KEY INFORMATION FOR CANNABIS AND DUIC POLICY

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June 2019

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RESEARCH PROGRAMS

MDT

Key Information for Cannabis and DUIC Policy

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16. Abstract

There is growing concern about driving under the influence of cannabis (DUIC), especially as more states consider changing laws to legalize cannabis. A key question regarding the legalization of cannabis for recreational or medical purposes is its potential impact on public health issues such as traffic safety. To address the needs of traffic safety practitioners and policymakers, this synthesis report seeks to summarize key information about the role of cannabis in traffic safety in order to inform policy regarding cannabis legalization and traffic safety.

Main conclusions include:

- Cannabis is a plant-based drug that is typically smoked or ingested.
- Cannabis is the most commonly used illicit drug in the U.S.
- The primary psychoactive compound of cannabis is delta-9-tetrahydrocannabinol (THC).
- THC is transported by the circulatory system to the brain where it alters neural activity and brain functions.
- Changes in neural activity and brain functions can impair core cognitive functions such as attention.
- Cognitive impairment results in impaired driving behaviors.
- Impaired driving behaviors increase driver responsibility for motor vehicle crashes.
- THC-positive drivers are twice as likely to be killed in a motor vehicle crash.
- The fatal crash risk is much higher when THC is combined with alcohol.

Currently, there is some evidence that the legalization of recreational cannabis increases crashes. However, because it has been only recently that relatively few states have adopted this legislation, the amount of evidence is insufficient for a definitive conclusion. Thus, there is a need for more research to examine the effect of cannabis legalization on traffic safety. Such research will require longer post-legalization periods and more states that have enacted these legislative changes.

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1 INTRODUCTION

There is growing concern about driving under the influence of cannabis (DUIC), especially as more states consider changing laws regarding cannabis possession and use. A key question regarding the legalization of cannabis for recreational or medical purposes is its potential impact on public health issues such as traffic safety. There is considerable uncertainty – and even debate – about the impact of cannabis and its legalization on traffic safety. For example, among the general population, one study indicated that a sizeable percentage of the population (36%) perceive no risk associated with DUIC (Swift, Jones, and Donnelly 2010). Indeed, a minority (10%) even perceive that DUIC reduces crash risk (Swift, Jones, and Donnelly 2010).

This uncertainty and debate can be attributed to the greater complexity of the effects of cannabis on traffic safety compared to alcohol, which is a very different form of drug with a long history of research and attention in traffic safety. Information that might increase understanding and resolve debate about the effects of cannabis on traffic safety is often published in academic journals. However, this information is not accessible to lay audiences as well as traffic safety practitioners and policymakers who do not have formal training in the scientific disciplines that conduct and publish this research. This inaccessibility can hinder attempts for traffic safety practitioners and policymakers to decide on appropriate policies and implement effective strategies to mitigate risk.

To address the needs of traffic safety practitioners and policymakers, this synthesis report seeks to summarize key information about the role of cannabis in traffic safety in order to inform policy regarding cannabis legalization and traffic safety.

The issues surrounding the effects of cannabis on traffic safety are complex. Therefore, it is necessary to provide some background about these issues. Awareness of these issues is important to understanding and applying the key information provided in this synthesis report.

2 BACKGROUND

The term "cannabis" refers to different forms of the drug derived from the leaves and flowers of its namesake plant, Cannabis sativa L. (USDA 2019). As shown in Figure 1, cannabis is the most commonly used drug (excluding alcohol and tobacco) in the U.S. (SAMHSA 2017). Most commonly, it is inhaled or ingested (Grotenhermen 2003; Quickfall and Crockford 2006). For recreational purposes, it is used for its intoxicating effects, which include sensory intensification, euphoria, relaxation, drowsiness, and depersonalization (Grotenhermen 2003). However, it can also produce anxiety, panic, and hallucinations – particularly in inexperienced users (Grotenhermen 2003).

Figure 1. Past month users of five most common "illicit" drugs in U.S. for 2017 (SAMHSA, 2017).[1]

The principal psychoactive compound of cannabis is delta-9-tetrahydrocannabinol (THC) (Quickfall and Crockford 2006). THC acts primarily upon cannabinoid receptors to alter brain functioning in regions associated with cognitive functioning (Quickfall and Crockford 2006). The larger the dose of THC, the greater the impairment of these cognitive functions, such as slower reaction times to events or not noticing relevant information (Ramaekers, Berghaus and Drummer 2004). However, interpreting the relevance of such impairment to traffic safety is complicated by several drug-related factors and methodological issues (Capler et al. 2017; Compton 2017).

2.1 Drug-Related Factors

Several factors that determine the level and duration of THC in the body influence the magnitude and duration of acute impairment (Capler et al. 2017; Sewell, Poling, and Sofouglu 2009).

2.1.1 Cannabis Potency

Cannabis smokers adjust their consumption and dose to achieve their preferred level of "high." Given the dose-dependent effect of THC, it is important to note that the amount of THC in cannabis (potency) has tripled from 4% in 1995 to 12% in 2014 based on an analysis of national samples from cannabis seized by the U.S. Drug Enforcement Agency (ElSohly et al. 2016). THC levels may be over 24% in special cannabis strains produced for markets where purchasing and using cannabis is legal (Leafly 2019). Unless users can accurately and reliably titrate their consumption of THC with these higher-potency strains of cannabis (Logan 2007), the more potent strains may result in more impairment than expected.

[1] Width of rectangles are proportional to number of reported users of drug.

2.1.2 Type of Cannabis

There are different types of cannabis products that vary in terms of the relative proportion of the two main active cannabinoids, namely delta-9-tetrahydrocannabinol (THC) and cannabidiol (CBD). These two cannabinoids are believed to have antagonistic effects (Karila et al. 2014; Solowitz and Pesa 2012). THC can produce anxiety and is believed to be responsible for impairment of cognitive functions. In contrast, CBD can reduce anxiety without comparable impairment of cognitive functions. Therefore, it is possible that CBD in cannabis could offset the anxiety produced by THC. It is reasonable to speculate that the experience of using cannabis may vary depending on the relative proportions of these cannabinoids and use frequency (Morgan et al. 2018).

2.1.3 Method of Use

The method of cannabis consumption influences the level and duration of THC in the body, thereby influencing the magnitude and time course of impairment. For example, Figure 2 shows the subjective "high" experienced over time as a function of method of use (e.g., eaten, drank, smoked, or intravenous) for different doses (mg) of THC (Grotenhermen 2003). Intravenous use transports THC into blood immediately whereas oral consumption requires some digestion before THC is absorbed into blood through the stomach and intestines. Smoked cannabis transports THC to the blood through the lining of the lungs. Thus, peak level of THC is achieved sooner with intravenous use than other methods of consumption.

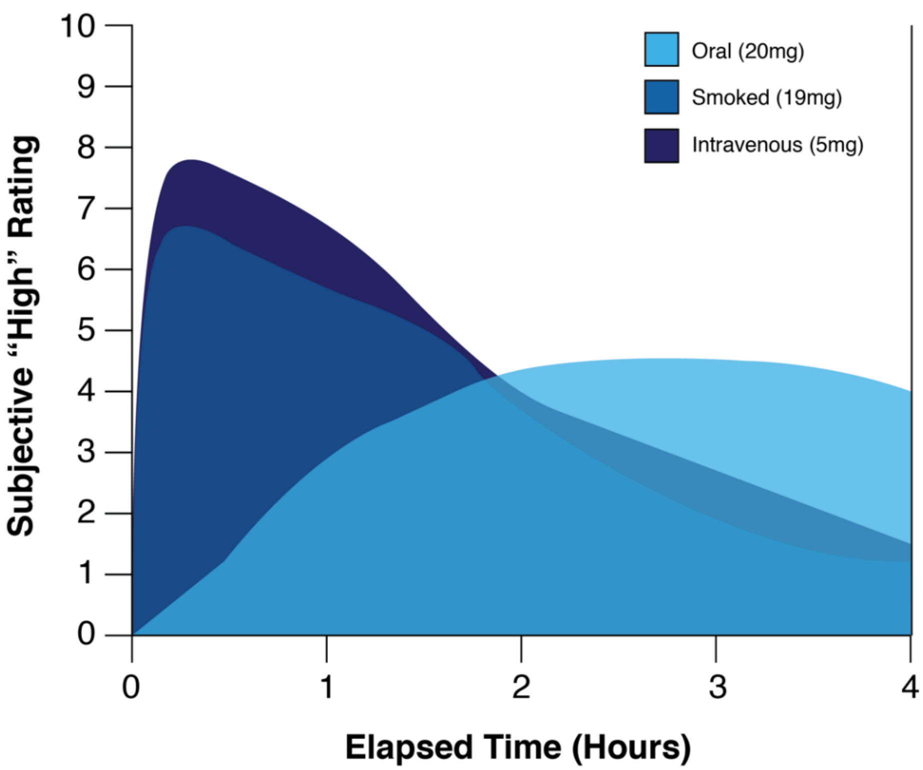

Figure 2. Subjective "high" over time as a function of THC dose method of use (Grotenhermen 2003).

2.1.4 Individual Differences

Individuals differ in many ways that influence the absorption and processing of THC within the body (e.g., physique, physiology, etc.), resulting in variability among people in the absorption of THC forms of the same dose. For example, Figure 3 shows THC levels (whole blood) overtime from the same THC dose administered orally to three different cancer patients (Grotenhermen 2003). As this example shows, the same THC dose and method of use can produce different peak levels and durations among different people (Grotenhermen 2003; Huestis 2007).

