs and tested positive for alcohol. d 627 drivers who were blood tested for drugs and tested positive for alcohol over .08.. † p <.1, *p <.05, **p <.01, ***p <.001.*

The results for the sub-group analysis are somewhat consistent with the results for the speeding model presented above. The results from a model of blood tested drivers indicate that young males, driving a motorcycle, on curvy wet roads, who test positive for alcohol, carboxy-THC or delta-9-THC over 5 nanograms per mL, or other drugs, are more likely to be speeding when involved in a fatal crash, though some of these results are only marginally significant. Regarding a model of BAC positive drivers, the results demonstrate that young males on curvy roads are more likely to be speeding when involved in a fatal crash. It is important to note that alcohol positive (both lesser and greater than .08) drivers are less likely to engage with other vehicles in a fatal crash related to speeding. It is also worth noting that delta-9-THC, carboxy-THC, and other drugs are not likely to affect speeding on alcohol positive drivers (both lesser and greater than or equal to .08 drivers). No significant interaction terms in the three sub-groups were found.

Driver Error Models

Results for the main effects and three interaction models where driver error is regressed on driver characteristics, contextual factors, and drug and alcohol involvement are presented in Table 5.

TABLE 5. Logit Models of Drug and Alcohol on Driver Errors (n = 5,464; drivers from 2008-2016 WA FARS data)

Covariates		Main Effects Model		Interaction Model 1		Interaction Model 2		Interaction Model 3	
		Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR
Driver Characteristics									
Age	*15 – 25 (reference)*	--	--	--	--	--	--	--	--
	26 – 35	-.26(.09)	0.77**	-.26(.09)	0.77**	-.28(.09)	0.76**	-.28(.09)	0.76**
	36 – 45	-.61(.10)	0.54***	-.61(.10)	0.55***	-.62(.10)	0.54***	-.63(.10)	0.54***
	46 – 55	-.61(.10)	0.54***	-.61(.10)	0.55***	-.61(.10)	0.54***	-.61(.10)	0.54***
	56 – 65	-.44(.11)	0.65***	-.43(.11)	0.65***	-.45(.11)	0.64***	-.45(.11)	0.64***
	Over 65	-.04(.11)	0.96	-.03(.11)	0.97	-.05(.11)	0.95	-.05(.11)	0.95
Gender (1 = male)		.12(.07)	1.13†	.12(.07)	1.13†	.11(.07)	1.12	.12(.07)	1.12
Unlicensed driver		.57(.10)	1.77***	.57(.10)	1.77***	.57(.10)	1.76***	.57(.10)	1.76***
Other traffic conviction		.15(.07)	1.17*	.15(.07)	1.16*	.15(.07)	1.17*	.16(.07)	1.17*
Natural Conditions									
Time of crash (1 = night)		-.34(.07)	0.71***	-.34(.07)	0.71***	-.35(.07)	0.70***	-.36(.07)	0.70***
Road Conditions									
Asphalt		.18(.09)	1.20*	.18(.09)	1.20†	.18(.09)	1.20*	.19(.09)	1.21*
Speed limit		.01(.00)	1.01***	.01(.00)	1.01***	.01(.00)	1.01***	.01(.00)	1.01***

Covariates		Main Effects Model		Interaction Model 1		Interaction Model 2		Interaction Model 3	
		Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR
Drivers' Vehicle Conditions									
Passenger vehicle (Reference)		--	--	--	--	--	--	--	--
Vehicle type	*Heavy truck*	-1.27(.19)	0.28***	-1.27(.19)	0.28***	-1.25(.19)	0.29***	-1.26(.19)	0.28***
	Motorcycle	-.63(.11)	0.53***	-.63(.11)	0.53***	-.64(.11)	0.53***	-.65(.11)	0.53***
	Others	-.76(.29)	0.47**	-.76(.29)	0.47**	-.75(.29)	0.47*	-.76(.29)	0.47*
Other External Conditions									
Number of vehicles in crash		-.19(.04)	0.83***	-.18(.04)	0.83***	-.18(.04)	0.83***	-.18(.04)	0.83***
Heavy truck involved		.57(.13)	1.76***	.57(.13)	1.76***	.57(.13)	1.76***	.57(.13)	1.77***
Head-on involved		.65(.08)	1.91***	.65(.08)	1.91***	.64(.08)	1.90***	.64(.08)	1.89***
Traffic control device		1.09(.09)	2.98***	1.09(.09)	2.98***	1.09(.09)	2.98***	1.09(.09)	2.97***
Lap and shoulder belt used		-.31(.08)	0.73***	-.31(.08)	0.73***	-.29(.08)	0.75***	-.30(.08)	0.74***
Drug and Alcohol Involvement									
BAC < .079		.81(.16)	2.24***	.81(.16)	2.24***	.80(.16)	2.21***	.81(.16)	2.22***
BAC > .080		.80(.09)	2.23***	.84(.09)	2.32***	.99(.10)	2.69***	.97(.10)	2.64***
THC < 5.00		.10(.18)	1.11	.10(.18)	1.10	.08(.18)	1.08	.08(.18)	1.08
THC > 5.00		-.29(.16)	0.75†	-.30(.16)	0.74†	-.32(.16)	0.73*	-.32(.16)	0.73*
Carboxy only without THC		.65(.17)	1.91***	.92(.22)	2.50***	.88(.22)	2.41***	.88(.22)	2.41***
Other drugs[a]		.42(.08)	1.52***	.41(.08)	1.51***	.59(.09)	1.81***	.59(.09)	1.81***
Interactions									
BAC>.080*Carboxy		--	--	-.68(.34)	0.51*	-.63(.33)	.53†	-.32(.36)	.72
BAC>.080*Other drugs		--	--	--	--	-.76(.19)	.47***	-.66(.19)	.52**
BAC>.080*Other drugs*Carboxy		--	--	--	--	--	--	-1.29(.62)	.28*
Model χ^2		648.577***		652.827***		668.345***		672.977***	
Nagelkerke R^2		.158		.159		.163		.164	

Note: *Significant interaction terms in the models are presented. OR = odds ratios. BAC = blood alcohol concentration. THC = delta-9-tetrahydrocannabinol. a other drugs include narcotics, depressants, stimulants, hallucinogens, phencyclidine, inhalants, and other unknown types of drugs. † p <.1, *p <.05, **p <.01, ***p <.001*

The results for the main effects model for driver errors are similar to the results for the speeding model presented above. Particularly, a number of driver characteristics (including expected risk factors, like age, unlicensed driver, and other traffic conviction) and contextual factors significantly predict whether a driver committed an error during a fatal crash. Similar to the findings from the speeding models, drivers with elevated BAC levels and drivers who tested positive for other drugs were significantly more likely to commit a driver error leading to a fatal crash. However, while the presence of carboxy-THC was significantly associated with driver errors, delta-9-THC did not significantly predict driver errors. Indeed, drivers with delta-9-THC greater than or equal to 5.00 nanogram were marginally and significantly less likely to commit a driver error leading to a fatal crash. The interaction

models reveal significant interactions between BAC > .80 and carboxy-THC and other drugs, with all interactions suggesting that the combination of alcohol and other drugs seems to decrease the likelihood that a driver is found to have committed an error. This might indicate something of a self-correcting measure in that drivers under the influence of multiple substances might attempt to driver more carefully to compensate for their impairment. Alternatively, it might be that police are less likely to note driver errors in the crash reports in these incidents, as the presence of multiple drugs might largely make the cases for them.

Sub-group analyses were then conducted, including drivers who were given a drug test, drivers who were given a drug test and tested positive for alcohol, and drivers who were given a drug test and tested positive for alcohol greater than or equal to .08. The results are presented in table 6.

TABLE 6. Sub-Group Analysis: Logit Models of Drug and Alcohol on Driver Errors

Covariates		Drug Tested Drivers (n=2,007)[b]		Interaction Model of Drug Tested Drivers (n=2,007)		BAC Positive Drivers (n=683)[c]		BAC >.08 Drivers (n=570)[d]	
		Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR
Driver Characteristics									
Age	*15 – 25 (reference)*	--	--	--	--	--	--	--	--
	26 – 35	.00(.15)	1.00	-.01(.15)	0.99	.30(.23)	1.34	.28(.25)	1.33
	36 – 45	-.52(.16)	0.59**	-.54(.16)	0.58**	-.12(.28)	0.89	-.02(.31)	0.98
	46 – 55	-.72(.17)	0.49***	-.73(.17)	0.48***	-.77(.30)	0.47*	-.53(.33)	0.59
	56 – 65	-.71(.18)	0.49***	-.73(.18)	0.48***	-.98(.35)	0.38**	-.83(.38)	0.44*
	Over 65	-.20(.18)	0.82	-.22(.19)	0.80	.07(.11)	1.07	.46(.61)	1.58
Gender (1 = male)		.20(.12)	1.22†	.19(.12)	1.21	-.18(.23)	0.84	-.37(.26)	0.69
Unlicensed driver		.34(.14)	1.41*	.34(.14)	1.40*	.45(.20)	1.57*	.50(.22)	1.65*
Other traffic conviction		.11(.11)	1.12	.12(.11)	1.12	-.06(.18)	0.94	-.02(.20)	0.98
Natural Conditions									
Time of crash (1 = night)		-.36(.11)	0.70**	-.36(.11)	0.70**	-.27(.21)	0.77	-.20(.24)	0.82
Road Conditions									
Asphalt		-.01(.15)	0.99	-.00(.15)	1.00	-.01(.24)	0.99	-.10(.26)	0.90
Speed limit		.01(.00)	1.01*	.01(.00)	1.01*	-.01(.01)	1.01	.02(.01)	1.02†
Drivers' Vehicle Conditions									
Vehicle type	*Passenger vehicle (Reference)*	--	--	--	--	.60(.25)	1.82*	.69(.29)	2.00**
	Heavy truck	-1.44(.33)	0.24***	-1.42(.33)	0.24***				
	Motorcycle	-.73(.17)	0.48***	-.72(.17)	0.49***				
	Others[a]	-.95(.49)	0.39†	-.95(.49)	0.39†				
Other External Conditions									
Number of vehicles in crash		.27(.08)	1.31**	.26(.08)	1.30**	.34(.15)	1.40*	.54(.18)	1.72**
Heavy truck involved		.60(.22)	1.82**	.61(.22)	1.83**	.77(.51)	2.15	.45(.53)	1.57
Head-on involved		1.17(.14)	3.22***	1.16(.14)	3.20***	1.79(.36)	5.99***	1.61(.41)	5.02***
Traffic control device		1.27(.16)	3.57***	1.27(.16)	3.56***	1.50(.35)	4.48***	1.50(.39)	4.47***
Lap and shoulder belt used		-.00(.12)	1.00	.01(.12)	1.01	.25(.19)	1.28	.22(.21)	1.25
Drug and Alcohol Involvement									

