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Relative Risk of Cannabis, Alcohol, and Their Combination on Driver Behavior in Fatal Crashes in Washington State

Youngki Woo[1]*, Dale W. Willits[2], Mary K. Stohr[2], Craig Hemmens[2] and Staci Hoff[3]

[1]Department of Criminal Justice, University of Texas Rio Grande Valley, BMSLC 3.211, Brownsville, TX 78500
[2]Department of Criminal Justice and Criminology, Washington State University, Wilson-Short 111, Pullman, WA 99164-4872
[3]Research and Data Division, Washington Traffic Safety Commission, 621 8th Ave SE, Ste. 409, Olympia, WA 98504
** Corresponding author. E-mail:* youngki.woo@utrgv.edu, *Phone: 956-882-7446*

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Abstract: The greater availability of cannabis following legalization increases the likelihood that more drivers will drive drugged, rendering the determination of its effect on crashes a matter of vital public policy interest. For criminal justice agencies, this issue takes on increased importance, as drugged driving is a criminal offense. We examine the relative risk of cannabis (Delta-9-Tetrahydrocannabinols [hereafter THC]), alcohol, and the combination of the two, on fatal crashes in Washington state, using data from the Washington Coded Fatal Crash (WA-CFC) Files, which includes appended toxicology results. Findings indicate the presence of alcohol or the combination of alcohol and THC in the blood of a driver involved in a fatal crash is more likely to be associated with risky driving behaviors, fatal injuries, and death compared to THC alone.

Keywords: cannabis; fatal crashes; propensity score analysis, Washington, WA-CFC

Introduction

Driving under the influence of drugs (DUID) is a dangerous crime and a serious threat to public safety (Benedetti *et al.*, 2021; Berning, Compton, & Wochinger, 2015; Brady & Li, 2012; Compton & Berning, 2015; Dahlgren *et al.*, 2020; Dubois, Mullen, Weaver,

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& Bédard, 2015; Hartman & Huestis, 2013; Romano & Voas, 2011; Slater, Castle, Logan, & Hingson, 2016). After alcohol, cannabis is the most commonly used and frequently detected drug among crash-involved drivers in the United States (Bates & Blakely, 1999; Brady & Li, 2012; Compton & Berning, 2015; National Institute on Drug Abuse [NIDA], 2016). The 2018 National Survey on Drug Use and Health (NSDUH) reported that approximately 12.6 million drove under the influence of illicit drugs in 2018 (NIDA, 2019). This makes impaired driving one of the most commonly committed crimes in the United States. Several studies have shown that approximately one-third of fatally injured drivers in the United States tested positive for drugs and 20% of fatally injured drivers tested positive for polydrugs (Brady & Li, 2012; Romano & Voas, 2011). Even before cannabis became legal for recreational use in many states, it was the most frequently detected drug among crash-involved drivers (Washington Traffic Safety Commission [WTSC], 2018).

Given the increasing prevalence of DUID (Berning *et al.*, 2015; Brady & Li, 2012, 2014; Dubois *et al.*, 2015) following cannabis legalization for recreational use in states like Colorado and Washington, considerable attention has been paid to cannabis legalization because of its likely economic, public health, and public safety concerns (Aydelotte *et al.*, 2019). Of particular concern is the impact of cannabis legalization on the incidence of drugged driving. Yet, the contribution of THC, which is the psychoactive chemical in cannabis, to drugged driving and any increased risk of traffic crashes remains somewhat limited (Atchison, 2017; Dahlgren et al., 2020; Lacey et al., 2016)" is revised to "Yet, the contribution of THC, which is the psychoactive chemical in cannabis, to drugged driving and any increased risk of traffic crashes remains somewhat understudied (Atchison, 2017; Dahlgren *et al.*, 2020; Lacey *et al.*, 2016). While alcohol intoxication is one of the strongest predictors of fatal crashes (Dubois *et al.*, 2015; Kelly, Darke, & Ross, 2004; Li, Brady, & Chen, 2013; Penning, Veldstra, Daamen, Olivier, & Verster, 2010), the extant empirical evidence examining the effects of THC intoxication on fatal crashes has shown mixed results (Bates & Blakely, 1999; Blows *et al.*, 2005; Hartman, Richman, Hayes, & Huestis, 2016). In addition, most studies make use of perhaps overly simple measures of cannabis. Most studies utilize data that includes a dichotomous measure of the presence of cannabis and often rely on urine tests to confirm a cannabis positive finding, which is a test that does not distinguish between THC and carboxy-THC which is the inactive metabolite of THC in cannabis (Washington Traffic Safety Commission, 2018). In short, carboxy-THC may be in the bloodstream for weeks and does not indicate that the person is currently impaired (Dahlgren *et al.*, 2020). Therefore, the reliance on urine tests and the inclusion of those who may not have been impaired in their analyses is likely to have resulted in mixed or null conclusions (Ramaekers, Berghaus, van Laar, & Drummer, 2004; Washington Traffic Safety Commission, 2018).

One of the major limitations of the prior research is derived from unobserved heterogeneity (Mannering & Bhat, 2014; Mannering, Shankar, & Bhat, 2016). As there is a lack of determinants of motor vehicle crashes and fatalities involved in drugs (Fell, Kubelka, & Treffers, 2018), investigation of potential correlates of fatal crashes and substance use might be an initial step to conduct research on fatal crashes. Using the Washington Coded Fatal Crash (WA-CFC) Files for the years 2008-2017, this study replicated and extended a prior research (Woo, Willits, Stohr, Hemmens, and Hoff, 2019) by identifying potential confounders that are causally related to substance use and fatal crashes through the examination of (a) individual-level correlates of THC; (b) ecological-level correlates of THC; (c) vehicle-level and other external-level correlates of THC; and. (d) substance-level correlates of THC. Given this research and the prior literature on the effects of THC on drivers' risky behavior and fatal crashes, the current study attempts to further explore the gap in knowledge about these effects by examining the links between THC, alcohol, their interaction, and driver behavior and undesirable outcomes in fatal crashes using a quasi-experimental method (Propensity Score Matching and Weighting). Measuring the relative risk of cannabis and alcohol on driver behavior and fatal crashes is crucial to determining the appropriate policy modifications to deal with this serious public health and safety issue.

Literature Review

Cannabis Legalization in Washington

As of March 2023, 21 states have legalized cannabis for recreational use. Along with other states like California and Colorado, Washington State is one of the front runners in legalizing cannabis in the United States. In 1998, Washington voters approved a medical cannabis law (I-692, which passed with 59% of the vote); in 2003 and 2011, voters in Seattle and Tacoma, two of Washington's most populous cities, passed initiatives that made possession of cannabis a low priority for police enforcement.