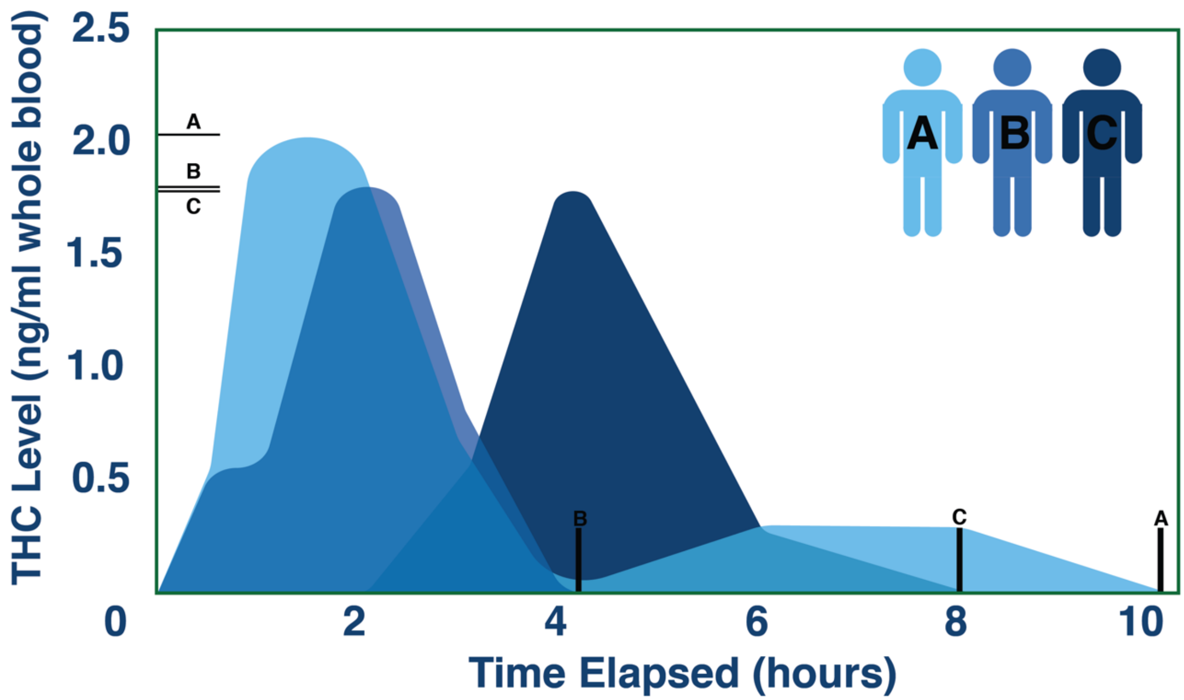

Figure 3. Example of individual differences in THC levels (whole blood) from standard oral dose (Grotenhermen 2003).

2.1.5 Tolerance

Perhaps the most important individual difference is experience with cannabis use. Occasional users tend to show greater impairment of cognitive functions and driving behavior than do frequent users. Indeed, some studies have observed no acute impairment among chronic users who consume cannabis multiple times every day (Ramaekers et al. 2009).[2]

Such tolerance may result from their (1) development of compensatory strategies (e.g., devoting more attention and effort) or (2) integration of alternative brain neural networks (Cohen and Weinstein 2018; Theunissen, Kauert, and Toennes 2012). Regardless, tolerance is rarely sufficient to overcome all aspects of acute impairment from cannabis. For example, users can only compensate by devoting more attention to those driving tasks that are under conscious control. Many driving tasks are routine and automatic such as lane keeping. In the absence of conscious control, it is not possible to compensate for such tasks.

[2] Indeed, it has also been speculated that these “chronic users” are motivated to consume cannabis in order to achieve what they perceive to be a level of “normal” functioning (Crean, Crane, and Mason 2011).

> Drivers certainly do try to compensate, but they do not always succeed. In my view the compensation strategy is often misquoted. Virtually all studies demonstrate that drivers are not able to fully compensate for their impairments. There is compensation on some parameters, but there is none on others. (Ramaekers 2019)

Admittedly, we do not fully understand the conditions of use by which tolerance is developed. Indeed, any evidence of tolerance can be attributed to poor experimental designs. For example, research using stronger experimental designs (e.g., large sample size, controlling for baseline THC levels) demonstrates no apparent tolerance, regardless of the frequency of cannabis use.

> This implies that cognitive function of daily or near daily cannabis users can be substantially impaired from repeated cannabis use, during and beyond the initial phase of intoxication. As a consequence, frequent cannabis use and intoxication can be expected to interfere with cognitive performance in many daily environments such as school, work or traffic. (Ramaekers et. al. 2016, 7)

2.2 Methodological Issues

Several methodological issues complicate the measurement and interpretation of cannabis impairment and associated crash risk (Compton 2017).

2.2.1 Units

THC levels in blood can be assessed with different methods and reported in different units. In discussion and debates about the impairment and crash risk associated with cannabis, it’s important to use the same units for THC level. For example, THC levels in the U.S. are commonly assessed and reported as units (ng/ml) in *whole blood*. In contrast, THC levels in Europe are more often assessed and reported as units (ng/ml) in *blood serum* after the red blood cells have been removed (ng/ml). This is an important distinction because the removal of the red blood cells reduces the volume of the remaining serum (ml). As a result, a given amount of THC (ng) reported in serum (ng/ml) will be higher than the same amount reported in whole blood. To convert THC serum values to whole blood equivalent values, the reported THC level in serum (ng/ml) is divided by two (Urfer et al. 2014). For consistency and relevance to the U.S. context, all THC levels listed in this report were converted to ng/ml in whole blood.

2.2.2 Phase

There are distinct phases of THC processing within the body (Huestis 2007). In the absorption and distribution phase (ascending), blood proteins in the circulatory system move THC throughout the body to the brain and into fatty tissues. In the metabolism and elimination phase (descending), THC is removed from the body through oxidation and excretion processes. These cycles mean the same THC level can appear in both phases. As shown in Figure 4, subjective impairment is generally greater during the descent than the ascent phase for the same THC level (Desrosiers et al. 2015; Grotenhermen 2003). Therefore, knowing the phase in which THC is detected is important for predicting the expected impairment effect.

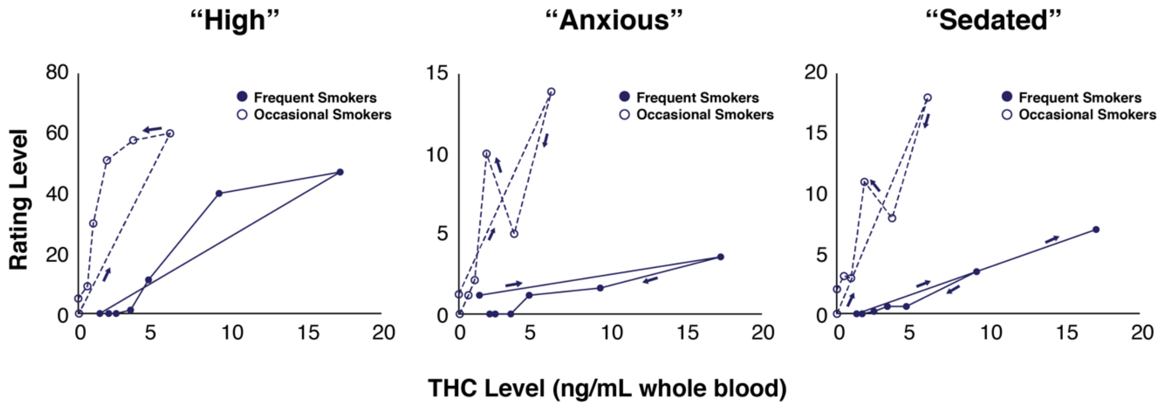

Figure 4. Subjective experience of THC as a function of absorption and distribution phases (Desrosiers et al. 2015).

2.2.3 Impairment

> "Knowing that a driver tested positive for cannabinoids does not necessarily indicate that the person was impaired at the time of the crash" (Berning and Smither 2014, 1).

Impairment can be defined as less accurate, responsive, or stable performance with THC compared to conditions without THC, which has implications for health or safety as a person interacts with their environment. For example, a slower reaction time resulting from THC may cause a driver to crash when braking to avoid another car in the roadway environment.

The level of THC detected in whole blood (or blood serum) is not always an accurate indication of impairment for several reasons:

1) The peak "high" resulting from cannabis occurs after the peak in THC level (whole blood) as shown in Figure 5. This delay reflects the time needed for the circulatory system to transport THC to the brain (Capler et al. 2017).
2) THC levels can drop rapidly during the initial stages of oxidation and elimination (Wong, Brady, and Li 2014), whereas the "high" resulting from the effects of THC on the brain can persist much longer, again as shown in Figure 5.
3) Because of THC stored in fatty tissues, trace levels may still be detected hours, days, or even a full month after use (especially in chronic users), at such time remaining impairment effects are unlikely (Crean, Crane, and Mason 2011; Huestis, Mitchell, and Cone 1996; Karschner et al. 2009; Wong, Brady, and Li 2014).
4) It is important to note that the median delay between a motor vehicle crash and the collection of driver blood to assess THC levels is approximately 165 minutes (Compton 2017). With such a delay, it is difficult to predict the degree of impairment that preceded the crash.