Covariates	Drug Tested Drivers (n=2,007)[b]		Interaction Model of Drug Tested Drivers (n=2,007)		BAC Positive Drivers (n=683)[c]		BAC >.08 Drivers (n=570)[d]	
	Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR	Logit (*Robust SE*)	OR
BAC < .079	.80(.22)	2.18***	.79(.22)	2.20***	--	--	--	--
BAC > .080	.75(.13)	2.11***	.89(.15)	2.44***	--	--	--	--
THC < 5.00	-.10(.20)	0.91	-.11(.20)	0.90	-.16(.29)	0.85	-.25(.33)	0.78
THC > 5.00	-.52(.18)	0.60**	-.54(.18)	0.58**	-.80(.26)	0.45**	-.90(.29)	0.41**
Carboxy only without THC	.36(.20)	1.43†	.34(.20)	1.40†	.63(.28)	1.87*	.42(.30)	1.52
Other drugs[a]	.19(.11)	1.20†	.31(.13)	1.37*	-.04(.20)	0.96	-.16(.22)	0.85
Interactions								
BAC>.080*Other drugs	--	--	-.46(.24)	0.63†	--	--	--	--
Model χ^2	341.777***		344.246***		148.746***		129.136***	
Nagelkerke R^2	.215		.217		.273		.289	

Note: *Significant interaction terms in the models are presented. OR = odds ratios. BAC = blood alcohol concentration. THC = delta-9-tetrahydrocannabinol. a other drugs include narcotic, depressant, stimulant, hallucinogen, phencyclindine, inhalant, and other unknown types of drugs. b 2,866 drivers who were* ***blood test given*** *for drugs. c 750 drivers who were blood test given for drugs and tested positive for alcohol. d 627 drivers who were blood test given for drugs and tested positive for alcohol over .08.. † p <.1, *p <.05, **p <.01, ***p <.001*

The results from a model of drug tested drivers indicate that unlicensed young males, on curvy wet roads, who test positive for alcohol, carboxy-THC or other drugs, are more likely to commit driver errors when involved in a fatal crash, though again some of these results are only marginally significant. Interestingly, drivers who test positive for delta-9 THC over 5.00 ng are less likely to commit driver errors.

The results also indicate that drivers who were given a drug test are more likely to have been involved in a head-on collision and with other vehicles, like heavy trucks, in a fatal incident. It is interesting that drivers who were given a drug test are more likely to commit a driver error at daytime when involved in a fatal crash. There is a statistically significant interaction between other drugs and BAC over .08 limit. However, this interaction was negative, meaning that drivers who had consumed alcohol and tested positive for some other drug were less likely to commit driver errors. The interaction, however, only provides modest improvements to model fit as evidenced by the small increases in Nagelkerke R^2 values.

With regard to a model of BAC positive drivers, the results demonstrate that unlicensed young drivers in a passenger vehicle are more likely to commit driver error when involved in a fatal crash. Significance of gender effects and time of crash disappears in this sub-analysis. In addition, the presence

of other drugs is no longer associated with driver error. Moreover, the presence of carboxy-THC is significantly associated with driver error for alcohol positive drivers, but no effects on driver error for those drivers alcohol positive greater than or equal to .08 occurs. It is important to note that all sub-groups of drivers are more likely to engage in crashes with other vehicles and head-on collisions when the crash involved driver error in a crash and lap and shoulder belts were not used. Delta-9-THC, carboxy-THC, and other drugs have some mixed effects on driver errors on these sub-group drivers and no significant interaction terms in the BAC positive sub-groups are found.

Second Set of Analyses

Research Questions

In this portion of the study we were interested in examining the relationship between THC, alcohol and their combination and driver culpability and fatalities, contextual conditions and collision type in these crashes. In particular, we were concerned that there might be issues with covariate imbalance when comparing incidents involving THC to those not involving THC. As such, we employed matching techniques to produce more comparable observations. Our research questions included:

1. Is there an association among THC, alcohol, and a combination of THC and alcohol intoxication and *drivers' culpabilities* involving fatal crashes in WA?
2. Is there an association among THC, alcohol, and a combination of THC and alcohol intoxication and *driver fatalities* involving fatal crashes in WA?
3. Is there an association among THC, alcohol, and a combination of THC and alcohol intoxication and *contextual conditions* involving fatal crashes in WA?
4. Is there an association among THC, alcohol, and a combination of THC and alcohol intoxication and *collision type* involving fatal crashes in WA?

Methods

For these analyses, we selected data from the same nine-years of WA FARS, from January 2008 to December 2016, as this is the period of time in which driver delta-9-THC information is included in the data. To answer the research questions, we initially limited the target sample to only drivers involved in fatal crashes in WA (n=5,931). We then further restricted the driver samples to drivers who had been

blood tested for intoxicants with known results, further grouped into drivers who had a negative test result for alcohol and any forms of drugs (clean drivers, *n*=3,737), drivers with a positive test result for THC only (*n*=130), drivers with a positive test result for alcohol only (*n*= 778), and drivers with a positive test result for both THC and alcohol only (*n*= 200). To eliminate the effects of any other drugs, drivers with a positive test result for any substance intoxications like carboxy-THC and other drugs, including narcotic, depressant, hallucinogen, phencyclindine, inhalant, and other unknown forms of drugs were excluded in the final analytic sample. Consequently, a series of matches was conducted, including delta-9-THC alone vs. clean drivers, alcohol alone vs. clean drivers, and both THC and alcohol positive vs. clean drivers.

Outcome measures

We analyzed four study outcomes: 1) drivers' culpability; 2) driver fatalities; (3) contextual circumstances of fatal crashes; and (4) collision type of fatal crashes. Regarding the first outcome, there are fifty-one indicators that reflect driver culpabilities, like evidence of speeding, driving errors or fault, and any other traffic violations. Given that many of these individual variables occurred relatively infrequently, as with our first set of analyses, we combined these measures into three dichotomous outcome variables representing driver culpability, including speeding and driver errors (identified by police)[2]. For the second outcome, we selected driver fatalities using two measures, fatal injuries and death on the scene. Moreover, contextual/environmental conditions of the fatal crash was included in study outcomes, such as number of vehicles in crash, heavy truck involved, motorcycle involved, bicycle involved, pedestrian involved, and number of fatalities in crash. Finally, we examined whether some forms of collision type differed significantly by study group, including "head-on," "cross centerline," and "run off the road."

Treatment variables

[2] Driver error variable contains several sub-categories. For example, in the driver error variable, there were 34 sub-types of driving errors or fault (e.g., driving in an erratic reckless, negligent manner, or abrupt speed change, and overcorrecting etc.). Given that our primary focus is on examining the link between alcohol and THC intoxication and driver errors, fatalities, contextual conditions and collision type of fatal crashes, we recoded these measures into a dichotomous variable for the group comparison.

Based on prior studies that highlighted the confounded nature of THC and alcohol (Dubois et al., 2015; Hartman et al., 2015; Li et al., 2013), we conceptualize alcohol and THC intoxication as the treatment variable and measure this in three ways: 1) a positive test result for THC only; 2) a positive test result for alcohol only; and 3) a positive test result for both THC and alcohol only. THC alone was measured through a single variable that indicated whether the driver tested positive for THC only, regardless of whether they were above or below the per se limit in Washington state. Alcohol positive was measured via a single variable that indicated whether the driver tested positive for blood alcohol content only. A combination of THC and alcohol variable was also measured via a single variable that indicated whether the driver tested positive for both alcohol and THC only, with no positive test for any other substance as well as no positive test for combining alcohol/THC and other drugs.

Table 7. Descriptive Statistics for Study Variables.