On November 6, 2012, the state of Washington passed I-502 on cannabis legalization with 56% of the popular vote in support. Specifically, possession of up to 1 oz (28g) of recreational cannabis by adults 21 and over became legal, but private cultivation for recreational users and sale remained illegal. Moreover, I-502 set up a *per se* legal limit for driving under the influence (DUI), establishing that a person aged 21 years or older is in violation of DUI law when the person has 5.00 or more nanograms of THC concentration in the blood while driving (R.C.W. 46.61.502). The law also established that a person under the age of 21 is in violation of DUI law if the person has, within 2 hours after operating or being in physical control of a motor vehicle, any detectable THC concentration in the blood (R.C.W. 46.61.503).

Cannabis Legalization, Cognitive Impairment, and Safety Risks Associated with Cannabis Use

Findings from many studies have shown negative cognitive effects of cannabis use in the domains of abstraction/executive functioning, attention, verbal/language abilities, and driving skills such as lane position, higher variation in speed, prolonged reaction time and longer time to decide (Brubacher *et al.*, 2019; Downey *et al.*, 2013; Huestis, 2015; Nazif-Munoz, Oulhote, & Ouimet, 2020; Schreiner & Dunn, 2012). Given these findings, there is clear reason to examine the link between cannabis impairment and driving performance, especially in the context of legalization (Benedetti *et al.*, 2021; Chow *et al.*, 2019). Whether legalization of cannabis for recreational use causes increased number of fatal crashes and the role social contexts may play in such drug use behavior is unclear (Ellickson, Tucker, Klein, & Saner, 2004; Foster, Ecker, Zvolensky, & Buckner, 2015; Rosekind, Ehsani, & Michael, 2020). Because cannabis legalization could lead to greater accessibility (Brady & Li, 2012; Cerda *et al.*, 2012; Chihuri *et al.*, 2017; O'Malley & Johnston, 2007) and make it more acceptable and affordable to use (Cerda *et al.*, 2016), recreational cannabis laws may have an adverse influence on young adults' and adolescents' health and safety (Aydelotte *et al.*, 2019), in terms of the development of delinquent peer networks, substance abuse and drug addiction, and harmful incidents such as violence, DUID, and fatal crashes. Using a sample of 10,924 university students in Oregon, for example, Kerr and colleagues (2017) found that rates of cannabis use increased from pre- to post-recreational cannabis legalization (cannabis legalization for recreational purposes went into effect in Oregon in July 2015) at six of the seven universities studied. They also found that increases in rates of cannabis use were stronger among Oregon students than non-legalization state students, but only within the subsample of students who reported recent heavy alcohol use. They concluded that recreational cannabis legalization accounted for the increase in cannabis use among Oregon students, and that the effects of recreational cannabis legalization vary based on individual and contextual factors. Indeed, the relationship between deviant behavior and drug use is firmly established in criminology and generally supported by a large body of empirical research indicating that drug users are more likely to engage in delinquency, risky behaviors, and criminal activities (Blumstein, Cohen, Roth, & Visher, 1986; Gottfredson & Hirschi, 1990; Sullivan & Piquero, 2010).

Cannabis and Driving

Effects of Cannabis Use on Motor Vehicle Crash Risk. DUID is a serious threat to public safety nationally and internationally (Berning *et al.*, 2015; Brady & Li, 2012; Compton & Berning, 2015; Dubois *et al.*, 2015; Hartman & Huestis, 2013; Romano & Voas, 2011; Slater *et al.*, 2016). In the United States, cannabis is the most widely

used illicit drug (WTSC, 2016). It is also one of the most commonly detected non-alcoholic drugs in drivers involved in fatal and nonfatal crashes in the United States and worldwide (Brady & Li, 2012, 2014; Farrell, Kerrigan, & Logan, 2007; Romano & Pollini, 2013; WTSC, 2016, 2018; Woratanarata *et al.*, 2009). Comparing trends in drug use among drivers killed in crashes in the United States from 2009-2010 to 1999-2000, Rudisill, Zhao, Abate, Coben, and Zhu (2014) found that the prevalence of drug use among these drivers increased 49% (Rate Ratio [RR] = 1.49; CI 95% 1.42-1.55). The largest increases in broad drug categories were narcotics (RR = 2.73; CI 95% 2.41-3.08), depressants (RR = 2.01; CI 95% 1.80-2.25), and cannabinoids (RR = 1.99; CI 95% 1.84-2.16). 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. Moreover, the WTSC (2018) reported that after alcohol, cannabis is the most prevalent drug, and alcohol and drugs are the most important factors affecting impaired driving in fatal crashes in the state of Washington.

The psychoactive chemical in cannabis, THC, has been linked with driver culpability such as impaired driving, driving risks, causing short- and long-term driving impairment and fatal crashes (Aydelotte *et al.*, 2019; Dahlgren *et al.*, 2020; Drummer *et al.*, 2004; Laumon, Gadegbeku, Martin, & Biecheler, 2005; Lenné *et al.*, 2010). Using a sample of Australian drivers killed in traffic crashes from 1990-1999, Drummer *et al.* (2003) found that cannabis in the blood of drivers was more frequently detected in single-vehicle crashes than in multiple-vehicle crashes (16% versus 11%). Moreover, Lenné *et al.* (2010) found that high levels of cannabis generally led to greater driving impairment than lower levels of cannabis. They also found that both alcohol and cannabis were associated with speeding and lateral position variability. In addition, several studies have revealed that cannabis use is associated with poor driving performance, including an increase in weaving, poor reaction time, altered attention to the road, and the standard deviation of lateral position (Arkell *et al.*, 2020; Hartman *et al.*, 2015; Hartman & Huestis, 2013; Lenné *et al.*, 2010). Epidemiologic and case-control studies have also demonstrated that cannabis consumption before driving may substantially increase the risk of fatal crash involvement (Asbridge, Hayden, & Cartwright, 2012; Chihuri, Li, & Chen, 2017; Li *et al.*, 2012).

Still, the evidence regarding cannabis is not unequivocal. Some research demonstrates that the effects of cannabis are not as pronounced as other substances. For example, in a study of drug use and fatal crash assessment in the United States, researchers found that the presence of cannabis increased the odds of a fatal crash, but less so than other drugs, such as narcotics, stimulants, and depressants (Li, Brady, & Chen, 2013). Brubacher and colleagues (2019) found that with a sample of non-fatally injured motor vehicle drivers in British Columbia in Canada, there was no evidence of

increased crash risk in drivers with THC less than 5 ng/mL. Moreover, findings from a by Blows and colleagues (2005) indicated that cannabis use was not a significant predictor for vehicle crash injury after controlling for confounding variables (e.g., BAC, speed, and seat-belt use).