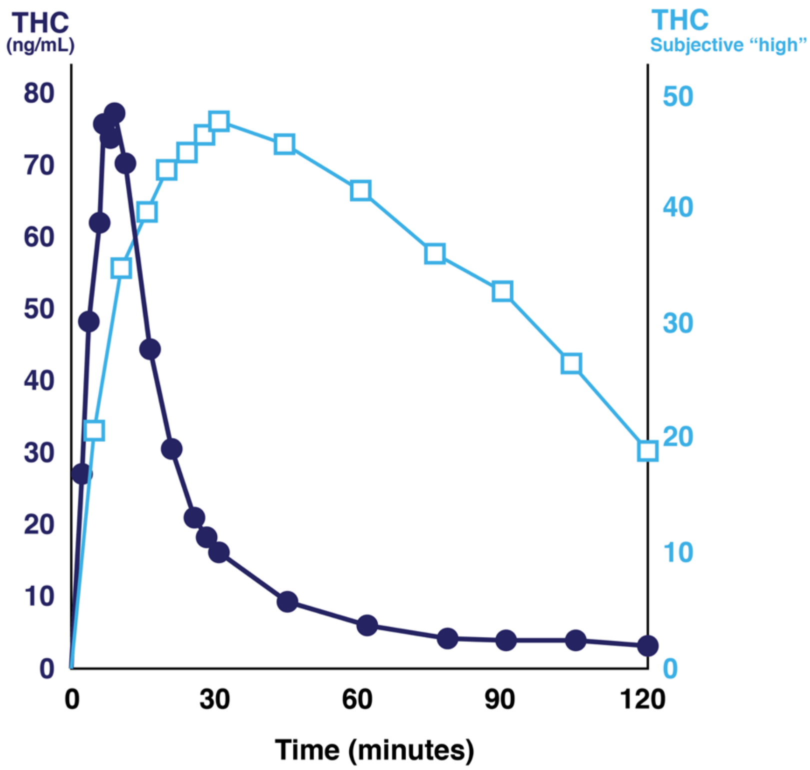

Figure 5. THC level (whole blood) and reported "high" as a function of elapsed time from cannabis use (Capler et al. 2017).

2.2.4 THC Threshold

As was done with alcohol, many jurisdictions are trying to establish a limit for cannabis (in terms of THC detected in whole blood), which – by itself – is illegal for driving ("per se" law). The presumption is that this limit represents a threshold of unacceptable impairment (and elevated risk). Without valid research to quantify fatal crash risk for a range of THC levels, it is necessary to estimate this limit from published research on THC impairment.

For example, Kruger and Berghaus (1995) conducted a review of 257 published studies to calculate percentage individual tests of cognitive, behavioral, and driving performance that showed significant impairment related to different (estimated) levels of THC and alcohol. A THC level of 5.5 ng/ml (whole blood) represented the threshold at which these tests were more likely (> 50%) to demonstrate significant impairment. This is slightly higher than the highest per se THC limit (5 ng/ml in whole blood) currently adopted by some U.S. states in Colorado, Montana, and Washington (NCSL 2015).

2.2.5 Testing Policy

Because THC levels are predominately determined from obtained blood samples, there is considerable variation within states and between states in terms of policies that govern the collection and reporting of THC levels in drivers (NHTSA 2010). There is also large variation in testing methods used to quantify THC levels (Berning and Smither 2014). As a result, many drivers are not tested for drugs (other than alcohol),[3] and the criteria for asserting a drug-positive test may vary between sites. As a result, available databases for drug-positive drivers in fatal crashes (e.g., Fatal Crash Reporting System) are generally incomplete and may provide unreliable estimates of cannabis involvement in crashes (Berning and Smither 2014). For this reason, research based on such databases should be interpreted carefully.

2.2.6 Postmortem Redistribution

With blood collected during postmortem to assess THC, there may be passive redistribution of THC throughout the body in the absence of the blood circulation without heart activity. THC stored in heart, lung, and liver tissues can diffuse back into the central portion of the cardiovascular system (Holland et al. 2011). This "postmortem redistribution" of drugs can increase levels of THC in central blood sources compared to peripheral sources (Holland et al. 2011; Lemos and Ingle 2011). This distribution effect increases with the amount of time between death and the postmortem (Lemos and Ingle 2011). As a result, postmortem THC levels may not reflect the THC level at the time of the crash, depending on the time of the postmortem and the site used to collect the blood (Brunet et al. 2011; Lemos and Ingle 2011).

2.2.7 Risk Factors

Driving under the influence of cannabis (DUIC) correlates with a number of other risk factors (Reisfield et al. 2012). For example, young drivers and male drivers are more likely to be frequent cannabis users (SAMHSA 2017). Frequent users of cannabis are more likely to DUIC (Ramaekers et al. 2009). And, young drivers and male drivers are more likely to take risks while driving (e.g., speeding) that increase fatal crash risk (Compton and Berning 2015).

Consequently, the crash risk resulting from cannabis use can be difficult to isolate from the crash risk associated with common demographics of cannabis users. To isolate the effect of cannabis on crash risk, it is also necessary to examine cases of cannabis use without any other drug present (see section 5.2).

To address these other risk factors, calculations of crash risk related to cannabis use (DUIC) can be statistically adjusted to account for crash risk associated with specified demographic variables. For example, a recent study of the fatal crash risk associated with different drugs calculated an odds ratio of 1.25 for cannabis, representing a significant (25%) increase in risk ($p < .01$) for THC-positive drivers (Compton and Berning 2015). However, after adjusting this calculation to account for the age and gender of the driver, the risk associated with THC was no longer significant.

But, what does this adjustment really mean about the risk associated with THC?

Adjusting estimates of risk (odd ratios) in this way must be interpreted carefully. In the current example, the fact that adjusting for driver demographics resulted in a non-significant crash risk estimate does <u>not</u> mean cannabis use has no impact on crash risk. Rather, it only means that the inherent risk from certain demographic variables is greater than the risk associated with cannabis use (Christenfeld et al. 2004; Kraemer et al. 2001). Nevertheless, each of these demographic

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[3] It is common to not test for other drugs if alcohol is first detected because alcohol impairment laws are more readily enforceable in most states (Berning and Smither 2014).

groups are expected to have a higher crash risk after using cannabis. For example, young male drivers are still expected to have a higher crash risk after using cannabis than when sober. Young male drivers are just as susceptible to the effects of THC because their brains share the same cannabinoid receptors as any other demographic group.

Rather than adjusting risk estimates, “case-control studies” offer an alternative way of handling a confounding variable (Houwing, Mathijssen, and Brookhuis 2009). In case-control studies, drug levels are assessed in drivers involved in fatal crashes (cases). A sample of non-involved drivers (control) with similar demographics are then sampled around the same time and location as the fatal crash. The prevalence of THC in the case group is then compared to the prevalence of THC in the control group.

The usefulness of the case-control method depends on the rigor of matching controls with cases on all other relevant risk factors (Huestis 2015). Low quality case-control studies that do not adequately match controls with cases on relevant variables can produce misleading results (Hostiuc et al. 2018; Rogeberg and Elvik 2016). For example, if infrequent users are overrepresented in the case group and frequent users in the control group, estimates of the impairment effects of cannabis may be underestimated because frequent users are more likely to DUIC (Ramaekers et al. 2009).

3 METHODS

This project used a two-stage method. First, a list of contemporary DUIC policy issues were identified with experts in cannabis impairment and DUIC policy (see Table 1).

Based on this list, members of the Traffic Safety Culture (TSC) Pooled Fund project prioritized these policies in terms of importance to traffic safety. Second, a literature review was conducted to synthesize key information addressing main issues related to the highest ranked policy.

3.1 Issue Identification

To identify the key issues relevant to DUIC policy making, the CHSC team conducted confidential interviews with traffic safety practitioners involved in cannabis laws and DUIC policies at the state and federal levels. Selected practitioners were contacted by email and requested to identify DUIC policy issues that need to be resolved:

> Our center is leading a project to provide a useful source of information to support policy regarding Driving Under the Influence of Cannabis (DUIC). The goal is to identify the key information needed to develop effective policy and present that information in a clear and informative manner to assist policymakers and practitioners.
>
> To start the process, we need to understand what the most important policy decisions are that traffic safety agencies are facing today. In particular, we need to understand the specific questions and issues that need to be addressed in order to inform those policy decisions. Stated differently, what DUIC-related policies are people struggling with, and what are the key questions they need answered in order to formulate that policy?
>
> We recognize that you are leaders in the area of traffic safety policy related to drug use including cannabis.
>
> Through this email, I would like to ask you to list DUIC policy decisions that your agency (or the traffic safety community as a whole) is currently wrestling with or seeking to develop. For each of these policies under consideration, what are the key questions or issues that need to be answered or resolved in order to finalize the policy?
>
> The final summary of responses will be anonymous. We will not be linking names or agencies to responses.

As a result of this enquiry, we received several documents including agency reports, committee minutes, and opinion summaries about which DUIC policy issues are most relevant to traffic safety practitioners. These policies and their underlying issues are summarized in Table 1.

Table 1. Summary of Commonly Reported DUIC Policy Issues.