Variable	THC alone (n = 130)		Alcohol Alone (n = 778)		THC + Alcohol (n = 200)		Clean Drivers (n = 3,737)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age	34.55	15.23	37.08	14.92	31.94	12.16	44.45	19.13
Gender (male = 1)	0.87	0.34	0.87	0.34	0.84	0.37	0.72	0.45
Unlicensed driver	0.15	0.36	0.21	0.41	0.34	0.47	0.06	0.24
License restrictions	0.19	0.39	0.24	0.43	0.23	0.42	0.31	0.46
Prior DUI records	0.03	0.17	0.07	0.25	0.06	0.24	0.01	0.12
Prior other traffic convictions	0.48	0.50	0.39	0.49	0.54	0.50	0.25	0.43
Prior speeding convictions	0.40	0.49	0.33	0.47	0.38	0.49	0.23	0.42
Prior crashes	0.16	0.36	0.15	0.35	0.17	0.37	0.16	0.36
Time of crash (1 = night)	0.35	0.48	0.69	0.46	0.72	0.45	0.31	0.46
Weekends	0.47	0.50	0.64	0.48	0.61	0.49	0.46	0.50
Motorcycle	0.21	0.41	0.18	0.38	0.13	0.34	0.08	0.28
Passenger vehicle	0.78	0.42	0.79	0.41	0.85	0.36	0.80	0.40
Weather condition (1 = clear)	0.66	0.48	0.75	0.43	0.69	0.46	0.71	0.46
Surface condition (1 = dry)	0.24	0.43	0.19	0.39	0.20	0.40	0.20	0.40
Road type (1 = rural road)	0.43	0.50	0.57	0.49	0.45	0.50	0.50	0.50
Road class (1 = county road)	0.25	0.44	0.38	0.48	0.40	0.49	0.23	0.42
Number of occupants	1.41	0.87	1.49	0.88	1.58	0.87	1.56	0.96
Lap and shoulder belt used	0.51	0.50	0.38	0.49	0.33	0.47	0.74	0.44

Balancing covariates

A total of 18 variables that were empirically and significantly related at the bivariate level to alcohol and THC presence were selected as covariates (see Table 7). A set of demographic measures were included as covariates: age (in years); gender (male = 1; female = 0); license status (unlicensed: yes = 1; no = 0); license restrictions (restrictions = 1; no restrictions = 0); prior DUI records (within the past three years[3]: yes = 1; no = 0); prior other traffic convictions (within the past three years: yes = 1; no = 0); prior speeding convictions (within the past three years: yes = 1; no = 0); prior crashes (within the past three years: yes = 1; no = 0); time of crash (night = 1; day = 0 where night refers to time between 7:00 P.M. to 5:59 A.M. and day refers to time between 6 A.M. to 6:59 P.M.); weekends (Friday, Saturday, and Sunday = 1; Other day = 0); motorcycle (yes = 1; no = 0); passenger vehicle (yes = 1; no = 0); weather condition (clear: yes = 1; no = 0); surface condition (dry: yes = 1; no = 0); road type (rural road: yes = 1; no = 0); road class (county road: yes = 1; no = 0); number of occupants in the vehicle (ranged from 1 to 5 where 1 refers to a single occupant and 5 refers to 5 or greater occupants); and lap and shoulder belt used (used: yes = 1; no = 0).

Statistical Analyses

Propensity score analysis was used to examine the association between alcohol alone, THC alone, and a combination of alcohol and THC and (1) drivers' culpabilities; (2) drivers' fatalities; (3) contextual conditions of crash; and (4) collision type. Propensity score modeling (PSM) is a statistical matching approach that approximates a randomized experiment using observational data by estimating the effect of a given treatment after accounting for factors that predict receiving treatment. PSM is specifically useful to address potential issues of selection bias and to determine whether the difference in outcomes between treated and non-treated groups can be attributed to the treatment effect (THC, alcohol, and combination of alcohol and THC), while relevant covariates are controlled for. Though PSM falls short of a true experiment in that it can only match based on observed covariates, matching techniques are known to reduce covariate imbalance and produce more efficient and unbiased estimates of treatment

[3] Actual numbers of prior events recorded on this driver's record during the previous three (through 2014) and the lookback period was extended from three years to five years since 2015.

effects than standard control variable applications in regression modeling (Ho, Imai, King, & Stuart, 2007; Iacus, Ging, & Porro, 2011). Once observations are matched, the effect of treatment can be estimated by comparing the means of matched pairs along outcomes of interest. No studies we are aware of have used this method to estimate THC effects on outcomes related to fatal crashes.

Table 8. Logistic Regressions on Matching Variables.

	THC alone (*n* =3,694)	Alcohol alone (*n* = 4,321)	THC+Alcohol (*n* = 3,760)
Variable	OR	OR	OR
Age	0.97***	0.99***	0.97***
Gender (male = 1)	2.35**	2.06***	1.55*
Unlicensed driver	1.54	2.37***	3.56***
License restrictions	0.71	0.92	1.08
Traffic records (previous three years)			
Prior DUI records	0.96	2.07**	1.38
Prior other traffic convictions	1.70*	1.02	1.42
Prior speeding convictions	1.28	1.17	1.16
Prior crashes	0.69	0.77	0.77
Time of crash (1 = night)	0.93	4.35***	4.01***
Weekends[a]	0.95	1.82***	1.70**
Motorcycle (1 = yes)	7.94**	2.44**	1.54
Passenger vehicle (1 = yes)	6.85**	3.04***	2.77*
Weather condition (1 = clear)	0.68	1.08	0.68
Surface condition (1 = wet)	0.99	0.95	0.67
Road type (1 = rural road)	0.82	1.39**	0.76
Road class (1 = county road)	0.95	1.48***	1.58*
Number of occupants in vehicle	0.78*	0.85**	0.87
Lap and shoulder belt used	0.47**	0.24***	0.22***
-2 Log likelihood	977.529	3,021.635	1104.271
Negelkerke R^2	.132	.336	.316

Note: OR = odds ratios. *a* Friday, Saturday, and Sunday are included. *p <.05. **p <.01. ***p <.001.

The procedure for the PSM analysis went through three steps. First, a set of balancing covariates were selected and then a binary logistic regression modeling was used to estimate propensity scores (see Table 8). This assessment includes examination of box-plot and bivariate tests that is a comparison of all covariate means between the two groups prior to and following the matching procedure. The distribution of estimated propensity scores between drivers who have a cannabis positive finding compared to those who did not demonstrated ample overlap across the full range of propensity scores between the treated group and potential matched group. We also examined "The Area Under the Curve" (AUC), which is referred to as the industry standard method to evaluate the subjects' raw scores using a Receiver Operating Characteristics (ROC) analysis, producing the Area Under the Curve[4] (available upon request). Before the match, the AUC estimates of THC alone, alcohol alone, and combining alcohol and THC were. 776, .837, and .876, respectively, indicating that those models were strongly predicting group assignment.

In this portion of the study, alcohol alone positive drivers, THC alone positive drivers, and both alcohol and THC positive drivers (treatment groups) were matched to clean drivers (comparison group). The nearest neighbor matching within a caliper is used which is typically utilized if the sample is suitably large (Guo & Fraser, 2015). The smaller caliper setting indicates the better match quality (Rosenbaum & Rubin, 1985). A one-to-ten, one-to-one, and one-to-two nearest neighbor matching algorithm (THC alone, alcohol alone, and both alcohol and THC, respectively) was utilized for matching the two groups with a caliper of .05[5].

After PSM was completed, diagnostic tests were then performed to examine whether the group balance was appropriately achieved by the PSM. Prior to the match eight (THC alone), eleven (alcohol

[4] Howard (2017) explained that "Some authors have ascribed a "glass ceiling" of predictive validity to an AUC level at or slightly above .70, where an AUC of .50 would be attained by a tool with no predictive value (chance accuracy)" (p.103).

[5] Since the WA FARS data contain enough of a sample for the matching on treatment groups, 1-to-3 match for alcohol group and 1-to-10 match for both THC and alcohol + THC group with a caliper of .05 was initially performed. After the match on alcohol and alcohol + THC group, however, a couple of covariates (i.e., unlicensed driver, time of crash, and lap and shoulder belt used, etc.) were still significantly different. Therefore, 1-to-1 matching for alcohol and 1-to-2 for alcohol + THC with a caliper of .05 was employed in the current study.

alone), and ten (combining alcohol and THC) of the eighteen item means were significantly different between the two groups. As shown in appendix A, balance between the two groups was achieved on nearly all covariates in terms of bivariate difference tests, standardized differences (STD), and AUC (see Austin, 2008; Rosenbaum & Rubin, 1985).

Results

Table 9 includes the results of differences in study outcomes after the match. Findings indicate that compared to clean drivers, drivers with the presence of THC only were significantly more likely to engage in speeding (95% CI: -.173,-.005, p = .039). On the other hand, drivers with alcohol were significantly more engaged in speeding (95% CI: -.328, -.228, p = .0001) and driver errors (95% CI: -0.202, -0.096, p =.0001) than clean drivers.

Table 9. Outcomes Comparisons by Study Group (THC N = 1,040, Alcohol N = 1,322, THC+Alcohol N = 471)