Many questions still remain about the effects of cannabis use on motor vehicle crash risk (Benedetti *et al.*, 2021; Dahlgren *et al.*, 2020; Lacey *et al.*, 2016; Lenné *et al.*, 2010). Particularly, the contribution of THC to drugged driving and any increased risk of traffic crashes remains unclear (Atchison, 2017; Lacey *et al.*, 2016; McCartney, Arkell, Irwin, & McGregor, 2021). Indeed, while alcohol intoxication is found to be one of the strongest predictors of fatal crashes (Dubois *et al.*, 2015; Kelly *et al.*, 2004; Li *et al.*, 2013; Penning *et al.*, 2010), the empirical evidence examining the effects of THC intoxication on fatal crashes has shown mixed results (Bates & Blakely, 1999; Benedetti *et al.*, 2021; Hartman *et al.*, 2016) with little attention placed on the role of cannabis in polydrug use. Other research suggests that while cannabis is a factor involved in risky driving behavior (Asbridge *et al.*, 2012), alcohol is a much larger risk factor and that the magnitude of the interaction between alcohol and cannabis may be overstated (Woo *et al.*, 2019).

Effects of Combining Alcohol and Cannabis on Motor Vehicle Crash Risk

Interaction effects of multiple substances on drivers involved in fatal crashes may be substantially greater than the effect derived from one substance (Brady & Li, 2012; WTSC, 2016). However, several prior studies have reported weak or no interaction effect of cannabis and alcohol (Lamers & Ramaekers, 2001; Liguori *et al.*, 2002). For example, with 12 subjects (4 female, 8 male, 1 African American, 11 Caucasian) between the ages of 21 and 45, Liguori *et al.* (2002) examined the separate and combined effects of alcohol and cannabis on simulated emergency braking and dynamic posturography. They found that there were no combined effects of alcohol and cannabis on driver mood or behavior.

However, other empirical evidence has generally supported the assertion that the combination of alcohol and cannabis creates a higher risk of driving impairment and fatal crashes (Brady & Li, 2012; National Highway Traffic Safety Administration [NHTSA], 2000). Indeed, the presence of both cannabis and alcohol is the most commonly discovered poly-drug combination in the general driver population (Berning *et al.*, 2015), and the combination of drugs and alcohol has been found to be the most lethal in terms of fatalities (Dubois *et al.*, 2015; Li *et al.*, 2013). In a double-blind and placebo-controlled driving simulator study of Australian younger drivers impaired by different levels of alcohol and THC, Downey *et al.* (2013) found that performance was most impaired when drivers had both alcohol and THC in their blood. They also noted

that THC was 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. Several simulation studies have shown consistent findings that use of alcohol with cannabis made drivers more impaired, causing even more lane weaving (Hartman *et al*., 2015; Lenné *et al*., 2010). As Chihuri *et al*. (2017) stated, it is important to understand how cannabis and its interactions with alcohol and other drugs affect drivers involved in traffic crashes. Moreover, as access to cannabis increases in many states, this question takes on increased importance, as it is likely that the number of drivers who have consumed has increased.

Systematic Review and Meta-Analyses. Early meta-analytic studies examining the effects of THC intoxication on fatal crashes showed unclear and mixed results. Using a systematic search, for example, Bates and Blakely (1999) found that alcohol intake increased fatalities in all studies, and the combination of cannabis and alcohol increased the likelihood of a fatal crash. However, they also reported that the presence of cannabis in the drivers did not increase the odds of a fatal crash in most studies. The authors admitted that the latter finding might be related to the inclusion of drivers with only carboxy-THC in their blood, which is an inactive metabolite of THC. In this respect, many previous studies, including meta-analytic studies, may have arrived at mixed or null conclusions because the drivers with carboxy-THC in their blood were not actually impaired at the time they were tested (Ramaekers *et al*., 2004; WTSC, 2018).

Given the increasing awareness of the data issue regarding the measurement of cannabis use, recent meta-studies have reviewed and screened prior studies more thoroughly. Asbridge *et al*. (2012) included observational epidemiology studies of motor vehicle collisions with an appropriate control group. Additionally, they selected empirical studies where measures of recent cannabis use in drivers were confirmed by toxicological analysis of blood or self-report. They excluded experimental or simulator studies due to the fact that the relationship between cannabis use and crash risk is unclear with regard to driving ability and collision risk outside the laboratory, though laboratory studies have consistently shown the negative effects of cannabis use on driving performance (Asbridge *et al*., 2012). Consequently, nine studies from five countries published from 1982 to 2007 were selected in the meta-analysis, and Asbridge *et al*. (2012) found that drivers who were under the influence of cannabis experienced more motor vehicle crashes compared with unimpaired drivers (*OR* = 1.92 [95% CI: 1.35 to 2.73]; P = 0.0003). They also found that the odds of collision risk were greater in case-control studies (*OR* = 2.79 [95% CI: 1.23 to 6.33]; P = 0.01) and studies of fatal collisions (*OR* = 2.10 [95% CI: 1.31 to 3.36]; P = 0.002) than in studies of non-fatal collisions (*OR* = 1.74 [95% CI: 0.88 to 3.46]; P = 0.11) and in culpability studies (*OR* = 1.65 [95% CI: 1.11 to 2.46]; P = 0.07) (Asbridge *et al*., 2012).

Similarly, Li *et al.* (2012) conducted a meta-analysis of nine epidemiologic studies written in English from six countries, published from 2001 to 2010. Of the nine studies, two studies assessed cannabis use based on blood tests, two used urine tests, and five used self-reported data. They found that cannabis use by drivers was associated with a significantly increased risk of motor vehicle crashes. More specifically, the studies that employed self-reported data showed a crash risk 1.7 to 7.16 times greater, the studies that used urine tests showed 0.85 to 3.43 times the risk, and the studies that used blood tests showed a crash risk 2.10 to 2.11 times greater. The overall odds ratio estimated from the random-effects model was 2.66 (Li *et al.*, 2012).

While the meta-analysis by Li *et al.* (2012) included data from studies that relied on urine or blood samples confirming the presence of carboxy-THC alone, the meta-analysis by Asbridge *et al.* (2012) included only data from studies that relied on blood samples confirming the presence of THC. As with Li *et al.*'s (2012) study, Asbridge *et al.* (2012) also included two studies that used direct self-reported data (reporting use in the 3 hours before the crash). Rogeberg and Elvik (2016) stated that while the selection criteria for Li *et al.*'s study (2012) were unclear and difficult to rationalize, the study selection criteria used by Asbridge *et al.* (2012) were clear. Interestingly, Rogeberg and Elvik (2016) replicated the two meta-studies performed by Li *et al.* (2012) and Asbridge *et al.* (2012) and reported that "the replication study substantially revised previous risk estimates downwards, with both the originally reported point estimates lying outside the revised confidence interval" (p. 1,348). They further conducted a meta-analysis including 21 observational studies from 13 countries published in the period 1982-2015. They found that cannabis-impaired driving was associated with a significant increase in motor vehicle crashes, with a low to moderate magnitude (random effects model odds ratio: 1.36 [CI: 1.15-1.61], meta-regression odds ratio: 1.22 [CI: 1.1-1.36]) (Rogeberg & Elvik, 2016).