ID	Policy	Issue
A	Legalization of recreational cannabis	How dangerous is it? What are its effects? Do motor vehicle crashes go up with legalization? Impacts of combining alcohol and cannabis? Social implications – does legalization mean it's safer?
B	Setting per se or zero tolerance laws	What Driving Under the Influence of Cannabis (DUIC) laws have been developed and enforced (internationally)? What are the pros and cons of a zero-tolerance law versus a per se law?
C	Develop and implement an educational campaign on DUIC	What is the message? Who is the audience? How do we communicate the message in the context of public sentiment for legalization? What role can traffic safety culture have in this process?
D	Evaluate data collection for DUIC crashes	What information is necessary? What information is already collected? How is it collected? Who has access for integration and analysis? How are results communicated and used (by whom)?
E	Seek dedicated funding from cannabis taxes revenues for education and enforcement	What are funding models that connect cannabis tax revenues to traffic safety programs (e.g., Colorado and California)? What should the funds be used for? How much should be directed specifically to impaired driving programs?
F	Law enforcement training (SFSTS, ARIDE, DRE)	How is DRE viewed as evidence of impaired driving? Is this evidence a priority for prosecutors for DUI cases? What role can SFSTS and ARIDE play? What are realistic and effective models for using SFST and ARIDE when full DRE implementation is not possible? What are the most effective forms of DRE training?
G	Chemical evidence will be used to confirm impairment (cannabis)	What types of evidence collection are feasible - oral swabs, blood, or urine? Is there a need for additional LE officer training (e.g., phlebotomy)? What are possible forms of access to blood (e.g., search warrants or implied consent warning)? Toxicology evidence collection and analysis – how will it be collected? What drugs are collected? What are the necessary screening levels, sensitivity, or tolerances? How can these parameters be made consistent across jurisdictions? How will the data be used, analyzed, and reported – and by who? Should all fatally injured drivers have a toxicology examination? Should all surviving drivers get assessed on scene by a DRE or if transported (even if no alcohol present or detected)?
H	Authorized to conduct green labs similar to "Wet Labs"	Which federal laws are relevant to the approval of green labs to see real time impairing effects?
I	Commercial vehicle carrier testing	How can Safety Manager training for drug and alcohol recognition under 49 CFR 382.603 be updated? What methods of testing are necessary to capture the synthetics currently undetectable by current testing procedures? What are most effective drug testing protocols (given that the FMCSA has noted the highest drug failure rate in 7 years)?

3.2 Policy Prioritization

Panel members of the Traffic Safety Culture Pooled Fund project voted on which policy issues were most important. Prioritization was based on the top four ranks (1 to 4) reported by all members.[4] In the case of a tied rank, the policy issues with the most members providing a ranking were given priority.

From this prioritization process, it is apparent that policy issues related to the **legalization of recreational cannabis** were ranked as the highest priority among the panel. Accordingly, this topic became the focus of this synthesis project. Specifically, this report focuses on the immediate effect of cannabis use (acute impairment) in relation to driving and crash risk. In this context, cannabis use is limited to recreational purposes. Medical use and the long-term effects of repeated use (chronic impairment) are excluded.

3.3 Literature Review

As already discussed, there are many sources of variability that can influence the effects of cannabis reported in any single study (see Background section). Consequently, conclusions should be based on preponderance of evidence across multiple studies. Meta-analyses use statistical methods to aggregate the effects reported by multiple studies. By quantifying the variability among the reported effects, this aggregation process can provide an estimate of the "true" (average) effect of cannabis with a stated margin of certainty (95^{th} Confidence Interval). Accordingly, this literature review relied on recent published meta-analyses.

[4] Not all members used all ranks (1 to 9). All members used ranks 1 to 4. Therefore, average ranking is based on top four ranks to minimize missing data in computation of average.

4 SYNTHESIS

To understand the effects of cannabis on traffic safety, it is necessary to consider the process by which cannabis access may influence crash risk. A summary of this process is illustrated in Figure 6.

Figure 6. Process relating cannabis use to traffic safety.

4.1 Access to Cannabis

An important determinant for access to cannabis is the jurisdictional laws governing sales and possession of cannabis. By the end of 2018, 33 states and the District of Columbia had laws that legalized cannabis for medical or recreational use as shown in Figure 7 (Governing 2019). Alaska, California, Colorado, Maine, Massachusetts, Michigan, Nevada, Oregon, Vermont, Washington, and the District of Columbia have the most expansive laws regarding recreational use of cannabis. Most of the remaining states only permit limited use of cannabis for medical use. Not only does access provided by legalizing cannabis increase reported use, it also reduces perceptions that using cannabis is harmful (Cerda et al. 2017).

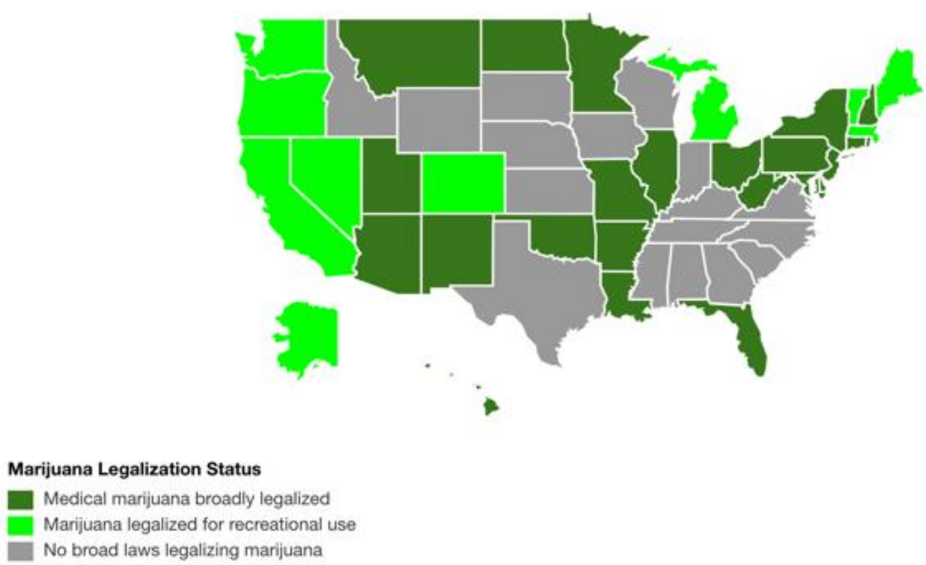


Figure 7. Types of laws regarding cannabis use in states by end of 2018 (Source: Governing 2019).

4.2 Recreational Cannabis Use

As shown in Figure 8, cannabis use is most common among people aged 18 to 25 years (SAMHSA 2017). Indeed, reported use within this age group has increased annually since 2008. As a result, nearly 20% of people in this age group reported "recent use" of cannabis in 2015.

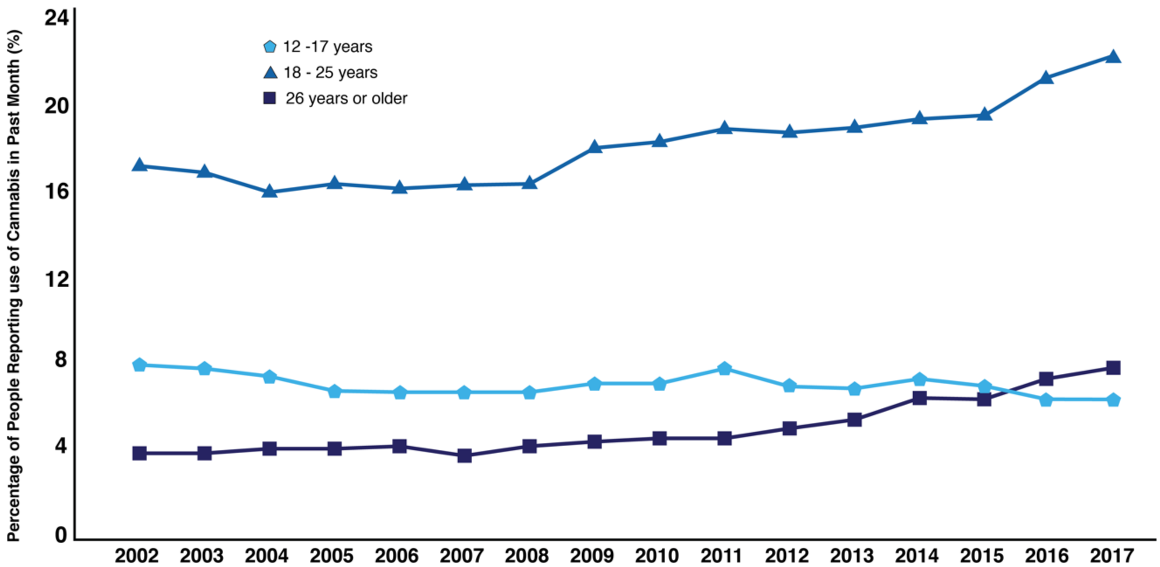


Figure 8. Reported use of cannabis in past month (between 2002 and 2017) by age group (SAMHSA 2017).

Given that many cannabis users are also drivers, it is not surprising that some may drive under the influence of cannabis (DUIC). In 2013 and 2014, a random roadside survey that tested drivers for THC based on oral fluid and blood samples determined that 12.7% of all weekend nighttime drivers testing positive for THC, which was a 47% increase from 2007 (Kelley-Baker et al. 2017). Moreover, the percentage of fatally injured drivers testing positive for THC has been increasing since 2002 as shown in Figure 9, especially among drivers 25 years and younger (Brady and Li 2014).