Culpabilities and Fatalities	THC Alone	Clean Drivers	t Statistic	Alcohol	Clean Drivers	t Statistic	THC+Alcohol	Clean Drivers	t Statistic
	M (SD)	M (SD)	(95%CI)	M (SD)	M (SD)	(95%CI)	M (SD)	M (SD)	(95%CI)
Speeding	0.29 (.46)	0.20 (.40)	-2.08* (-0.17, -0.01)	0.51 (.50)	0.23 (.42)	-10.94*** (-0.33, -0.23)	0.61 (.49)	0.26 (.44)	-7.89*** (-0.43, -0.26)
Errors	0.44 (.50)	0.36 (.48)	-1.59 (-0.17, 0.02)	0.50 (.50)	0.36 (.48)	-5.53*** (-0.20, -0.10)	0.49 (.50)	0.36 (.48)	-2.24** (-0.23, -0.05)
Fatal injuries	0.67 (.47)	0.38 (.49)	-6.54*** (-0.38, -0.21)	0.73 (.45)	0.45 (.50)	-10.71*** (-0.33, -0.23)	0.70 (.46)	0.39 (.49)	-7.14*** (-0.40, -0.23)
Died at the scene	0.48 (.50)	0.25 (.43)	-4.98*** (-0.33, -0.14)	0.59 (.49)	0.28 (.45)	-11.90*** (-0.36, -0.26)	0.61 (.49)	0.25 (.44)	-8.08*** (-0.44, -0.27)
Contexts	M (SD)	M (SD)	t, (95% CI)	M (SD)	M (SD)	t, (95% CI)	M (SD)	M (SD)	t, (95% CI)
Number of vehicles in crash	1.76 (.86)	1.89 (.79)	1.55 (-0.04, 0.28)	1.46 (.66)	1.76 (.79)	7.58*** (0.22, 0.38)	1.46 (.69)	1.73 (.72)	4.10*** (0.14, 0.40)
Heavy truck Involved	0.09 (.28)	0.07 (.26)	-0.48 (-0.06, 0.04)	0.05 (.22)	0.07 (.26)	1.64 (-0.01, 0.05)	0.05 (.22)	0.07 (.25)	0.73 (-0.03, 0.06)
Motorcycle involved	0.23 (.42)	0.25 (.43)	0.44 (-0.06, 0.10)	0.20 (.40)	0.26 (.44)	2.81** (0.02, 0.11)	0.15 (.35)	0.21 (.40)	1.71 (-0.01, 0.13)
Bicycle involved	0.03 (.18)	0.02 (.14)	-0.86 (-0.04, 0.02)	0.01 (.10)	0.01 (.10)	-0.00 (-0.01, 0.01)	0.01 (.10)	0.03 (.16)	1.24 (-0.02, 0.04)
Pedestrian involved	0.13 (.34)	0.16 (.37)	0.70 (-0.04, 0.09)	0.05 (.22)	0.18 (.39)	7.34*** (0.09, 0.16)	0.04 (.19)	0.18 (.38)	5.27*** (0.09, 0.19)
Number of fatalities in crash	1.10 (.35)	1.08 (.29)	-0.94 (-0.08, 0.03)	1.10 (.36)	1.09 (.33)	-0.88 (-0.05, 0.02)	1.12 (.38)	1.06 (.26)	-2.14* (-0.13, -0.01)
Collision Type	M (SD)	M (SD)	t, (95% CI)	M (SD)	M (SD)	t, (95% CI)	M (SD)	M (SD)	t, (95% CI)
Head-on	0.17 (.37)	0.19 (.39)	0.60 (-0.05, 0.09)	0.13 (.34)	0.16 (.37)	1.87 (-0.02, 0.07)	0.14 (.35)	0.18 (.38)	1.07 (-0.03, 0.10)
Cross centerline	0.22 (.42)	0.09 (.29)	-3.37** (-0.20, -0.05)	0.19 (.39)	0.12 (.32)	-3.52*** (-0.11, -0.03)	0.25 (.44)	0.10 (.31)	-4.11*** (-0.22, -0.08)
Run off the road	0.18 (.39)	0.16 (.37)	-0.61 (-0.09, 0.05)	0.42 (.50)	0.19 (.39)	-9.61*** (-0.28, -0.19)	0.43 (.50)	0.21 (.41)	-5.12*** (-0.31, -0.14)

Note. M = Mean; SD = Standard deviation; CI = Confidence interval; t-tests were used for comparisons of outcome means.

*p <.05. **p <.01. ***p <.001

In addition, drivers with the presence of both alcohol and THC were significantly more likely to commit driver error (95%, CI: -.230, -.048, p = .003) and engaged in speeding (95% CI: -.434,-.261, p = .0001) than clean drivers. Findings also indicated that compared to clean drivers, differences in fatalities such as fatal injuries and died at the scene of the crash remained statistically different after the match for all three groups. Taken together, the three treatment groups, including THC alone, alcohol alone, and both alcohol and THC positive drivers were at much greater risk of being fatally injured and subject to death at the scene when compared to clean drivers in WA, though the causal mechanism of fatal collision related to alcohol and THC intoxication remained unknown.

Findings of contextual conditions outcomes demonstrate that non-significant differences by study group were found for all contextual conditions of fatal crashes in the THC alone model. In addition, significant differences by study group were found for the number of vehicles in the collision, motorcycle involved, and pedestrian involved in alcohol alone. It is worth noting that compared to alcohol positive drivers, clean driver crashes were more likely to involve other vehicles (95% CI: .224, .381, p = .0001), motorcycles (95% CI: .020, .110, p = .005), and pedestrians (95% CI: .093, .161, p = .0001). Clean driver crashes were also more likely to involve other vehicles (95% CI: .142, .403, p = .0001) and pedestrians (95% CI: .088, .192, p = .0001) than combined alcohol and THC positive drivers in fatal crashes, but the combined alcohol and THC positive drivers tend to have more fatalities in the crash (95% CI: -.128, -.005, p = .033).

Significant differences in some collision types between treatment subjects and the comparison subjects were found. Compared to clean drivers, all the three treatment groups were more likely to collide from a driver crossing the centerline. Particularly, drivers with alcohol only (95%, CI: -.284,-.188, p = .0001) and both alcohol and THC positive (95%, CI: -.307,-.136, p = .0001) were significantly more likely to be involved in run-off-the-road event than clean drivers.

Third Set of Analyses

Qualitative File Review

One potential limitation of our multivariate regression and matching analyses is that while they examine the link between THC and a variety of driving errors or issues, it is not clear that the analysis of

indicator variables is a consistent method of examining the effects of marijuana consumption on driver crashes. For example, it is possible to envision a scenario where a driver was speeding and yet their speeding was not the direct cause of the crash. As such, while our analysis provides correlational information on the link between marijuana consumption and the pattern of driver behaviors during crashes, the FARS codes do not demonstrate driver culpability.

Data Set

As a means of verifying any link between marijuana consumption and driver culpability, we conducted supplementary analyses of a total of 181 police crash reports from January 2010 to December 2015. Using the previously described matching scheme, we randomly selected a set of 100 incidents in which a driver was positive for THC and then matched on 100 incidents in which no drugs were recorded for the driver. We then obtained crash narratives written by the investigating officer and a diagram showing how each crash happened for 181 of these incidents from the Washington Traffic Safety Commission. These documents were qualitatively coded for driver culpability by two primary well-trained coders in the Department of Criminal Justice and Criminology at Washington State University. They worked independently in order to maintain inter-coder reliability. In order to make sure the coders understood the research purpose and design, group meetings were held regularly to review and check on each rater's interpretation in consistent ways.

After reviewing 20 initial incident reports, we opted for a three-tiered coding system to rate the culpability of drivers. Specifically, drivers could be coded as having no, partial, or full culpability. In order to ensure data quality, we made use of a two-step coding process. The first step involved one of the co-principle investigators and a graduate research assistant independently reading and identifying the presence of pre-determined codes for the first 20 reports. After comparison, the research team refined and then agreed upon guidelines for the coding protocol. The second stage involved the graduate research assistant independently coding the rest of the 161 reports. Codes determined from the content of reports included: time of police dispatch to the crash, the culpability of the drivers involved, factors associated with culpability, and whether there were any witnesses to the crash. The culpability of the drivers involved was determined based on various factors identified in the report. Examples of items

considered included speeding, distracted driving (e.g., cell phone use), weather (e.g., snow on the ground or limited sight due to fog), and failing to obey traffic control devices (e.g., stop lights or yield signs). Crash reports that did not include adequate information to assess the culpability of a driver were coded as unknown. Driver's whose actions did not contribute to the crash were coded as "no culpability." For example, if driver number one was in their lane of travel when driver number two crossed the centerline and hit them head-on due to being distracted, driver number one would be coded as having no culpability. Another example is if driver number one was traveling through an intersection and was hit by driver number two who failed to obey the traffic control device. Driver number one would be coded as having no culpability whereas driver number two would be coded as having full culpability. However, if both driver 1 and driver 2 made errors, each would be coded as partially culpable.

Findings

A total of 273 drivers were identified in the 181 crash reports. The culpability of all 273 drivers was analyzed. Out of the 86 drivers who were positive for delta 9 THC, 11.6 percent (n= 10) had no culpability, 14 percent (n= 12) had partial culpability, 73.3 percent (n= 63) had full culpability, and 1.2 percent (n= 1) had an unknown culpability. For the 187 drivers who tested negative for delta 9 THC, 37.4 percent (n= 70) had no culpability, 18.2 percent (n= 34) had partial culpability, 43.3 percent (n= 81) had full culpability, and the remaining 1.1 percent (n= 2) had an unknown culpability.

A Chi-Squared Test (omitting the "Could not determine" group) was used to analyze if there were culpability differences between drivers who tested positive for delta 9 THC and those who did not. The test result showed that there is a statistically significant difference in culpability between the two groups of drivers ($\chi 2$= 24.03, p<.001). Moreover, the relationship between THC and culpability is moderately strong, as indicated by Cramer's V (V = .21). Given that a larger percentage (73% versus 43%) of drivers who tested positive for THC were deemed fully culpable, this supplementary analysis suggests that marijuana consumption may in fact be associated with fatal crashes. This is an interesting result, as the majority of our quantitative analyses suggested only marginal differences between drivers who tested positive for delta 9 THC and those who did not. Though we do not view these results as

absolutely definitive as they are based on a small sample of all crashes in the Washington FARS data, they are compelling as these differences exist despite the fact that we selected cases for coding based on the results of our matching analysis. This suggests that any differences in culpability were not the result of any of the factors we matched on. Future research should expand upon the number of cases coded and should also incorporate alcohol and other drugs into these qualitatively informed comparisons.

SECTION 4: DISCUSSION

The quantitative portion of the study examined the degree to which cannabis consumption, measured both as delta-9-THC (that is, potential active impairment) and carboxy-THC (recent use, but not active impairment), were related to speeding and driver error during fatal crashes in Washington State. The results were mixed in that delta-9-THC positively and significantly predicted speeding, but negatively predicted driver error. Only carboxy-THC consistently predicted speeding and driver error. In the sub-group analyses, the null or negative relationship between delta-9-THC and speeding/errors might seem to run contrary to prior research which finds that cannabis intoxication is a risk factor for crashes. We caution against this interpretation, as our data consist of only crashes resulting in fatal injuries and therefore cannot be used to identify predictors of non-fatal crashes. Instead, our results simply suggest that in fatal crashes that occurred in Washington, drivers who tested positive for delta-9-THC were no more likely to be speeding or committing driver errors than other drivers. This result may in fact be in line with prior research, as it is possible that cannabis impaired drivers recognize their impairments (Dubois et al., 2015; Smiley, 1999) and take active steps to drive slower and to avoid distractions (Lenne, Dietze, Triggs, Walmsley, Murphy, & Redman, 2010).