A recent meta-analytic study examining the effects of cannabis usage and unfavorable traffic events produced mixed results. Hostiuc and colleagues (2018) performed a meta-analysis to examine whether driving under the influence of cannabis (DUIC) was associated with an increased risk of unfavorable driving outcomes compared to chronic cannabis use. They included observational studies of motor vehicle collisions that used a control or comparison group and were published after 2000. They also excluded case studies without a control group and studies with a lack of relevant information needed for the analysis. From the selection criteria, studies that relied on urine tests, blood tests, self-report, and official databases were included, and 24 observational studies were finally selected in the meta-analysis. Of the 24 studies, nine studies assessed cannabis use based on blood tests, three studies contained THC blood levels above 0.5 ng/mL, eight studies were based on self-reported data, and five studies contained data about

chronic cannabis use. Using a random effects and inverse variance heterogeneity model, Hostiuc and colleagues found that the overall effect size for DUIC on unfavorable traffic outcomes was not statistically significant. However, they reported significant differences between subgroups. For example, they found significant increases in the effect size for DUIC tested through blood analysis (*OR* = 2.27 [CI: 1.36-3.80]). In addition, they found significant increases in the effect size for driver death (*OR* = 1.56 [CI: 1.16-2.09]), and case-control studies as a type of study (*OR* = 1.19 [CI: 1.05-3.80]).

More recently, McCartney and colleagues (2021) performed multiple meta-regression analyses and they found that regular cannabis users are less likely impaired than occasional cannabis users and the magnitude of impairment by THC varied by other factors.

In sum, given the increased availability and accessibility of cannabis due to changes in international and domestic drug policies, the public and policymakers have concerns about substance abuse and public safety because cannabis use and cannabis legalization may be associated with risky behaviors such as DUID. There are many previous studies, including meta-analyses, examining the effects of cannabis use on fatal crashes, but they have shown mixed results. However, there are several issues with these prior studies. First, several of them relied on inaccurate measures, such as the use of urine tests rather than the more reliable blood tests to identify cannabis use. In addition, data used for prior studies typically did not isolate the primary psychoactive chemical, THC; they indicated whether drivers were cannabis or cannabinoids positive only, without identifying whether drivers were positive for THC or inactive chemicals such as carboxy-THC. These limitations may explain why some of the previous studies of the effects of cannabis use on fatal crashes arrived at mixed or null conclusions. Moreover, several prior studies relied on experimental or simulator studies, but the effects of cannabis use on driving performance in the lab may differ from effects on the real road.

Based on the limitations of the prior research, the current study examines the link between THC and driver errors and crash characteristics in fatal crashes in Washington state using a robust quasi-experimental design in which drivers who test positive for THC are matched to drivers who test negative for any drugs, to better estimate the independent effects of THC consumption on driver outcomes in fatal crashes. Given the extant research on the likely effects of THC in drivers on circumstances surrounding a crash, or a fatal crash, our research hypotheses are as follows:

1. For fatal crashes in Washington, drivers who test positive for (A) THC, (B) alcohol, and (C) the combination of THC and alcohol are more likely to have engaged in risky driving behaviors than drivers who tested negative for any alcohol and non-alcohol drugs.

2. For fatal crashes in Washington, drivers who test positive for (A) THC, (B) alcohol, and (C) the combination of THC and alcohol are more likely to be fatally injured than drivers who tested negative for any alcohol and non-alcohol drugs.
3. Contextual conditions of fatal crashes involving drivers with the presence of (A) THC, (B) alcohol, and (C) the combination of THC and alcohol differ from contextual conditions of fatal crashes involving drivers who tested negative for any alcohol and non-alcohol drugs in Washington.
4. For fatal crashes in Washington, drivers who test positive for (A) THC, (B) alcohol, and (C) the combination of THC and alcohol are more likely to be in head-on collisions, cross the centerline, and run off the road than drivers who tested negative for any alcohol and non-alcohol drugs.

Data and Methods

Data

The data for this study comes from the Washington Coded Fatal Crash (WA-CFC) Files for the years 2008-2017. WA-CFC data provide information on all fatal crashes in the state of Washington and are organized into person-level and incident-level records and includes supplemental information from toxicology outcomes on drivers. The WA-CFC data is especially useful for examining the role of THC in driving outcomes, as the WA-CFC contains specified blood level THC results (delta-9 versus other cannabis metabolites) for all persons in fatal crashes who were blood tested for intoxicants. Consequently, this study relies solely on blood test results regarding THC, carboxy-THC, and Alcohol (blood alcohol concentration) variables.

Sample Selection

For these analyses, we used WA-CFC data from January 2008 to December 2017 and the fatal crash-involved driver (both surviving and deceased) was the unit of analysis. The total sample consisted of 11,477 individuals involved in fatal crashes in Washington between January 2008 and December 2017. Among these 6,728 drivers, 17 drivers under the age of 16, 60 drivers aged unknown, and 17 drivers aged not reported were excluded from the current study. Therefore, our overall sample is 6,634 drivers involved in fatal crashes in Washington.

Acknowledging that there were some cases of not reported, unknown test type, other test type, and unknown if tested, and not all drivers are tested for drugs and alcohol, we further restricted the samples to those who had been blood tested for