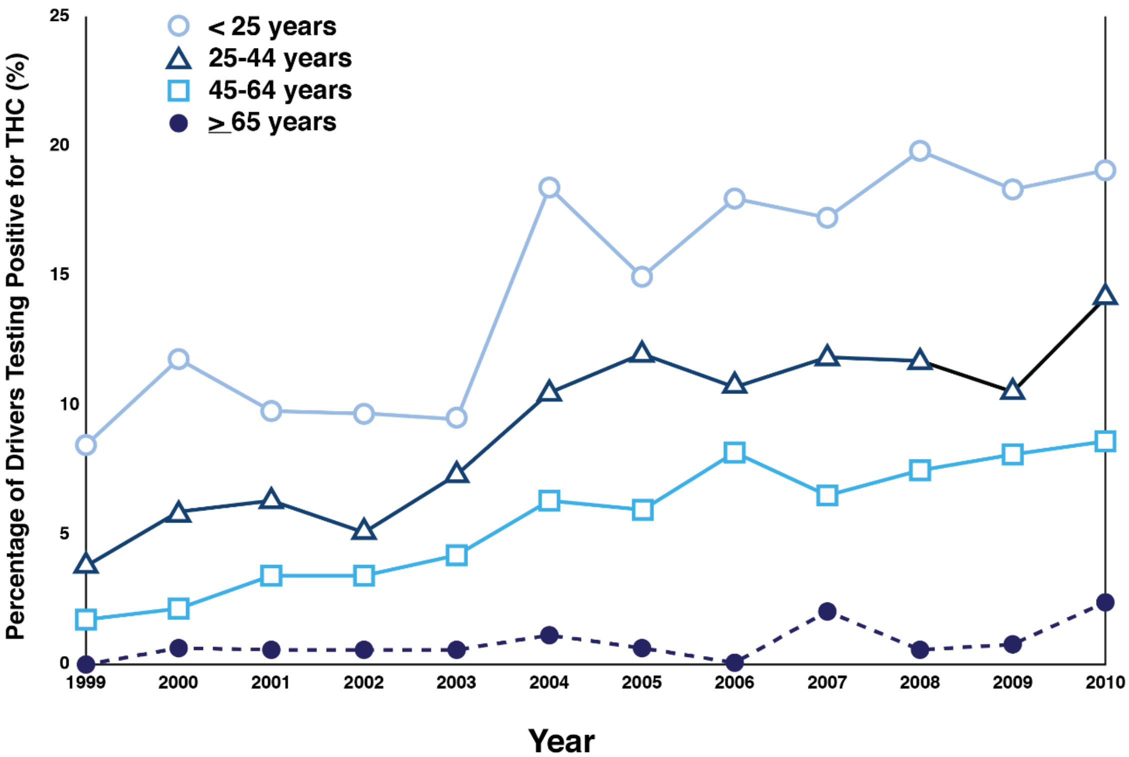


Figure 9. Percentage of THC-positive drivers killed in crashes as a function of driver age (Brady and Li 2014).

From such trends, the percentage of U.S. drivers testing positive for THC that died within one hour of a crash has doubled since 2002 (Brady and Li 2014). As a result, Figure 10 shows cannabis has become the most commonly detected non-alcohol drug in fatally-injured drivers. In comparison, the percentage of fatally-injured drivers that tested positive only for alcohol (39%) has remained stable over the same period.

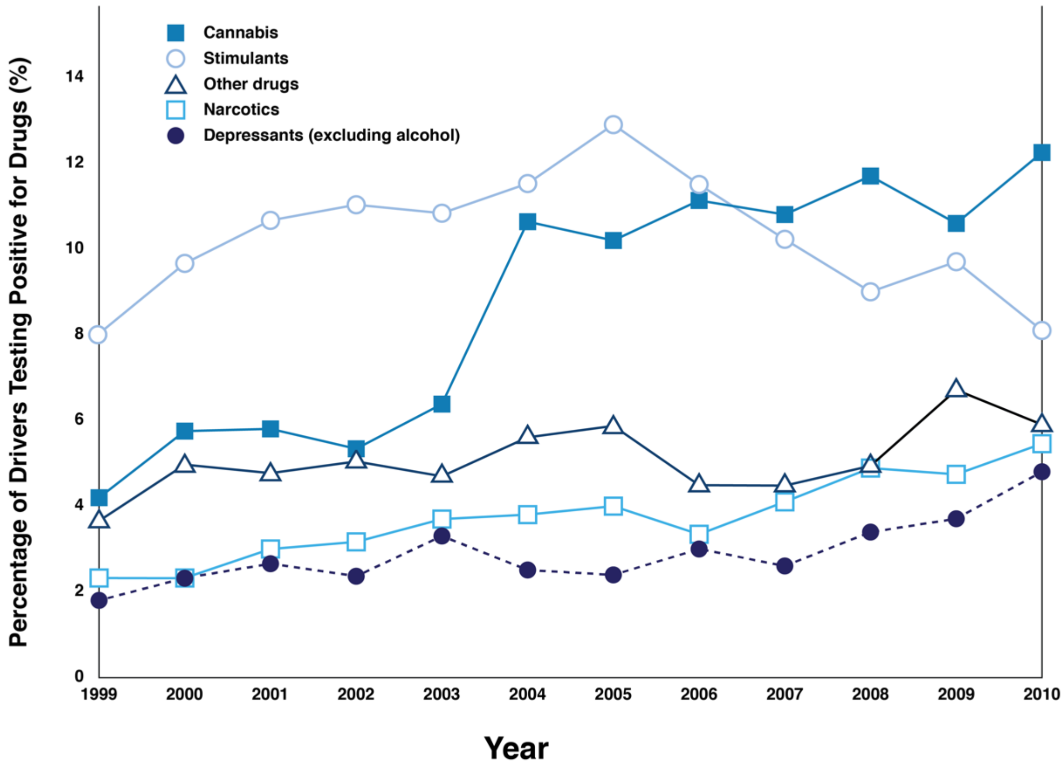


Figure 10. Percentage of drivers killed within one hour of a crash who tested positive for drugs including THC and alcohol (Brady and Li 2014).

4.3 Brain Functioning

The effects of cannabis are the result of THC binding with cannabinoid receptors in the brain (CB1) (Quickfall and Crockford 2006). THC changes the activation brain regions responsible for cognitive functioning (Quickfall and Crockford 2006) that are involved in different driving tasks such as car following, overtaking, and lane keeping (Pearlson et al. 2017). THC also impedes the creation of functional neural networks that connect relevant brain regions necessary for successful performance of these tasks. These neurological effects may be apparent at least five hours after cannabis use (Stevens et al. 2018).

4.4 Cognitive Functions

"Driving is a complex task that requires integrity of sensory, motor and cognitive functions" (Ramaekers 2018). Indeed, the Federal Drug Administration mandates that drugs be tested for their potential to impair cognitive functions critical to safe driving (FDA 2017).

Core cognitive functions include attention (e.g., directing attention to a relevant element in the environment, maintaining attention on a relevant element over time without distraction, and sharing attention among several relevant elements), memory (e.g., forming and retrieving memories of words and other abstractions involving language), and psychomotor control (e.g., quickly and accurately adjusting behavior in response to error feedback to maintain a target state). These core functions then support higher executive functions such as planning, reasoning, and problem solving, which involve conscious control (Broyd et al. 2016; Cohen and Weinstein 2018).

All of these functions are necessary for safe driving. For example, attention is critical for identifying and monitoring unexpected hazards in the traffic environment. Memory is important for remembering speed limits and destinations. Various aspects of psychomotor control involve corrective actions to reduce error in current speed, headway, or lane position. And, executive functions relate to mode choice, route planning, law compliance, and risk taking (e.g., choosing target speed and following distance for traffic and weather conditions).

Due to the pharmacological and methodological issues discussed previously, there can be considerable variability – and even contradictions – among individual studies examining the effects of THC on cognitive functioning. Table 2 summarizes a recent review that characterized the magnitude and consistency of evidence that cannabis use impairs cognitive functions (Broyd et al. 2016). This evidence was characterized separately for impairment from both acute and chronic use, as well as the persistence of impairment after cessation of use.

Table 2. Consistency of Evidence for THC Impairment of Core and Executive Cognitive Functions (Broyd et al. 2016).

Cognitive Domain	Acute	Chronic	Persistence
Attention	+ + +	+ + +	+ –
Memory	+ + +	+ + +	+ –
Psychomotor Control	+ + +	+	+
Executive Functions	+ –	+ –	+ –

Note: + + +, strong and largely consistent evidence for impairment; + +, moderate evidence for impairment; +, weak evidence for impairment, being based on only a small number of studies; + –, mixed evidence.

From this review, there was consistent evidence that acute cannabis use impairs the core cognitive functions such as attention, memory, and psychomotor control. The consistency of evidence was much weaker for executive functions. [5]

But, why do our executive functions (e.g., planning, reasoning, and problem solving) show less impairment than our core functions?

Executive functions operate with our conscious control (awareness), thereby providing the opportunity to compensate in an effort to overcome perceived impairment (Ramaekers 2019). In contrast, core functions are often routine or automatic, operating without our awareness, so there is less opportunity for compensation, which results in greater impairment of cognitive performance.

4.4.1 Dose Dependency

The degree of impairment observed from cannabis use depends on the amount (dose) of THC consumed and resulting concentration within the body. As an example Figure 11 shows performance on a simple psychomotor control task in which subjects used their dominant hand to tap a button in rhythm with a flashing rectangle appearing on a computer screen that varied its frequency over time (Boggs, Surti, and Gupta 2018). Performance in this task is measured in terms of the percentage of flashing rectangles correctly responded to the average reaction time to tap the button after the rectangles began flashing. Subjects completed this task without THC (placebo) and with an intravenous low (0.015 mg/kg) and high dose (0.030 mg/kg) of THC. As shown in Figure 11, THC dose increased the percentage of rectangles that were missed and slowed the average reaction time.