The PSM findings were similarly mixed in that compared to clean drivers, drivers with the presence of THC only were significantly more likely to engage in speeding, but not driver error. In addition, drivers with the presence of both alcohol and THC were significantly more likely to be engaged in speeding and commit driver errors than clean drivers. Findings also indicated that compared to clean drivers, differences in fatalities such as fatal injuries and died at the scene of the crash remained statistically different after the match for all three groups (THC alone, alcohol alone

and THC and alcohol). Taken together, the three treatment group drivers were at much greater risk of being fatally injured and subject to death at the scene when compared to clean drivers in WA, though the causal mechanism of fatal collision related to alcohol and THC intoxication remained unknown.

The qualitative analyses of a selection of the crash reports from these fatal crashes indicates that there is a moderately strong relationship between culpability and these fatal crashes for those drivers who tested positive for delta-9-THC. This finding suggests, as some portions of the logit and PSM analyses did, that marijuana consumption may in fact be associated with fatal crashes.

This finding aligns with prior research which found that cannabis intoxication is a risk factor for crashes. This interpretation of our findings, however, should be viewed with caution, as these data consist of only crashes resulting in fatal injuries and therefore cannot be used to identify predictors of non-fatal crashes. ***The results of this study simply suggest that in fatal crashes that occurred in Washington, drivers who tested positive for delta-9-THC or carboxy THC were at times involved in behaviors such as speeding or committed driver errors that were associated with fatal crashes and that the police, after assessing the circumstances of the crash, were more likely to deem them as culpable in the crash than "clean" drivers***. To the extent that we did not find that cannabis consumption was not involved in these crashes it may be because prior research has indicated that cannabis impaired drivers recognize their impairments (Smiley, 1999; DuBois, 2015) and take active steps to driver slower and less distracted (Lenne et al., 2010).

Prior research also indicated that cannabis impairment was perhaps most detrimental when combined with alcohol. The interaction models in the logit analyses did not provide support for this, as delta-9-THC did not interact with alcohol in any model. ***Much like prior research, however, alcohol intoxication was a strong and positive predictor of speeding and driver error*** (Dubois, Mullin, Weaver, & Bedard, 2015; Kelly, Darke, & Ross, 2004; Li, Brady, & Chen, 2013; Penning, Veldstra, Daamen, Olivier, Verster, 2010). Again, while the results cannot speak to the etiology of crashes or fatal crashes, ***the findings suggest that alcohol intoxication produces more serious driver errors than cannabis intoxication***.

It is noteworthy that delta-9-THC was not a significant predictor of driver speeding in the logit analyses, though it was in the PSM analyses, while carboxy-THC was. Given that our carboxy-THC measure is coded as a 1 for only those instances in which delta-9-THC was coded as a zero, this suggests that cannabis use, but not cannabis intoxication, may be related to driving behaviors. This is not an entirely surprising result, given that prior research indicates that drivers who consume cannabis tend to slow down to compensate for their impartment (Lenne et al., 2010; Smiley, 1999). Yet, the significant result for carboxy-THC indicates drivers who had consumed cannabis recently, but not in the immediate time period before the crash, were significantly more likely to speed during a fatal crash. Given that both variables suggest cannabis use, these contrary results require more attention. It is possible the carboxy-THC result may reflect the relationship between cannabis use more generally and driving behaviors, while the delta-9-THC results reflect recent cannabis usage and that general and recent usage need not have the same effects. As indicated in the foregoing, however, there may be alternate explanations for these findings.

It is important for research to explore why carboxy-THC is related to driving error. One possibility is that carboxy-THC, given the length of time it remains in the bloodstream, is a proxy measure for regular cannabis use. If so, it may be that cannabis use impairs cognitive functioning and thereby leads to poor driving decisions. Indeed, research suggests that persistent cannabis use may have both acute and long-term effects on decision-making (Crean, Crane, & Mason, 2011; Meier, Caspi, Ambler, Harrington, Houts, Keefe, McDonald, Ward, Poulton, & Moffitt, 2012). This explanation would suggest that over time, regular cannabis users become worse drivers. Alternatively, a positive result for carboxy-THC, a simple measure of drug use, might simply be a proxy for impulsivity or low self-control. A large body of research links impulsivity to both drug consumption (De Wit, 2009; Vangsness, Bry, & LaBouvie, 2005) and risky behaviors, including risky driving behaviors (Smith, Waterman, & Ward, 2006; Wickens, Toplak, & Wiesenthal, 2008). This explanation moves the causal emphasis away from cannabis and suggests, instead, that both cannabis use and driving problems are the result of the same underlying personality trait. It is important to note that FARS data are not suited for testing these explanations, as carboxy-THC is a crude proxy for variables

like regular cannabis use and an even weaker proxy for cognitive functioning. Clearly, more work is needed in this area.

A final and perhaps better explanation for why carboxy-THC is related to driving error in these data and delta 9-THC is not is that there is sometimes a considerable lag between the crash and the testing time. Research indicates that THC levels drop as much as 5ng/mL per every two hours (38). Therefore, if surviving drivers were tested immediately -- and they are not because the driver must first be examined by a trained officer and then a warrant to withdraw blood must be secured – then it might be that they would be more likely to have delta 9-THC in their blood than just carboxy-THC.

SECTION 5: SUMMARY AND CONCLUSIONS

Alcohol impairment and the role it plays in fatal crashes is well understood due to decades of research. Much less is known regarding THC impairment. The majority of THC drivers involved in fatal crashes also have other substances on board, limiting the research to date and making it difficult to understand the specific role THC impairment alone plays in crash outcomes. Even less is known regarding the poly-use of alcohol and THC on driving impairment, however it is widely acknowledged that the impairment caused by the combination is likely much more dangerous than either substance alone at similar levels. ***This study is one of the first of its kind to isolate drivers into mutually exclusive driver toxicology outcomes segregating alcohol and THC, and comparing those drivers with known (tested) clean drivers.*** As the three components of analyses employed in this study have demonstrated, driver impairment resulting in driver error manifests with both alcohol and THC and is amplified when the substances are combined. More research is needed to understand any causal links these variations in impairment have on crash risk.

Limitations

The WA-FARS data does not assign culpability. For this study, culpability was defined by using a variety of crash factors noted by the investigating officer. For this reason, this study associates

specific driver crash factors with toxicology outcomes, but does not provide a causal link between the presence of alcohol and THC to the specific driver behaviors noted.

Due to the fast rate of metabolism of THC in the blood and the length of time to obtain a blood sample following the crash event, it is possible that some drivers may have been under the influence of THC at the time of the crash but tested negative for THC thereby being excluded from this study. For drivers who died instantly, the metabolism of THC nearly stops negating this issue. However, for surviving drivers, some may have been excluded even though they were under the influence. Despite this limitation, the researchers by design also excluded them from all other comparison groups so as to not bias the other samples. In the event that the THC was no longer detectable, all drivers in this scenario would be positive for carboxy-THC, thereby to excluded all together due to the presence of another substance on the toxicology report, rather than erroneously being added to the 'alcohol only' group for example.

Moreover, FARS data only examine fatal crashes and therefore provide a sample of incidents in which driving, for whatever reason, has gone awry resulting in the death of a driver, passenger, or non-motorist. More research is needed on the effects of cannabis in a variety of driving contexts, including non-fatal crashes and traffic citations (not involving a crash). Moreover, the current analysis uses data only from Washington State. Though the WA FARS data provide more detailed drug information than other data sources, these results should be replicated in other states.

Related to this, while the WA FARS data is notable in their inclusion of drug-testing results, drug tests were not administered in all crashes. Approximately 35 percent of drivers (n = 2,109) of fatal crashes in the WA FARS data, from 2008 to 2016, were not given a drug test (Approximately 41 percent of drivers [n = 2,421] of fatal crashes in the WA FARS data during the same period were given a drug blood test, about 8 percent of drivers [n = 471] were given a drug urine test, about 7 percent of drivers [n = 400] were given a both blood and urine test). All models were re-estimated on the subset of cases involving incidents in which drivers were killed in crashes, as tests were conducted in over 90% of these instances in accordance with Washington RCW 46.52.065, which requires that all drivers who are killed in traffic crashes where the death occurred within four hours shall have

blood samples submitted to the WA State Toxicologist for drug and alcohol testing. These results are substantively similar and available upon request. A similar law does not exist for surviving drivers involved in fatal crashes; therefore, investigating law enforcement must gather probable cause of impairment to obtain a warrant for blood evidence. Lower drug testing rates among surviving drivers in fatal crashes is often seen as an insurmountable limitation in drugged driving research.

However, Washington already has a higher-than-average surviving driver testing rate (34.8% in 1997-2009) and police officers may use a combination of observation, crash circumstances, witness statements, and experience to determine whether or not probable cause exists for warrant blood draw to investigate impairment (Casanova, Hedlund, & Tison, 2012). WA fatal crash investigators insist that if impairment seems to have contributed to the crash circumstances, they will get that evidence either voluntarily or through a blood warrant. The crash investigation environment in Washington provides a unique opportunity to perform drugged driving research using fatal crash data with less limitations and bias than when using fatal crash information from other states. Put simply, the process in Washington makes it more likely that missing blood tests are indicative of a lack of probable cause of impairment and therefore more strongly suggest a lack of impairment rather than actual missing information. In this regard, researchers should be cautious about list-wise deletion of cases from WA data.

REFERENCES

Asbridge, M., Poulin, C., & Donato, A. (2005). Evidence from adolescents in Atlantic Canada. *Accident Analysis and Prevention,* 37, 1025-1034.