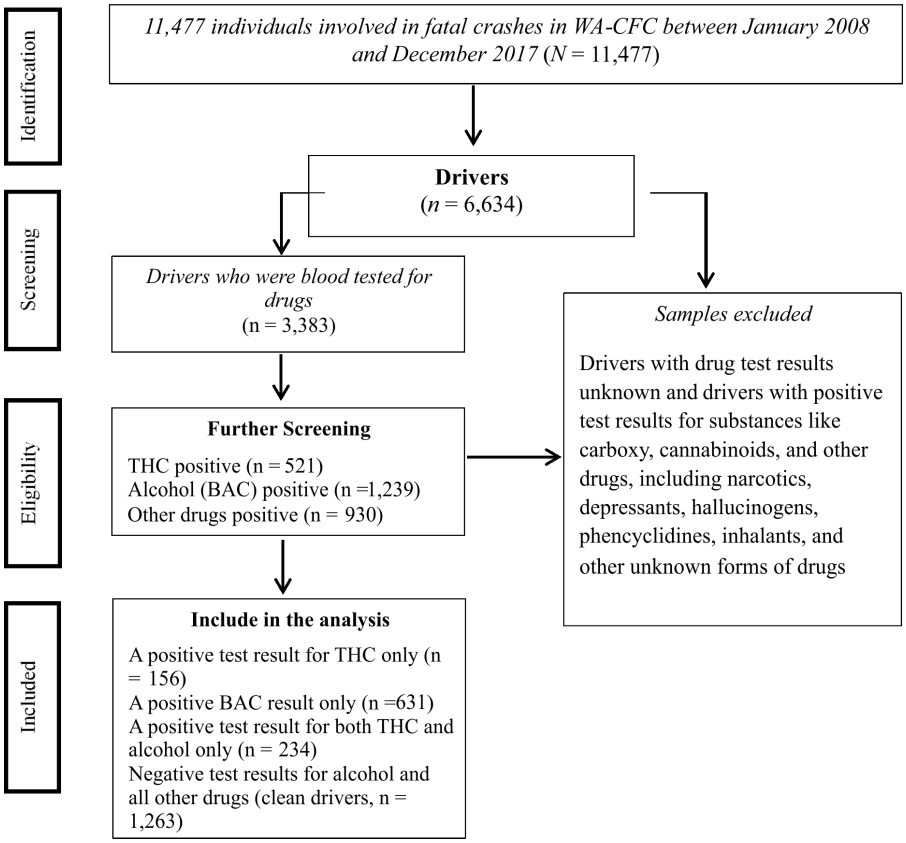

Figure 1: Sample selection process

intoxicants with known results (n = 3,383), of whom 521 were THC positive, 1,239 were alcohol (BAC) positive, and 930 were positive for other drugs. The drug-tested driver sample was further grouped into drivers who had negative test results for alcohol and all other drugs (clean drivers, n = 1,263), drivers with a positive test result for THC only (n = 156), drivers with a positive BAC result only (n = 631), and drivers with a positive test result for both THC and alcohol only (n = 234). To eliminate the effects of any other drugs, drivers with a positive test result for any other intoxicating substance including narcotics, depressants, hallucinogens, phencyclidine, inhalants, and other unknown forms of drugs were excluded in the final analytic sample.

Outcome Measures

We analyzed four study outcomes: (1) drivers' risky behaviors, (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 behaviors,

such as evidence of speeding, driving errors[1], and traffic violations. Given that many of these variables occurred relatively infrequently, we combined these measures into two dichotomous outcome variables that fall under driver's risky behaviors, including speeding and driver errors (identified by police).

For the second outcome, driver harm was measured using two dichotomous measures, fatal injuries and death on the scene. Due to drugged driving, it is possible to assume that drivers with the presence of THC, alcohol, and combined THC and alcohol are less likely to protect themselves at the time of the crash, thereby being more "fatally injured" and "died at the scene" when compared to clean drivers. Further, it is possible that DUID crashes are more severe, increasing the likelihood of driver fatality. The contextual/environmental conditions of the fatal crash were also included in study outcomes, such as: number of vehicles in the crash, whether a motorcycle, bicycle or pedestrian was involved, and the number of fatalities that occurred from the crash. Evidence from controlled experiments and simulator studies has shown that cannabis and alcohol intoxication generate a variety of deficits that diminish driving performance, such as lack of focus and concentration, poor tracking ability and decision making, slower reaction times, and decreased car handling (Brubacher *et al.*, 2019; Desrosiers, Ramaekers, Chauchard, Gorelick, & Huestis, 2015; Khiabani, Bramness, Bjørneboe, & Mørland, 2006; Ramaekers, Kauert, Theunissen, Toennes, & Moeller, 2009).

Finally, we examined whether some forms of collision type differed significantly by study group, including "head-on," "cross centerline," and "run off the road." We argue that certain collision types in fatal crashes such as "head-on," "cross centerline," and "run off the road" are potential indicators of driving impairment or, at least, driving fault and explore the link between these outcomes and THC, alcohol, and interaction of THC and alcohol use.

Treatment Variables and Balancing Covariates

Based on prior studies that highlighted the confounded nature of THC and alcohol (Dubois *et al.*, 2015; Hartman *et al.*, 2016; Li *et al.*, 2013), alcohol and THC consumption are selected as treatment variables and measured 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. THC alone was measured through a single variable that indicated whether the driver tested positive for THC only (we omitted cases with only carboxy-THC). Alcohol positive results were 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 blood alcohol content and THC only, with no positive test for any other substance and no positive

test for combining alcohol/THC and other drugs. A total of 17 variables that were significantly related at the bivariate level to THC and alcohol presence were selected as covariates (see Table 1).

Data Analysis

The current study used propensity score analysis (PSA) to examine the effects of THC and alcohol in blood on detrimental outcomes in fatal crashes. PSA 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. PSA is 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 PSA 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 effects than traditional multivariate regression modelling (Ho, Imai, King, & Stuart, 2007; Iacus, King, & Porro, 2011). In the present study, THC-positive subjects, alcohol-positive subjects, and subjects positive for both THC and alcohol (treatment groups) were matched to clean subjects who tested negative for all drugs and alcohol (comparison group) in terms of near-identical probabilities of presence of THC and alcohol.

We performed a series of propensity score weightings (PSW) for estimating average treatment effect for the treated (ATT). The procedure for the PSW analysis included three steps. First, drawing upon prior literature and correlation analyses using WA-CFC, a set of balancing covariates that were significantly related at the bivariate level to alcohol and THC presence were selected (see Table 1) and then a binary logistic regression model (results available upon request) was used to estimate propensity scores.

Second, average treatment effect for the treated (ATT) was estimated. For estimating ATT, weights were computed by taking 1 divided by the propensity score for THC-positive, alcohol-positive, and THC-plus-alcohol-positive subjects and the inverse was processed (propensity score/1-propensity score) for comparison subjects (clean drivers). The ATT is the weight for only those cases that received treatment.

Finally, diagnostic tests were then performed to examine whether the group balance was appropriately achieved by the PSW. This assessment includes examination of box-plot and bivariate tests that includes comparison of all covariate means between the two groups prior to and following the weighting procedure (all available upon request).

Prior to the weight for estimating ATT, seven (THC alone), twelve (alcohol alone), and thirteen (combining alcohol and THC) of the seventeen-item means were

Table 1: Descriptive Statistics for Study Variables

Variable	*THC Alone (n = 156)*		*Alcohol Alone (n = 631)*		*THC + Alcohol (n = 234)*		*Clean Drivers (n = 1,263)*			
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Min*	*Max*
Age	34.19	14.93	36.82	14.85	32.43	12.67	45.90	20.41	16	97
Gender (male = 1)	0.87	0.34	0.86	0.35	0.82	0.38	0.76	0.43	0	1
Unlicensed driver (yes = 1)	0.14	0.35	0.21	0.40	0.33	0.47	0.04	0.20	0	1
License restrictions (yes = 1)	0.22	0.42	0.25	0.43	0.23	0.42	0.36	0.48	0	1
Prior DUI records (yes = 1)	0.03	0.18	0.07	0.26	0.07	0.25	0.02	0.13	0	1
Prior other traffic convictions (yes = 1)	0.45	0.50	0.38	0.49	0.51	0.50	0.24	0.43	0	1
Prior speeding convictions (yes = 1)	0.39	0.49	0.33	0.47	0.38	0.49	0.25	0.44	0	1
Prior crashes (yes = 1)	0.18	0.38	0.15	0.36	0.19	0.40	0.16	0.37	0	1
Time of crash (1 = night)	0.34	0.48	0.69	0.46	0.72	0.45	0.30	0.46	0	1
Weekends (yes = 1)	0.44	0.50	0.62	0.49	0.61	0.49	0.44	0.50	0	1
Motorcycle (yes = 1)	0.22	0.41	0.19	0.39	0.12	0.33	0.17	0.37	0	1
Passenger vehicle (yes = 1)	0.74	0.44	0.77	0.42	0.81	0.39	0.71	0.46	0	1
Weather condition (1 = clear)	0.70	0.46	0.73	0.44	0.68	0.47	0.71	0.45	0	1
Surface condition (1 = dry)	0.26	0.42	0.20	0.40	0.22	0.42	0.19	0.39	0	1
Road class (1 = county road)	0.25	0.44	0.37	0.48	0.41	0.49	0.24	0.43	0	1
Number of occupants in vehicle	1.38	0.85	1.45	0.84	1.56	0.85	1.40	0.86	1	5
Heavy truck involved (yes = 1)	0.08	0.27	0.06	0.23	0.05	0.22	0.19	0.39	0	1