[5] To understand these cognitive functions, it may be helpful to understand how these functions are measured. Memory is often measured by having subjects hear or read a list of words and then later be asked to recall them or recognize previous words from a new list. The performance measure is memory accuracy. Such tests measure ability to code and encode information. Psychomotor control is often measured by having subjects move a controller to return a cursor on a computer screen to the middle target position in response to is being moved by a random displacement force. The performance measure is accuracy of keeping the cursor on the target. Such tests measure capacity and delay in processing information and controlling behavior. Attention is often measured by presenting unexpected signals to the subject while they focus on a primary task (such as a psychomotor task). The performance measures are the percentage of signals missed and reaction time to signals. Such tests measure attentional capacity. Executive functions are often measured by problem solving tasks, such as moving color rings spread across three poles to create a target pattern using the least number of moves possible. The performance measures are number of moves and time to solve the problem. Such tests measure capacity for planning, decision making and integration of information (conscious awareness).

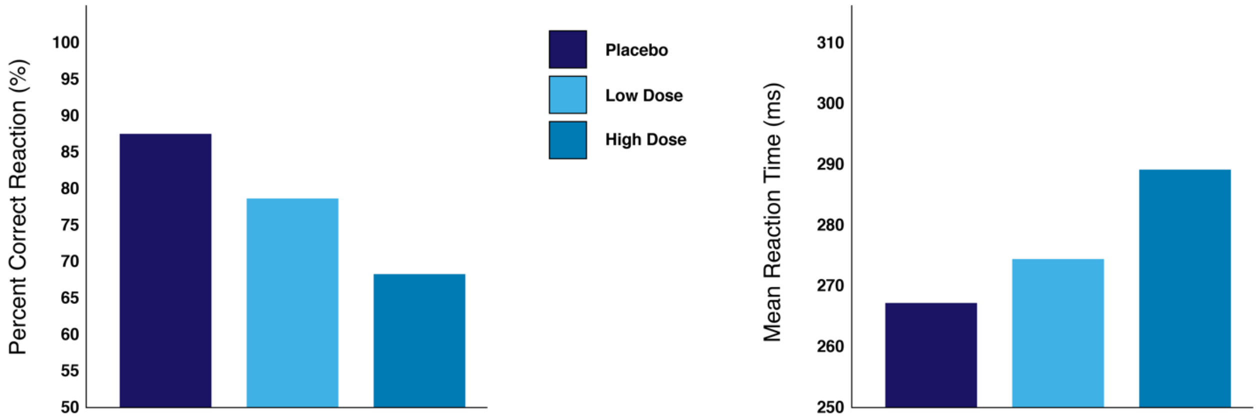


Figure 11. Dose effects of THC on basic psychomotor performance (Boggs, Surti, and Gupta 2018).

4.4.2 Functional Sensitivity

Certain cognitive functions are more sensitive than others to the acute effects of THC use. For example, Figure 12 is based on the same 559 individual tests of cognitive functions reviewed by Berghaus, Scheer, and Schmidt 1995. Each line in this figure shows the probability that tests of different cognitive functions show impairment in relation to THC level (whole blood). The dashed line represents the average probability across all tests.

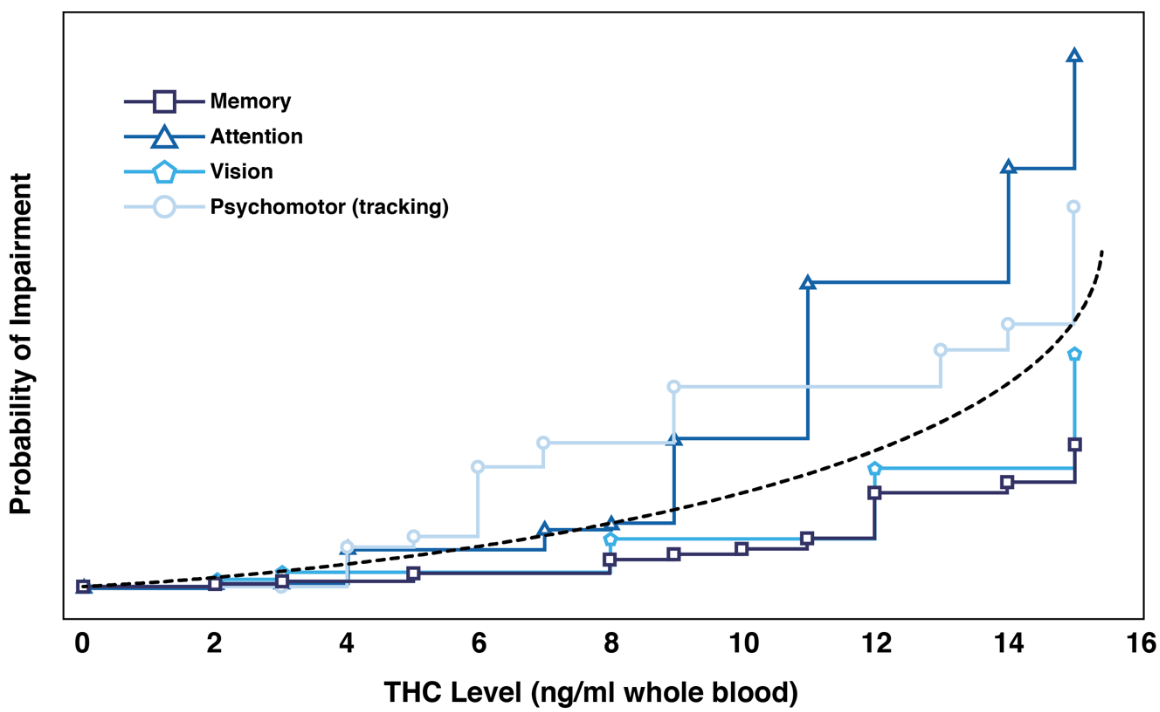


Figure 12. Accumulative percentage of specific cognitive function tests showing significant impairment as a function of THC level (whole blood) (Berghaus, Scheer, and Schmidt 1995).

The two lines above this dashed line indicate that attention and psychomotor control are more sensitive to the impairment effects of THC, at least at levels above 4 ng/ml (whole blood). These forms of impairment may relate to increased missed information in the driving scene (e.g., not noticing an unexpected pedestrian or hazard in roadway) and greater variability in vehicle control (e.g., standard deviation of lateral position).

4.5 Driving Behavior

It is logical to expect that impairment of cognitive functions by THC would translate to impairment of driving behaviors based on those cognitive functions. However, evidence that THC impairs driving behavior is sometimes absent, inconsistent, or contradictory (Hartman and Huestis 2013). Indeed, meta-analyses suggest that driving behavior is less sensitive to THC than (core) cognitive functions that underlay these behaviors (Berghaus, Scheer and Smidt 1995; Hartman and Huestis 2013).

Why is this?

There are three important factors that need to be understood when interpreting evidence for the effects of THC on driving behavior.

First, the timing of cognitive function tests in laboratory settings are often force based, meaning the stimulus in the tests are presented to subjects at a fixed rate to impose a workload demand on the subject. Lab settings also are highly controlled, so there are few other factors that can influence subject performance. In contrast, real world driving is self-cased in the sense that drivers can adjust their own driving for their own preferred level of workload. Impairment is likely to be more evident under high workload conditions such as those found in force-paced laboratory tests. Moreover, there are lots of sources of influence in the road environment that can create variability in driver behavior. Such variability may hide effects of THC impairment.

Second, as previously discussed (see Tolerance section), drivers may attempt to compensate for their perceived impairment by investing more effort in the driving task (e.g., focusing attention on the road ahead) or by increasing safety margins (e.g., slowing down, increasing following distance). Such compensation may reduce observable impairment. However, such compensatory strategies are rarely completely successful (Ramaekers et al. 2009).

Third, just like our different cognitive functions, driving tasks also differ in terms of the amount of conscious control required (Ramaekers, Berghaus and Drummer 2004). Some tasks require conscious control, such as deciding on a safe set point for speed, lane position, or following distance. Other tasks can be performed routinely and automatically without conscious control, such as reacting to changes in vehicle position relative to those set points (e.g., automatically adjusting the steering wheel in response to an unexpected wind gust). Whereas drivers are able to attempt compensation with tasks under their conscious control, they are less able for those activities that operate automatically.

> Not all driving tasks are equally sensitive to the detrimental effects of THC. Performance appears worst in tests measuring driving skills at the operational level (i.e. Lane tracking

and speed adjustment) as compared to performance in tests measuring driving performance at the maneuvering level (i.e. distance keeping and braking), and the strategic level (i.e. observation and understanding of traffic, risk assessment and route planning).

> Strategic and maneuvering levels are particularly demanding of resources in that they require effortful processing and attention. Thus, processing is relatively slow and flexible. In contrast, the operational level is an automatic, routine process, which is fast and relatively inflexible. Drivers may be particularly vulnerable to detrimental effects of THC in traffic situations where they specifically employ driving skills that are operated at lower automated levels, such as during highway driving. (Ramaekers, Berghaus and Drummer 2004, 117)

One of the most common measures of driving behavior used in on-road studies is variability of lane position because it occurs naturally and continuously, without risk to the driver. As an example, Figure 13 shows the effect of THC level on controlling vehicle lateral position in a lane (Ramaekers, Robbe, and O'Hanlon 2000).[6] This figure shows variability of performance increase with THC dose. Indeed, higher doses (200 μg/kg) can impair performance to a similar degree as alcohol (BAC 0.04%). Moreover, the impairment effects of THC and alcohol are additive. For example, the higher dose (200 μg/kg) combined with a low level of alcohol (BAC .04%) can create impairment that is equivalent to more than BAC .10%.