Asbridge, M., Hayden, J. A., & Cartwright, J. L. (2012). Acute cannabis consumption and motor vehicle collision risk: systematic review of observational studies and meta-analysis. *BJM*, 536, 1-9.

Atchison L. Drug driving in Europe: Policy measures for national and EU action. European Transport Safety Council 2017.

Austin PC. A critical appraisal of propensity-score matching in the medical literature between 1996 and 2003. Statistics in Med 2008: 27: 2037-2049.

Banta-Green, C., Rowhani-Rahbar, A., Ebel, B. E., Andris, L. M., & Qiu, Q. (2016). Cannabis use among drivers suspected of driving under the influence or involved in collisions: Analysis of Washington State Patrol data. Washington, D.C.: AAA.

Bates, M. N., & Blakely, T. A. (1999). Role of cannabis in motor vehicle crashes. *Epidemiologic Reviews, 21*(2), 222-232.

Brady, J. E., & Li, G. (2012). Prevalence of alcohol and other drugs in fatally injured drivers. *Addiction: Research Report*, *108*, 104-114.

Brady, J. E., & Li, G. (2014). Trends in alcohol and other drugs detected in fatally injured drivers in the United States, 1999-2010. *American Journal of Epidemiology*, *179*(6), 692-699.

Capron, B. (2016). Marijuana in Washington State: Pre and post I-502 implementation. Washington State Toxicology Laboratory. Received from brian.capron@wsp.wa.gov

Casanova, T., Hedlund, J., & Tison, J. (2012). *State blood alcohol concentration (BAC) testing and reporting for drivers involved in fatal crashes: Current practices, results, and strategies, 1997-*

2009. (Report No. DOT HS 811 661). Washington, DC: National Highway Traffic Safety Administration.

Center for the Study of Health and Risk Behaviors (2015). University of Washington, Young Adult Health Survey/Marijuana. Seattle, WA. Retrieved from http://learnaboutmarijuanawa.org/factsheets/YAHS%20Marijuana.pdf

Cerda, M., Wall, M., Feng, T., Keyes, K. M., Sarvet, A., Schulenberg, J., O'Malley, P. M., Pacula, R. L., Galea, S., & Hasin, D. S. (2016). Association of state recreational marijuana laws with adolescent marijuana use. *JAMA Pediatrics*, doi:10.1001/jamapediatrics.2016.3624

Downey, L. A., King, R., Papafotiou, K., Swann, P., Ogden, E., Boorman, M. & Stough, C. (2013). The effects of cannabis and alcohol on simulated driving: Influences of dose and experience. *Accident analysis and prevention*, *50*, 879-886.

Dubois, S., Mullen, N., Weaver, B., & Bedard, M. (2015). The combined effects of alcohol and cannabis on driving: Impact on crash risk. *Forensic Science International*, *248*, 94-100.

Ellison, (2012). New Approach Washington, Retrieved from *http://www.newapproachwa.org/*

Farrell, L. J., Kerrigan, S., & Logan, B. K. (2007). Recommendations for toxicological investigation of drug impaired driving. *Journal of Forensic Science*, *52*(5), 1556-4029.

Fergusson, D. M., Horwood, L. J., & Boden, J. M. (2008). Is driving under the influence of cannabis becoming a greater risk to driver safety than drink driving? Findings from a longitudinal study. *Accident Analysis and Prevention, 40*, 1345-1350.

Gerberich, S. G., Sidney, S., Braun, B. L., Tekawa, I. S., Tolen, K. K., & Guesenberry, C. P. (2003). Marijuana use and injury events resulting in hospitalization. *Annals of Epidemiology*, *13*(4), 230-237.

Gjerde, H., Christophersen, A. S., Normann, P. T., & Morland, J. (2011). Toxicological Investigations of driver skilled in road traffic accidents in Norway during 2006-2008. *Forensic Science International*, *212*, 102-109.

Gjerde, H., Normann, P. T., Christophersen, A. S., Samuelsen, S. O., & Morland, J. (2011). Alcohol, psychoactive drugs and fatal road traffic accidents in Norway: A case–control study. *Accident Analysis and Prevention, 43*, 1197-120.

Guo, S, & Fraser, M. W. (2015). *Propensity score analysis: Statistical methods and applications*, 2nd Ed. Thousand Oaks, CA: Sage.

Hall, W. (2015). What has research over the past two decades revealed about the adverse health effects of recreational cannabis use? *Addiction, 110*, 19-35.

Hall, W., Weier, M. (2015). Assessing the public health impacts of legalizing recreational cannabis use in the USA. *Clinical Pharmacology & Therapeutics, 97*(6), 607-615.

Hartman, R. L., Richman, J. E., Hayes, C. E., & Huetis, M. A. (2016). Drug recognition expert (DRE) examination characteristics of cannabis impairment. *Accident Analysis and Prevention*, *19*, 219-229.

Healthy Youth Survey Fact Sheet (2015). *Cannabis Use for Washington State*. Washington State Department of Health. Retrieved from www.askhys.net/FactSheets.

Healthy Youth Survey (2016). 2016 *Washington State Healthy Youth Survey Data Brief: Marijuana*. Washington State Department of Health. Retrieved from http://www.doh.wa.gov/DataandStatisticalReports/DataSystems/HealthyYouthSurvey

Ho, D. E., Imai, K., King, G., & Stuart, E. A. (2007). Matching as nonparametric preprocessing for reducing model dependence in parametric causal inference. *Political Analysis, 15*(3), 199-236.

House Bill 13-1325. Colorado General Assembly. Retrieved from *http://www.leg.state.co.us/clics/clics2013a/csl.nsf/fsbillcont/746F2A0BF687A54987257B5*

Howard, P. D. (2017). The effect of sample heterogeneity and risk categorization on area under the curve predictive validity metrics. *Criminal Justice and Behavior, 44*(1), 103-120.

Huestis, M. A. (2015). Deterring driving under the influence of cannabis. *Addiction, 110*, 1697-1698.

Iacus, S. M., King, G., & Porro, G. (2011). Multivariate matching methods that are monotonic imbalance bounding. *Journal of the American Statistical Association, 106*(493), 3 45-361.

Kahane, C. J. (2016, October). *Comparison of 2013 VMT fatality rates in U.S. States and in high-income countries*. (Report No. DOT HS 812 340). Washington, DC: National Highway Traffic Safety Administration.

Kelly, E., Darke, S., & Ross, J. (2004). A review of drug use and driving: epidemiology, impairment, risk factors and risk perceptions. *Drug & Alcohol Review, 23*, 319-344.

Lacey, J. H., Kelley-Baker, T., Berning, A., Romano, E., Ramirez, A., Yao, J… & Compton, R. *Drug and alcohol crash risk: A case-control study* (Report No. DOT HS 812 355). Washington, DC: National Highway Traffic Safety Administration 2016.

Li, G., Brady, J. E., & Chen, Q. (2013). Drug use and fatal motor vehicle crashes: A case-control study. *Accident Analysis and Prevention*, *60*, 205-210.

Li, M-Ch., Brady, J. E., DiMaggio, C. J., Lusardi, A.R., Tzong, K. Y., & Li, L. (2012). Marijuana Use and Motor Vehicle Crashes. *Epidemiological Reviews*, *34*, 65-72.

Lipari, R. N., Hughes, A., & Bose, J. (2016). *Driving under the influence of alcohol and illicit drugs*. The CBHSQ Report: December 27, 2016. Center for Behavioral Health Statistics and Quality, Substance Abuse and Mental Health Services Administration, Rockville, MD.

Logan, B. K., Kacinko, S. L., & Beirness, D. J. (2016). *An evaluation of data from drivers arrested for driving under the influence in relation to per se limits for cannabis*. Washington, D.C.: AAA.

Logan, B. K., Lowric, K. J., Turri, J. I., Yeakel, J. K., Limoges, J. F., Miles, A. K., Searnco, C. E., Kerrigan, S., & Farrell, L. J. (2013). Recommendations for toxicological investigation of drug-impairing driving and motor vehicle fatalities. *Journal of Analytical Toxicology*, *37*, 552-558.

Lovrich, N.P., Christensen, E., & Routh, D. (2016). Cannabis-impaired driving: The extent of the problem and countermeasures being taken now and to be taken in the future. In Marion, N.E. & Hill, J.B. (Eds.) *Legalizing Marijuana: A Shift in Policies Across America*. pp. 135-160. Durham, NC: Carolina Academic Press.

Masten, S.V., & Guenzburger, G.V. (2014). Changes in driver cannabinoid prevalence in 12 U.S. states after implementing medical marijuana laws. *Journal of Safety Research*, *50*, 35-52.

Movig, K. L. L., Mathijssen, M. P. M., Nagel, P. H. A., van Egmond, T., de Gier, J. J., Leufkens, H. G. M., & Egbert, A. C. G. (2004). Psychoactive substance use and the risk of motor vehicle accidents. *Accident Analysis & Prevention*, *36*, 631-636.

Mura, P., Chatelain, C., Dumestre, V., Gaulier, J. M., Ghysel, M. H., Lacroix, C., Kergueris, M. F., Lhermitte, M., Moulsma, M., Pepin, M., Vincent, F., & Kintz, P. (2006). Use of drugs of abuse in less than 30-year-old drivers killed in a road crash in France: A spectacular increase for cannabis, cocaine and amphetamines. *Forensic Science International*, *160*, 168-172.

Mura, P., Kintz, P., Ludes, B., Gaulier, J. M., Marquet, P., Martin-Dupont, S., Vincent, F., Kaddour, A., Goulle, J. P., 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.