Note: Clean Drivers refer to drivers with negative blood tests for alcohol and non-alcohol drugs.

significantly different between the two groups. After the weighting procedure, all the significant group differences on treatment subjects versus clean drivers were removed, indicating that selection bias was substantially reduced and the propensity weight was performed successfully (results available upon request).

Results

Results 1: THC Drivers VS. Clean Drivers

Table 2 shows the results of differences in outcomes by study group (THC-alone subjects vs. clean subjects) before and after PSW. Prior to the balancing there were significant differences in speeding, fatal injury, death at the scene, and crossing the centerline between the two groups, indicating that the THC-alone subjects were at greater risk than clean drivers on the road. Nonsignificant differences on other forms of outcomes were found. After weighting procedures, however, differences in speeding and died at the scene disappeared, but fatal injury and crossing the centerline remained marginally or statistically different. Specifically, after the weight by ATT, drivers who tested positive for THC were more likely to be fatally injured and engage in crossing the centerline. These findings indicate full support for research hypothesis 2 and partial support for research hypotheses 1 and 4, and no support for research hypothesis 3. Overall, with the exception of crossing the centerline, it is not clear that the presence of THC alone in the drivers' blood is related to these risky driver outcomes.

Results 2: Alcohol Drivers VS. Clean Drivers

Table 3 presents the results of differences in outcomes by study group (BAC-alone subjects vs. clean subjects) before and after PSW. Prior to weighting there were significant differences in most outcomes of interest between the two groups, other than motorcycle involved, bicycle involved, and number of fatalities in crash. It indicates that the alcohol-alone subjects were much more at risk for serious negative outcomes than clean drivers. Specifically, alcohol-alone subjects were more likely to engage in speeding and driver error, be fatally injured, die at the scene of the crash, cross the centerline, and run off the road.

After weighting procedures, differences in driver errors disappeared, but most other study outcomes remained statistically different. In addition, significant differences on other outcomes that were previously non-significant differences were found, including motorcycle involved in crash. More specifically, alcohol-alone subjects were more likely to engage in speeding, be fatally injured, die at the scene of the crash, cross the centerline, and run off the road compared to clean drivers. These findings indicate full support for research hypotheses 2 and 4, partially support hypothesis 1, and a lack of support for

Table 2: Outcomes Comparisons by Study Group: THC Alone vs. Clean Drivers.

	Before PSW (N = 1,419)				After PSW (Weight ATT) (N = 303)				
	THC	Comparison			THC	Comparison			
Outcome	Mean (SD)	Mean (SD)	t statistic	95% CI	Mean (SD)	Mean (SD)	t statistic	95% CI	Range
Speeding	0.31 (.46)	0.20 (.40)	-2.79**	-0.18, -0.03	0.32 (.47)	0.28 (.45)	-0.59	-0.14, 0.07	0-1
Driver error	0.43 (.50)	0.36 (.48)	-1.77	-0.16, 0.01	0.43 (.50)	0.39 (.49)	-0.79	-0.16, 0.07	0-1
Fatal injury	0.72 (.45)	0.64 (.48)	-2.08*	-0.16, -0.004	0.73 (.45)	0.63 (.48)	-1.87†	-0.21, 0.01	0-1
Died at the scene	0.55 (.50)	0.46 (.50)	-2.04*	-0.17, -0.003	0.55 (.50)	0.48 (50)	-1.28	-0.19, 0.04	0-1
Number of vehicles in crash	1.74 (.72)	1.80 (.66)	0.97	-0.06, 0.18	1.75 (.73)	1.76 (.65)	0.18	-0.14, 0.17	1-3
Motorcycle involved	0.24 (.43)	0.22 (.42)	-0.42	-0.08, 0.06	0.24 (.43)	0.28 (.45)	0.85	-0.06, 0.14	0-1
Bicycle involved	0.03 (.16)	0.01 (.10)	-1.18	-0.04, 0.01	0.03 (.16)	0.01 (.09)	-1.19	-0.05, 0.01	0-1
Pedestrian involved	0.12 (.32)	0.10 (.30)	-0.64	-0.07, 0.03	0.11 (.32)	0.12 (.32)	0.08	-0.07, 0.08	0-1
Number of fatalities in crash	1.10 (.30)	1.10 (.30)	-0.17	-0.05, 0.05	1.10 (.30)	1.08 (.28)	-0.47	-0.08, 0.05	1-2
Head-on	0.19 (.39)	0.22 (.41)	0.87	-0.04, 0.10	0.19 (.39)	0.19 (.39)	0.14	-0.08, 0.10	0-1
Cross centerline	0.23 (.42)	0.15 (.36)	-2.30*	-0.15, -0.01	0.23 (.42)	0.14 (.35)	-2.03*	-0.18, -0.00	0-1
Run off the road	0.22 (.41)	0.19 (.39)	-0.76	-0.09, 0.04	0.22 (.41)	0.20 (.40)	-0.33	-0.11, 0.08	0-1
N	156	1,263			151	152			
AUC		.751				.437			

Note: PSW = propensity score weighting; SD = standard deviation; CI = confidence interval; t-tests were used for comparisons of outcome means; AUC = area under the curve.

† p <.1. * p < .05. ** p < .01. *** p < .001.

Table 3: Outcomes Comparisons by Study Group: Alcohol Alone vs. Clean Drivers.