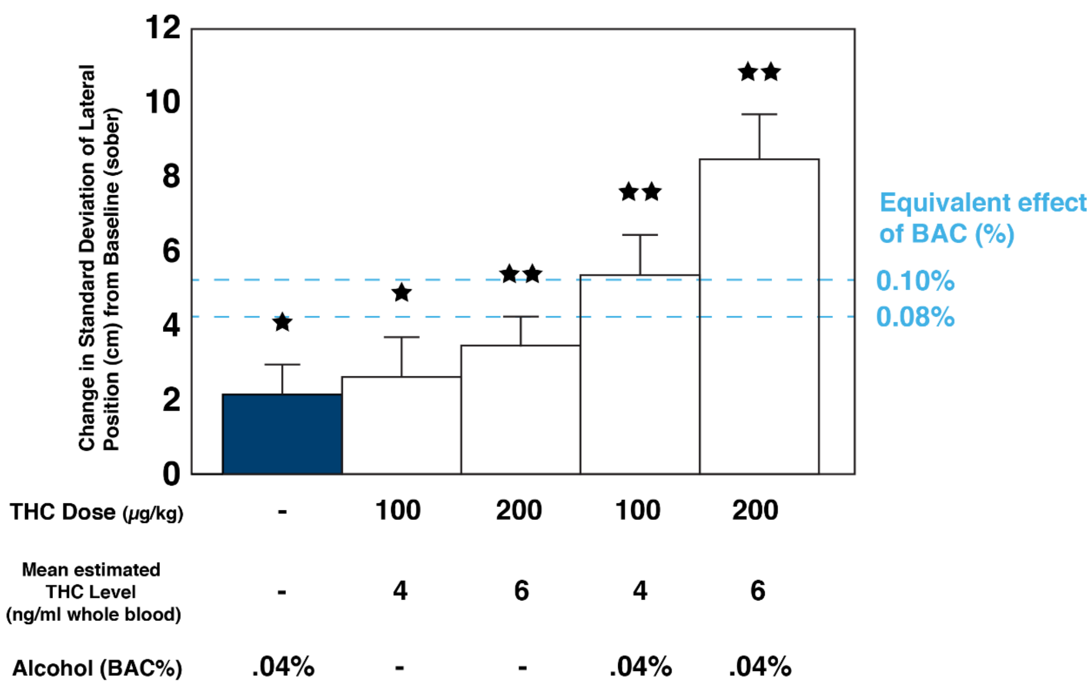
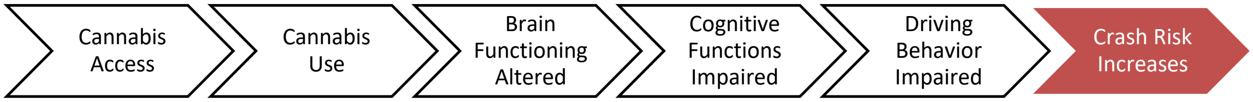


Figure 13. Variability of lateral position in lane during on-road driving as a function of THC dose, alcohol level (Ramaekers, Robbe, and O'Hanlon 2000) and estimated THC level (whole blood) (Ramaekers 2019).

[6] This task is based on psychomotor control functions and operates automatically. Corrective actions with the steering wheel are the unconscious reaction to perceived displacement of the vehicle from its target position (e.g., wind gust).

4.6 How does cannabis influence crash risk?



To understand the role of cannabis in traffic safety, we need to consider not only motor vehicle crashes but also the types of crash and driver actions that are responsible for those crashes.

4.6.1 Crash Type

Given the consistent evidence that THC impairs attention (see Table 2), we might expect that the role of THC would be greatest in conditions most dependent on attention for safe driving:

1. The need for attention cannot be anticipated (e.g., unexpected hazard in roadway or deceleration by lead vehicle).
2. There are multiple hazards requiring selective attention.
3. The drive is long and monotonous requiring sustained attention (i.e., vigilance).

Consistent with these expectations, Romano and Voas (2011) recently completed an epidemiological study of motor vehicle crashes and concluded that drivers testing positive for THC were more often involved in crashes involving inattention and speeding. [7]

4.6.2 Unsafe Actions

Given that cognitive impairment from THC is dose dependent, it would be expected that driver errors resulting from this impairment would increase in a similar manner. Consistent with this expectation, Dubois et al. (2015) used logistic regression models to predict the presence of unsafe acts by drivers (e.g., failure to stop at stop sign, unsafe turning, unsafe passing, improper merging, driving over lane boundary, entering opposing lane, etc.). This prediction model included driver demographics and driving record as well as levels of THC and alcohol. As shown in Table 3, the odds that a driver committed an unsafe act increased with THC level and blood alcohol level (BAC) level. The combination of both THC and alcohol increased the odds even more, especially for low BAC levels.[8]

[7] The finding that THC-positive drivers are over-represented in crashes related to speeding is interesting given that it is often assumed slowing down is one of the compensatory strategies used by drivers intoxicated by cannabis. Perhaps this reflects a biphasic relationship between THC concentration levels and compensation efforts (Solowitz and Pesa 2012). Low THC levels may create awareness without reducing capacity to compensate by driving slower, whereas higher THC levels may increase risk-taking tendencies (or an incapacity to compensate), resulting in a propensity for speeding.

[8] This may suggest that the impairment effect of high BAC levels may swamp the additional risk imposed by (low) THC levels.

Table 3. Predicted Odds of a Driver Committing an Unsafe Act in a Fatal Crash as a Function of THC and BAC Level (Dubois et al. 2015).

BAC	Predicted Odds	
	THC absent	THC present
0.00	1.07	1.25
0.01	1.19	1.37
0.02	1.32	1.50
0.03	1.46	1.64
0.04	1.61	1.79
0.05	1.78	1.94
0.06	1.95	2.10
0.07	2.13	2.27
0.08	2.32	2.44

4.6.3 Culpability

Given the evidence that drivers are more likely to commit an unsafe act during a fatal crash, we can also expect that THC-positive drivers are more likely to be deemed responsible (culpable) for fatal crashes in which they are involved. To examine crash culpability in relation to THC level, we can calculate a "Culpability Index" as shown in Equation 1.

$$Cupability\ Index = \frac{Responsible\ (cases)\ [\#of\ drivers\ THC\ positive : \#of\ drivers\ THC\ negative]}{Not\ responsible\ (controls)\ [\#of\ drivers\ THC\ positive : \#of\ drivers\ THC\ negative]}$$

Equation 1. Calculation of Culpability Index to estimate odds of DUIC driver being responsible for crash.

In this calculation, the odds of THC-positive drivers being responsible for crashes is compared to the odds of THC-positive drivers not being responsible for crashes. For such analyses, crash responsibility is generally determined from police reports or crash investigations, so there may be some degree of subjectivity. An odds ratio value greater than one suggests that THC-positive drivers are more likely to be responsible for crashes than drivers without THC present.

Figure 14 shows the calculated relationship between THC level (whole blood) and the calculated Culpability Index (Sewell, Poling, and Sofouglu 2009) based on data from a culpability study performed by Drummer et al. (2004). These results also show that driver responsibility for fatal crashes also increases with THC level.

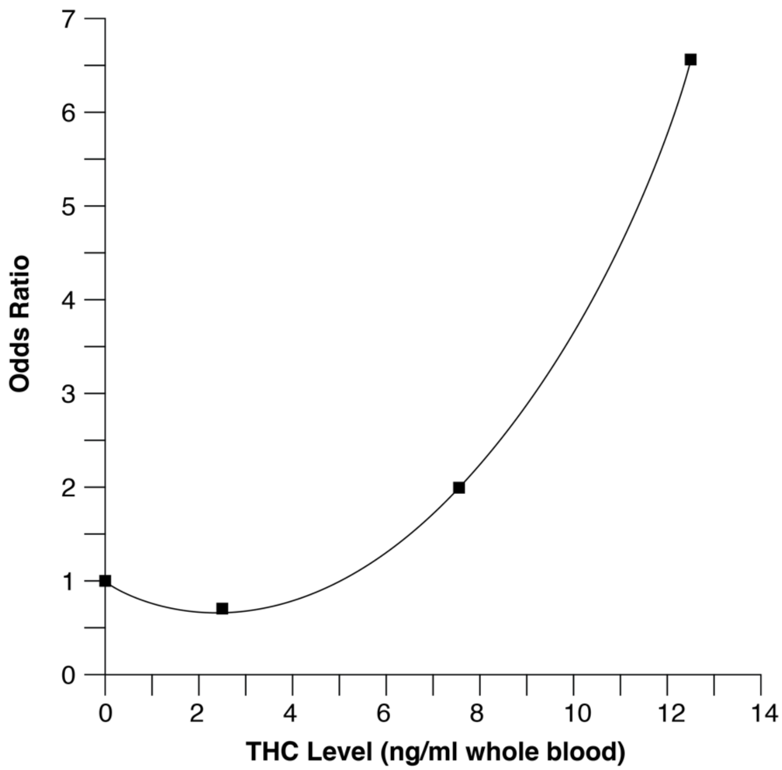


Figure 14. Estimated relationship of crash culpability (odds ratio) as a function of THC level (whole blood) (Sewell, Poling, and Sofouglu 2009).

4.6.4 Crash Risk

If THC-positive drivers are more likely to commit unsafe acts and be responsible for crashes, it is reasonable to expect THC-positive drivers to have a higher overall fatal crash risk. The risk of being fatally injured is quantified in terms of an "odds ratios" using Equation 2. An odds ratio above one means the likelihood of being fatally injured in a crash is greater for a driver with THC present than when absent.

$$Odds\ Ratio = \frac{THC\ positive\ [\#of\ drivers\ killed\ (cases):\#\ of\ matched\ living\ drivers\ killed\ (controls)]}{THC\ negative[\#of\ drivers\ killed\ (cases):\#\ of\ matched\ living\ drivers\ killed\ (controls)]}$$

Equation 2. Calculation of odds ratio to estimate fatal crash risk for THC-positive drivers.