National Highway Traffic Safety Administration (2015). FARS Data Trends. Retrieved on January 2, 2017 at https://www-fars.nhtsa.dot.gov/Trends/TrendsGeneral.aspx

National Highway Traffic Safety Administration (2016a). *Fatalities in the United States*. NHTSA's National Center for Statistics and Analysis. Retrieved on January 2, 2017 at https://crashestats.nhtsa.dot.gov/#/

National Highway Traffic Safety Administration (2016b). *Traffic Safety Facts: 2015 Data, State Alcohol-Impaired Driving Estimates*. NHTSA's National Center for Statistics and Analysis. Retrieved on January 2, 2017 at https://crashestats.nhtsa.dot.gov/#/

National Highway Traffic Safety Administration (2016c). *Traffic Safety Facts: 2015 Data, Alcohol Impaired Driving*. NHTSA's National Center for Statistics and Analysis. Retrieved on January 2, 2017 at https://crashestats.nhtsa.dot.gov/#/

National Safety Council (2016). *NSC Motor Vehicle Fatality Estimates,* National Safety Council. Retrieved on January 2, 2017 at http://www.nsc.org/NewsDocuments/2016/mv-fatality-report-1215.pdf

Northwest High Intensity Drug Trafficking Area (2017). Washington state: Marijuana impact report, V.2. *NWHIDTA* Retrieved from http://www.mfiles.org/home

O'Malley, P. M., & Johnston, L. D. (2007). Drugs and driving by American high school seniors, 2001–2006. *Journal of Studies on Alcohol Drugs, 68*(6), 834-842.

O'Malley, P. M., & Johnston, L. D. (2013). Driving after drug or alcohol use by US high school seniors, 2001-2011. *American Journal of Public Health, 103*(11), 2027-2034.

Pan, W., & Bai, H. (2009). A multivariate approach to a meta-analytic review of the effectiveness of the D.A.R.E. program. *International Journal of Environmental Research and Public Health, 6*(1), 267-277.

Penning, R., Veldstra, J. L., Daamen, A. P., Olivier, B., & Verster, J. C. (2010). Drugs of abuse, driving and traffic safety. *Current Drug Abuse Reviews, 3*, 23-32.

Pollini, R. A., Romano, E., Johnson, M. B., & Lacey, J. H. (2015). The impact of marijuana decriminalization on California drivers. *Drug and Alcohol Dependence*, *150*, 135-140.

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

Richer, I., & Bergeron, J. (2009). Driving under the influence of cannabis: Links with dangerous driving, psychological predictors, and accident involvement. *Accident Analysis and Prevention*, *41*, 299-307.

Rogeberg, O., & Elvik, R. (2016). The effects of cannabis intoxication on motor vehicle collision revisited and revised. *Addiction*, *111*, 1348-1359.

Romano, D., & Pollini, R. A. (2013). Patterns of drug use in fatal crashes. *Addiction: Research report, 108*, 1428-1438.

Rosenbaum, P. R., & Rubin, D. B. (1985). Constructing a control group using multivariate matched sampling methods that incorporate the propensity score. *The American Statistician, 39*(1), 33-38.

Salomonsen-Sautel, S., Min, S-J., & Sakai, J. T. (2014). Trends in fatal motor vehicle crashes before and after marijuana commercialization in Colorado. *Drug and Alcohol Dependence*, *140*, 137-144.

Santello-Tenorio, J., Mauro, C. M., Wall, M. W., Kim, J. H. Cerdá, M., Keyes, K. M., Hasin, D.S., Galea, S., & Martins, S. S. (2016). US Traffic Fatalities, 1985-2014, and their relationship to medical marijuana laws. *Research and Practice*, e1-e7.

Slater, M. E., Castle, I-J. P., Logan, B. K., & Hiingson, R. W. (2016). Differences in state drug testing and reporting by driver type in U.S. fatal traffic crashes. *Accident Analysis and Prevention*, *92*, 122-129.

Subramanian, R. (2002). *Transitioning to multiple imputation – A new method to estimate missing blood alcohol concentration (BAC) values in FARS* (DOT HS 809 403). Washington, DC: National Highway Traffic Safety Administration.

Trevino, R. A., & Richard, A. J. (2002). Attitudes towards drug legalization among drug users. *American Journal of Drug and Alcohol Abuse, 28*(1), 91-108.

Washington State Health and Youth Survey. (2015). *Healthy youth survey fact sheet, Marijuana use for Washington State*.

Washington Traffic Safety Commission (WTSC, 2016). *Driver toxicology testing and the involvement of marijuana in fatal crashes, 2010-2014*. Olympia, WA: WTSC.

West, S. L., & O'Neal, K. K. (2004). Project D.A.R.E. outcome effectiveness revisited. *American Journal of Public Health*, *94*(6), 1027-1029.

Wickens, C. M., Toplak, M. E., & Wiesenthal, D. L. (2008). Cognitive failures as predictors of driving errors, lapses, and violations. *Accident Analysis and Prevention, 40*(3), 1223-1233.

Woratanarata, P., Ingsathit, A., Suriyawongpaisal, P., Rattanasiri, S., Chatchaipun, P., Wattayakorn, K., & Anukarahanonta, T. (2009). Alcohol, illicit and non-illicit psychoactive drug use and road traffic injury in Thailand: A case-control study. *Accident Analysis and Prevention*, *41*, 651-657.

Zhuo, X., Cang, Y., Yan, H., Bu, J., & Shen, B. (2010). The prevalence of drugs in motor vehicle accidents and traffic violations in Shanghai and neighboring cities. *Accident Analysis and Prevention*, *42*, 2179-2184.

APPENDICES

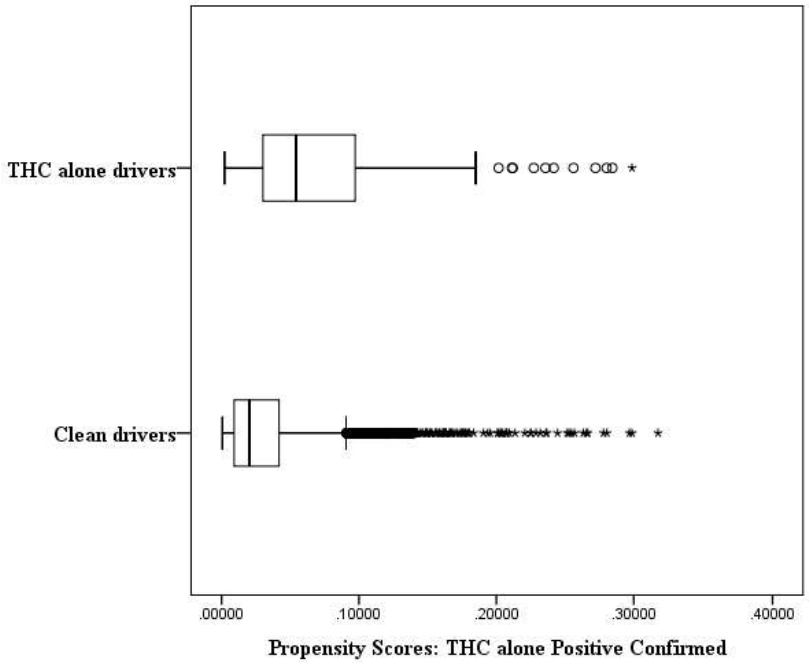
APPENDIX A

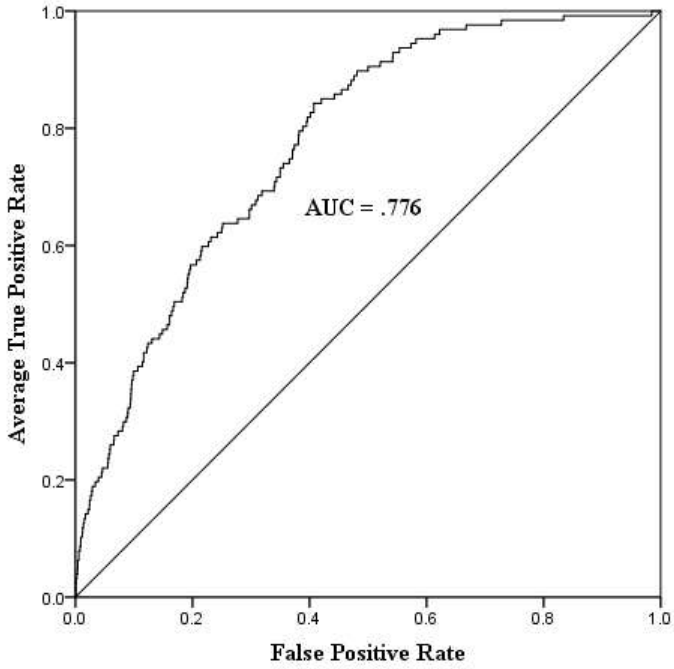
Balancing Statistics on THC alone vs. Clean drivers.