	Before PSW (N = 1,894)				*After PSW (weight ATT) (N = 1,220)*				
	Alcohol	*Comparison*			*Alcohol*	*Comparison*			
Outcome	*Mean (SD)*	*Mean (SD)*	*t statistic*	*95% CI*	*Mean (SD)*	*Mean (SD)*	*t statistic*	*95% CI*	*Range*
Speeding	0.53 (.50)	0.20 (.40)	-14.65***	-0.38, -0.29	0.54 (.50)	0.28 (.45)	-9.35***	-0.31, -0.20	0-1
Driver error	0.41 (.49)	0.36 (.48)	-2.08*	-0.10, -0.003	0.41 (.49)	0.37 (.48)	-1.55	-0.10, 0.01	0-1
Fatal injury	0.81 (.39)	0.64 (.48)	-8.19***	-0.21, -0.13	0.81 (.39)	0.64 (.48)	-6.63***	-0.22, -0.12	0-1
Died at the scene	0.67 (.47)	0.46 (.50)	-8.71***	-0.25, -0.16	0.67 (.47)	0.49 (50)	-6.62***	-0.24, -0.13	0-1
Number of vehicles in crash	1.40 (.60)	1.80 (.66)	12.70***	0.33, 0.45	1.41 (.60)	1.68 (.63)	7.52***	0.20, 0.33	1-3
Motorcycle involved	0.20 (.40)	0.22 (.42)	0.99	-0.02, 0.06	0.20 (.40)	0.26 (.44)	2.25*	0.01, 0.10	0-1
Bicycle involved	0.01 (.08)	0.01 (.10)	0.86	-0.01, 0.01	0.01 (.08)	0.01 (.11)	0.99	-0.01, 0.02	0-1
Pedestrian involved	0.03 (.17)	0.10 (.30)	6.58***	0.05, 0.09	0.03 (.17)	0.15 (.36)	7.89***	0.10, 0.16	0-1
Number of fatalities in crash	1.09 (.29)	1.10 (.30)	0.44	-0.02, 0.03	1.09 (.29)	1.12 (.32)	1.55	-0.01, 0.06	1-2
Head-on	0.12 (.33)	0.22 (.41)	5.50***	0.06, 0.13	0.12 (.32)	0.19 (.39)	3.46**	0.03, 0.11	0-1
Cross centerline	0.25 (.43)	0.15 (.36)	-4.90***	-0.14, -0.06	0.24 (.43)	0.13 (.34)	-5.16***	-0.16, -0.07	0-1
Run off the road	0.45 (.50)	0.19 (.39)	-11.34***	-0.30, -0.21	0.45 (.50)	0.20 (.40)	-9.44***	-0.30, -0.19	0-1
N	631	1,263			607	613			
AUC		.807				.493			

Note: PSW = propensity score weighting; *SD* = standard deviation; CI = confidence interval; *t*-tests were used for comparisons of outcome means; AUC = area under the curve.

† p <.1. * p < .05. ** p < .01. *** p < .001.

Table 4: Outcomes Comparisons by Study Group: THC Plus Alcohol Alone vs. Clean Drivers.

	Before PSW (N = 1,497)				*After PSW (weight ATT) (N = 450)*				
	THC+Alcohol	*Comparison*			*THC+Alcohol*	*Comparison*			
Outcome	*Mean (SD)*	*Mean (SD)*	*t statistic*	*95% CI*	*Mean (SD)*	*Mean (SD)*	*t statistic*	*95% CI*	*Range*
Speeding	0.58 (.49)	0.20 (.40)	-11.15***	-0.45, -0.31	0.58 (.50)	0.31 (.47)	-5.83***	-0.35, -0.17	0-1
Driver error	0.45 (.50)	0.36 (.48)	-2.51*	-0.16, -0.02	0.46 (.50)	0.41 (.50)	-1.01	-0.14, 0.04	0-1
Fatal injury	0.71 (.46)	0.64 (.48)	-1.85	-0.13, -0.004	0.70 (.46)	0.58 (.49)	-2.64**	-0.21, -0.03	0-1
Died at the scene	0.62 (.49)	0.46 (.50)	-4.33***	-0.22, -0.08	0.61 (.49)	0.45 (50)	-3.50**	-0.25, -0.07	0-1
Number of vehicles in crash	1.43 (.62)	1.80 (.66)	8.20***	0.27, 0.46	1.44 (.63)	1.68 (.63)	4.02***	0.12, 0.36	1-3
Motorcycle involved	0.15 (.36)	0.22 (.42)	2.79**	0.02, 0.12	0.15 (.36)	0.18 (.38)	0.89	-0.04, 0.10	0-1
Bicycle involved	0.01 (.09)	0.01 (.10)	0.25	-0.01, 0.02	0.01 (.09)	0.01 (.10)	0.14	-0.01, 0.02	0-1
Pedestrian involved	0.04 (.20)	0.10 (.30)	3.58***	0.03, 0.09	0.04 (.21)	0.18 (.39)	4.69**	0.08, 0.19	0-1
Number of fatalities in crash	1.09 (.28)	1.10 (.30)	0.61	-0.03, 0.05	1.09 (.29)	1.12 (.32)	0.99	-0.03, 0.08	1-2
Head-on	0.13 (.34)	0.22 (.41)	3.34**	0.03, 0.13	0.14 (.35)	0.20 (.40)	1.79	-0.01, 0.13	0-1
Cross centerline	0.25 (.44)	0.15 (.36)	-3.40**	-0.16, -0.04	0.24 (.43)	0.13 (.34)	-2.96**	-0.18, -0.04	0-1
Run off the road	0.43 (.50)	0.19 (.39)	-6.97***	-0.31, -0.17	0.44 (.50)	0.19 (.39)	-6.00***	-0.34, -0.17	0-1
N	234	1,263			225	225			
AUC		.853				.509			

Note: PSW = propensity score weighting; *SD* = standard deviation; CI = confidence interval; *t*-tests were used for comparisons of outcome means; AUC = area under the curve.

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

research hypothesis 3, as alcohol-alone participants were at much greater risk of being fatally injured and dying at the scene, being involved in risky behavior, crossing the centerline, and running off the road when compared to the control group. However, alcohol-alone subjects were less likely to be involved in crashes with other vehicles and heavy truck-involved, bicycle-involved, and pedestrian-involved fatal crashes.

Results 3: Combination of THC and Alcohol Drivers VS. Clean Drivers

The results of differences in outcomes by study group (combined THC and alcohol subjects versus clean subjects) are similar to those for the alcohol-alone study group (see Table 3 and 4). The THC and alcohol combination in some cases (i.e. fatal injuries and died at the scene) may be exhibiting all these effects because of the overwhelming strength of the alcohol effect on crash outcomes. Clearly the presence of alcohol in the blood of a driver involved in a fatal crash is particularly likely to result in undesirable driver outcomes.

Discussion

Motor vehicle crashes are a crucial health, law enforcement, and public safety concern. Given that the legalization of recreational cannabis coincided with an increase in driving under the influence of the drug in Washington state, this study sought to examine the relative risk of THC, alcohol, and the combination of alcohol and THC intoxication on drivers' risky behavior, harm, contextual conditions at fatal crashes, and collision type using WA-CFC data. The findings from the PSW partially support the research hypotheses that drivers who had a positive blood test for THC, alcohol, or combined THC and alcohol are more likely to engage in risky behaviors and be exposed to detrimental outcomes than drivers who had a negative blood test for both alcohol and THC. However, findings from the PSW suggest that THC alone is generally not a major risk factor. Overall, comparing the relative risks of THC, alcohol, and their combination, alcohol alone was the strongest risk factor, combined THC and alcohol was next, and THC alone was the weakest risk factor for undesirable outcomes related to fatal crashes in Washington.

Though results from the PSW illustrated statistically nonsignificant *t*-test results in most outcomes in the THC-alone model, this does not mean that there are no actual differences between the two groups. Given the relatively small samples involved in the THC-alone and THC-and-alcohol-combination models, some of the nonsignificant results may reflect Type II errors. Therefore, a standardized metric, Cohen's d[5], was computed for each outcome variable, as standardized differences allow for better indication of the true difference between the treated and nontreated cases. Cohen (1988) outlined three cut-offs for interpreting effect sizes in terms of Cohen's *d*: small: $d = .20$; medium: $d = .50$; large: $d = .80$.

Table 5: Summary of Effect Sizes for Study Outcomes.

Outcomes	*THC Alone*		*Alcohol Alone*		*THC Plus Alcohol*	
	Weighting (ATT)		*Weighting (ATT)*		*Weighting (ATT)*	
	Cohen's d	*95%CI*	*Cohen's d*	*95%CI*	*Cohen's d*	*95%CI*
Speeding	0.087	-0.138, 0.312	0.547	**0.432, 0.661**	0.556	**0.369, 0.745**
Driver error	0.081	-0.144, 0.306	0.082	-0.03, 0.195	0.10	-0.085, 0.285
Fatal injuries	0.215	-0.011, 0.441	0.389	**0.275, 0.502**	0.253	**0.067, 0.438**
Died at the scene	0.14	-0.085, 0.365	0.371	**0.258, 0.484**	0.323	**0.137, 0.509**
Head-on	0.00	-0.225, 0.225	-0.196	**-0.309, -0.084**	-0.16	**-0.345, -0.025**
Cross centerline	0.233	**0.007, 0.459**	0.284	**0.171, 0.397**	0.284	**0.098, 0.470**
Run off the road	0.049	-0.176, 0.275	0.552	**0.438, 0.667**	0.558	**0.369, 0.746**

Note: Bolding CIs indicates that no zero is contained in the range. CI = confidence interval; ATT = average treatment effect for the treated where weight is 1 for a treated case and $P(1-P)$ for a comparison case

As presented in Table 5, alcohol alone and the combination of THC and alcohol had similar effect sizes (low to medium in terms of Cohen's *d*) with the same directions in all outcomes, while crossing the centerline was the only outcome affected by THC alone and its effect size was 0.233, which is low. Based on these findings, we can confirm that alcohol and the combination of THC and alcohol had large effect sizes for undesirable outcomes related to fatal crashes in Washington.

In addition, head-on crashes and driver error were less likely to be affected by THC and alcohol intoxication. Rather, clean drivers were more likely to be involved in head-on collisions than drivers with THC alone and the combination of THC and alcohol intoxication in fatal crashes. Moreover, speeding and running off the road had a medium effect size, indicating that these events were affected by alcohol and the combination of THC and alcohol.

Some of the undesirable outcomes, including fatal injuries, dying at the scene of the crash, and crossing the centerline had somewhat small effect sizes. However, this finding does not imply that small effects of THC and alcohol intoxication on these outcomes are not meaningful in fatal crashes. Indeed, these small effects can be important (Ellis, 2010) as these outcomes could lead to detrimental consequences when the margin for error may be low.

These findings are directly relevant to policymakers as they grapple with strategies to understand, document, and address public safety issues following the legalization

of cannabis. Specifically, these results may help to justify the investment in technology and data to detect and monitor drugged driving and subsequent greater efforts at prevention, and education around the dangers it raises. A first step should be the development of technology to accurately test for THC and legal protocols to guide this testing. There currently are no easy means of determining whether a driver is THC-impaired. Success in this area of detection would not only assist in better research on the link between cannabis and driving outcomes, but would also assist in DUID investigations. Blood testing is a superior matrix over other tests such as urine and oral fluid (D'Orazio *et al.*, 2021), but there are legal (the need for a search warrant) and medical (the need for a phlebotomist) hurdles that often delay testing, and in the interim the level of THC in the blood of the driver degrades, resulting in negative results several hours later. Post legalization Washington passed a law requiring that all persons "killed" in fatal crashes within four hours of the crash be blood tested for intoxicants (Washington Traffic Safety Commission, 2016). Due to this law, over 90% of deceased drivers in fatal crashes were tested (the untested 10% was typically due to drivers dying days after the crash or other uncommon reasons, such as inability to obtain a viable sample). For surviving drivers to be tested, there must be probable cause for impairment, which is then used to obtain a search warrant for a blood draw. But probable cause for impairment does not always result in a blood draw; sometimes law enforcement only obtains a breath sample for alcohol. It is also possible that the investigators may not ever do blood testing if alcohol results are enough to prosecute for DUI. There is also currently no valid breath test for THC in drugged drivers that might be administered by law enforcement on the scene or at the jail, though this is an active area of research.

Conclusion and Research Limitations

Given the nationwide trend toward cannabis legalization, it is vital that we better understand the role cannabis plays in traffic crashes (Rosekind *et al.*, 2020). While alcohol impairment and the role it plays in fatal crashes is well understood due to decades of research, less is known regarding THC impairment. This is unfortunate, as a number of states have legalized cannabis, thus increasing the likelihood that people may drive while impaired by THC. Most THC-positive drivers involved in fatal crashes have also ingested other substances, limiting the research to date and making it difficult to understand the specific role that THC impairment alone plays in crash outcomes. Even less is known regarding the poly-use of alcohol and THC (and potentially other drugs) on driving impairment. This study is one of the first to isolate drivers into mutually exclusive driver toxicology outcomes segregating alcohol and THC and comparing those drivers with known (tested) clean drivers.

As this study has shown,drivers under the influence of alcohol and the combination of alcohol and cannabis (THC) are atmuch greater risk for risky behaviors than those under the influence of cannabis only.The current study did not find a strong and consistent effect of THC only in the blood of drivers on undesirable outcomes related to fatal crashes usingWashington CFC data.

The primary limitation of the current study involves the measurement of drug testing results. Due to the fast rate of metabolism of THC in the blood and the length of time it takes to obtain a blood sample following a crash, 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 and were therefore 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 at the time of the crash. There may have been drivers under the influence of THC or alcohol but were not tested due to lack of probable cause for testing. The issue of testing all drivers and in a timely fashion remains a challenge in the context of legalization and the consequent increased drug use. As scholars continue to investigate the association between illicit drugs and driving impairment, further research from other states will enhance our understanding of the relative risk of alcohol, cannabis and their combination on fatal crashes.

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Disclosure statement

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Note

1. Driver errors variable in the WA-CFC data contains several sub-categories. For example, in the driver errors 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.).

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