Variable	Before PSM (n = 3,867)				After 1-to-10 PSM (n = 1,040)			
	Clean Drivers Mean	THC Mean	*t* for Difference in Means	STD	Clean Drivers Mean	THC Mean	*t* for Difference in Means	STD
Age	44.45	34.55	7.21***	-57.26	35.85	34.28	1.04	-10.14
Gender (male = 1)	0.72	0.87	-5.06***	37.56	0.87	0.87	0.22	0.00
Unlicensed driver	0.06	0.15	-2.93**	29.35	0.13	0.16	-0.95	8.57
License restrictions	0.31	0.19	3.44**	-28.05	0.21	0.19	0.66	-4.98
Prior DUI records	0.01	0.03	-1.08	13.48	0.02	0.03	-0.86	6.32
Prior other traffic convictions	0.25	0.48	-5.12***	49.04	0.42	0.48	-1.35	12.06
Prior speeding convictions	0.23	0.40	-3.96***	37.14	0.34	0.39	-1.13	10.35
Prior crashes	0.16	0.16	0.01	0.00	0.15	0.16	-0.25	2.77
Time of crash (1 = night)	0.31	0.35	-0.90	8.50	0.34	0.35	-0.35	2.10
Weekends	0.46	0.47	-0.15	2.00	0.48	0.46	0.30	-4.00
Motorcycle	0.08	0.21	-3.43**	37.30	0.18	0.20	-0.62	5.10
Passenger vehicle	0.80	0.78	0.66	-4.90	0.81	0.78	0.74	-7.40
Weather condition (1 = clear)	0.71	0.66	1.09	12.90	0.68	0.66	0.35	12.70
Surface condition (1 = wet)	0.20	0.24	-0.94	9.60	0.24	0.24	-0.19	0.00
Road type (1 = rural road)	0.50	0.43	1.59	8.00	0.46	0.43	0.76	8.00
Road class (1 = county road)	0.23	0.25	-0.55	4.60	0.25	0.26	-0.17	2.30
Number of occupants in vehicle	1.56	1.41	1.92	-16.40	1.40	1.39	0.13	-1.20
Lap and shoulder belt used	0.74	0.51	5.19***	-48.80	0.58	0.51	1.40	-14.10
n	3,737	130			913	127		
AUC		.776				.544		

Note: PSM = propensity score matching; STD = standardized differences; AUC = Area Under the Curve. *p <.05. **p <.01. ***p <.001.

Figure 1. Predicted probability (propensity) for confirming THC alone positive between treatment and comparison groups with ROC curve





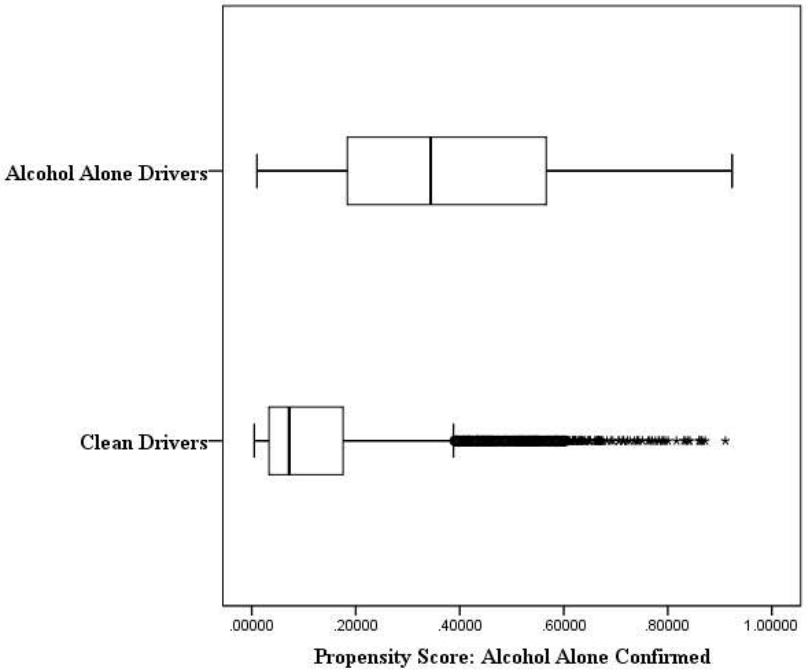
Balancing Statistics on Alcohol alone vs. Clean drivers.

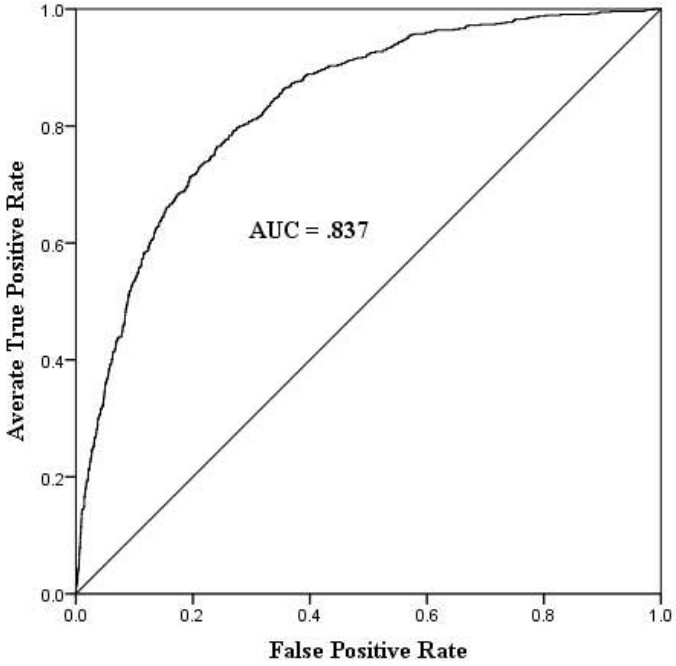
Variable	Before PSM (n = 4,515)				After 1-to-1 PSM (n = 1,322)			
	Clean Drivers Mean	Alcohol Mean	*t* for Difference in Means	STD	Clean Drivers Mean	Alcohol Mean	*t* for Difference in Means	STD
Age	44.45	37.08	11.86***	-42.96	37.63	37.77	-0.16	0.86
Gender (male = 1)	0.72	0.87	-10.98***	37.68	0.86	0.85	0.39	-2.85
Unlicensed driver	0.06	0.21	-9.95***	44.82	0.17	0.16	0.60	-2.71
License restrictions	0.31	0.24	3.90***	-15.73	0.22	0.25	-1.17	7.08
Prior DUI records	0.01	0.07	-5.66***	30.78	0.05	0.05	0.13	0.00
Prior other traffic convictions	0.25	0.39	-7.03***	30.37	0.39	0.37	0.74	-4.12
Prior speeding convictions	0.23	0.33	-5.55***	22.39	0.32	0.31	0.41	-2.15
Prior crashes	0.16	0.15	0.70	-2.79	0.16	0.15	0.30	-2.76
Time of crash (1 = night)	0.31	0.69	-20.97***	82.20	0.64	0.65	-0.57	2.10
Weekends	0.46	0.63	-9.18***	34.70	0.62	0.61	0.11	-2.10
Motorcycle	0.08	0.18	-6.45***	29.90	0.19	0.18	0.43	-2.60
Passenger vehicle	0.80	0.79	0.46	-2.50	0.78	0.79	-0.20	2.40
Weather condition (1 = clear)	0.71	0.75	-2.87**	13.50	0.75	0.75	0.13	13.80
Surface condition (1 = wet)	0.20	0.19	0.83	-2.50	0.20	0.20	0.28	0.00
Road type (1 = rural road)	0.50	0.57	-3.67***	8.00	0.57	0.54	1.16	8.00
Road class (1 = county road)	0.23	0.38	-7.70***	33.00	0.37	0.36	0.51	-2.10
Number of occupants in vehicle	1.56	1.49	1.99*	-7.60	1.44	1.52	-1.52	9.20
Lap and shoulder belt used	0.74	0.38	18.88***	-77.60	0.44	0.43	0.06	-2.00
n	3,737	778			661	661		
AUC		.837				.50		

Note: PSM = propensity score matching; STD = standardized differences; AUC = Area Under the Curve.

*p <.05. **p <.01. ***p <.001.

Figure 2. Predicted probability (propensity) for confirming Alcohol alone positive between treatment and comparison groups with ROC curve





Balancing Statistics on THC + Alcohol vs. Clean drivers.

Variable	Before PSM (n = 3,937)				After 1-to-2 PSM (n = 471)			
	Clean Drivers Mean	THC+Alcohol Mean	*t* for Difference in Means	STD	Clean Drivers Mean	THC+Alcohol Mean	*t* for Difference in Means	STD
Age	44.45	31.94	13.66***	-78.06	31.44	31.43	0.01	-0.08
Gender (male = 1)	0.72	0.84	-4.41***	29.02	0.82	0.84	-0.64	5.29
Unlicensed driver	0.06	0.34	-8.28***	74.44	0.25	0.33	-1.95	17.67
License restrictions	0.31	0.23	2.51*	-18.09	0.21	0.23	-0.63	4.81
Prior DUI records	0.01	0.06	-2.70**	26.54	0.05	0.06	-0.73	4.39
Prior other traffic convictions	0.25	0.54	-7.97***	61.97	0.47	0.54	-1.48	14.01
Prior speeding convictions	0.23	0.38	-4.24***	32.97	0.38	0.38	0.07	0.00
Crash history	0.16	0.17	-0.42	2.71	0.18	0.17	0.25	-2.63
Time of crash (1 = night)	0.31	0.72	-12.70***	90.00	0.65	0.73	-1.93	17.30
Weekends	0.46	0.61	-4.16***	30.40	0.57	0.62	-0.97	10.20
Motorcycle	0.08	0.13	-1.88	16.20	0.16	0.12	1.05	-11.50
Passenger vehicle	0.80	0.85	-1.69	13.10	0.82	0.85	-0.75	8.10
Weather condition (1 = clear)	0.71	0.69	0.35	13.10	0.71	0.69	0.42	13.10
Surface condition (1 = wet)	0.20	0.20	0.15	0.00	0.18	0.20	-0.61	5.10
Road type (1 = rural road)	0.50	0.45	1.42	8.00	0.44	0.45	-0.07	8.10
Road class (1 = county road)	0.23	0.40	-4.73***	37.10	0.41	0.39	0.28	-4.10
Number of occupants in vehicle	1.56	1.58	-0.33	2.20	1.56	1.58	-0.18	2.20
Lap and shoulder belt used	0.74	0.33	11.81***	-89.80	0.41	0.35	1.31	-12.40
n	3,737	200			278	193		
AUC		.876				.579		

Note: PSM = propensity score matching; STD = standardized differences; AUC = Area Under the Curve. *p <.05. **p <.01. ***p <.001.

Figure 3. Predicted probability (propensity) for confirming THC + Alcohol positive between treatment and comparison groups with ROC curve