The most recent meta-analysis of crash risk with THC used a novel analytical method to reduce variability among odds ratio estimated across 16 case-control studies published since 2000. This method produced an (unadjusted) odds ratio of **1.99 (95th Confidence Interval: 1.05 – 3.80)** (Hostiuc et al. 2018). This result indicates that the presence of THC in a driver doubles the likelihood of that driver being fatally injured in a crash. This is broadly consistent with other published meta-analyses that have used a variety of other analytical methods (Li et al. 2011; Li, Brady, and Chen 2013).

5 DISCUSSION

5.1 How dangerous is cannabis compared to other drugs?

It is important to recognize that other drugs impose a substantially higher fatal crash risk than cannabis as shown in the case-control study Li, Brady, and Chen (2013) summarized in Table 4. This data also shows that cannabis (THC) nearly doubles the risk of being fatally injured in a crash. However, these data also remind us that alcohol still has a much higher fatal crash risk, especially when combined with other drugs.

Table 4. Odd ratios (Unadjusted) for 2007 U.S. fatal crashes for different drug types (Li, Brady, and Chen 2013).

Drug Type	Odds Ratio	95th Confidence Interval
Cannabis	1.83	1.39 – 2.39
Narcotics	3.03	2.00 – 4.48
Stimulants	3.57	2.63 – 4.76
Depressants	4.83	3.18 – 7.21
Any drug (average)	2.22	1.68 – 2.92
Polydrug	3.41	2.43 – 4.73
Alcohol	13.64	11.12 – 16.72
Alcohol + Drug	23.24	17.79 – 30.28

However, focusing on crash risk alone does not fully address the public health impact of drug-impaired driving. The number of drivers killed in crashes depends on both the crash risk associated with the drug (odds ratio) and the prevalence of that drug in the driving population (exposure). Whereas other drugs may have a higher fatal crash risk than cannabis, the prevalence of cannabis use among drivers may be higher, which means the overall incidence of fatal crashes related to cannabis may also be higher.

For example, whereas the odds ratios for narcotics and depressants are 1.7 and 2.6 times greater than for cannabis, there were nearly twice as many fatally injured THC-positive drivers (cases). Therefore, even with a lower crash risk, the higher prevalence of drivers using cannabis may result in a larger overall number of fatally injured drivers in drug-related crashes.

5.2 What are the effects of combining cannabis with alcohol on fatal crash risk?

Whereas cannabis tends to impair highly automated driving functions, alcohol impairs conscious functions. Thus, combining these drugs makes it difficult to compensate effectively for perceived impairment (Sewel, Poling, and Sofouglu 2009). Such conditions would be predicted to increase crash risk compared to either drug alone. Indeed, a recent case-control study (Chihuri, Li, and Chen 2017) estimated that the risk of fatal injury in a crash was 16 times greater for drivers combining alcohol with cannabis (odds ratio adjusted for age, gender, region = 25.09, 95^{th} CI 17.97 – 35.03) than for drivers using cannabis alone. Additional case-control studies are needed to corroborate these estimates of fatal crash risk resulting from combining alcohol and cannabis.

5.3 How dangerous is cannabis in relation to fatal motor vehicle crashes compared to other causes of death?

A recent study examined the role of cannabis in motor vehicle crashes compared to other causes of death (e.g., found dead, suicide, falling, collapsed, other) (Andrews et al. 2015). In such studies, cases from other causes of death served as a control group to estimate the relative effect of THC levels on crash fatalities. The results showed a similar percentage of cases testing positive for THC in both crash (18%) and other causes (14%) groups. However, the median THC level for the crash group was 1.6 times higher (4.2 ng/ml) than for the other group (2.6 ng/ml). The distribution of THC levels was also different, with the crash group including higher THC levels. Recalling that impairment from THC may be dose dependent, such evidence may suggest that THC has a larger role in crash fatalities than other fatality causes. However, because THC levels in this study were measured in postmortem blood samples, these results must be interpreted cautiously given the possibility of postmortem redistribution of THC in the body (see Postmortem Redistribution section).

5.4 How does legalization of cannabis affect traffic safety?

Based on the evidence reported here, policymakers are concerned that the legalization of cannabis may be detrimental to traffic safety. What evidence is there for this concern?

Whereas the number of fatal crashes may increase after cannabis legalization (GHSA 2019), such evidence does not “prove” the change in law was the cause. For example, many other factors coincidental with the timing of the law change could have resulted in more fatal crashes (e.g., more drivers, more mileage, dangerous weather conditions, etc.). In order to attribute causality to changes in laws that legalize cannabis, a more sophisticated form of analysis is needed that can control for these other coincidental factors.

Once such analytic method is the case-control study design (Houwing, Mathijssen, and Brookhuis 2009). In such studies, states that enacted legislation to legalize cannabis (cases) are compared to their neighboring states (controls). In order to support valid conclusions, the selection of control states has two phases:

1) Only neighboring states (controls) whose crash rates correlate over time with the case states are selected. This selection criterion matches cases and controls in terms of similar crash trends over time.
2) Crash rates for both cases and controls are adjusted for various demographic and economic variables that also correlate with crash rate. In essence, these adjustments make the cases and control states equivalent in terms of the selected variable.

Recently, Monfort (2018) applied this case-control design to estimate the effect of legalization of cannabis retail sales in Colorado, Oregon, and Washington. By examining police-reported crashes (per million vehicle registrations) it was concluded that the legalization of sales in these states increased crashes by 5.2% compared to the same period in neighboring states that did not enact this legislation (Monfort 2018).

Another form of analytic method to quantify the effect of changes in cannabis legislation is called the "difference in difference estimator" method. As shown in Figure 15, this method uses predictive models based on demographic and economic variables to represent pre-legislation trends in crash fatality rates over time for both case and control states. These models are then used to predict fatal crash rates during the post-legalization period. The legalization is only concluded to affect fatal crash rates if the actual rates are higher than predicted in the case states but similar in the control states.

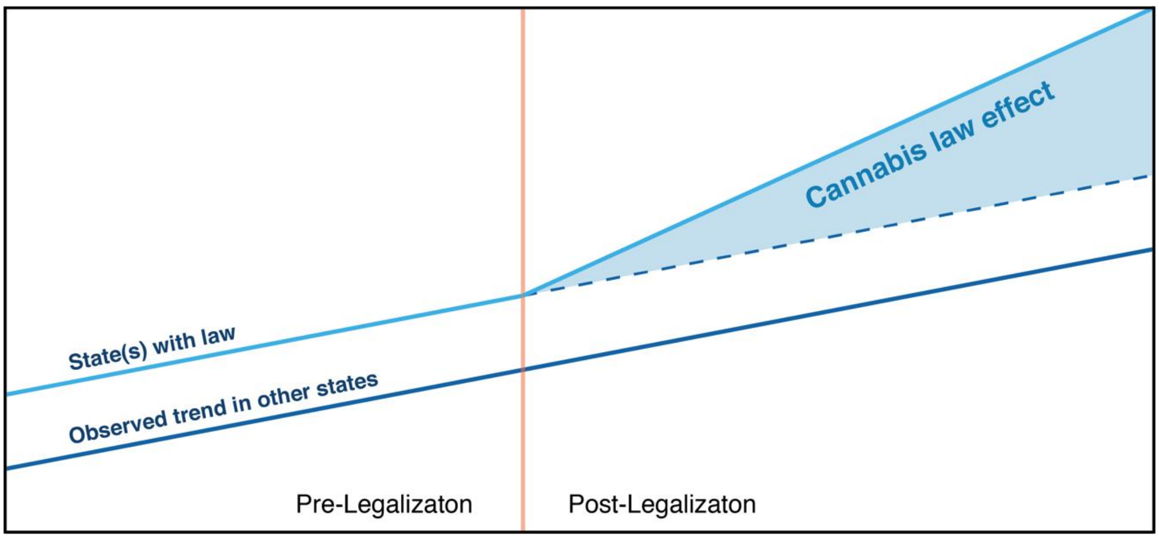


Figure 15. Illustration of "difference in difference estimator" method to isolate effect of cannabis legislation on traffic safety (Coyle 2018).

Using this method, no change in crash fatality rate (per vehicle mile traveled) was initially noted over a three-year post-legislation period in Colorado and Washington (Aydelotte et al. 2017). However, increasing the post-legislation period with additional year of data did result in an estimated 7.14% increase in the crash fatality rate (per capita) due to the laws passed on Colorado and Washington (Coyle 2018).

Extending this "difference in difference estimator" method to also "weight" comparable control states based on demographic and economic variables to be more comparable case states showed no effect of legislation in Colorado and Washington on crash fatality rate (per vehicle mile travelled) (Hansen, Miller, and Weber 2018).

Together, these results suggest that legislation to legalize recreational cannabis can increase crash risk. However, current evidence is not conclusive because only a few states with such legislation have been examined over relatively short post-legislation periods. Certainly, there is no evidence to prove that legalization improves traffic safety. To reach consensus about the effect of cannabis legislation on crash fatalities, there is a need for additional research using more case states and longer post-legislation periods.

5.5 Social implications – How is legalization interpreted by society?

The perceptions of such laws do influence people's beliefs and behaviors. For example, as a result of the law to legalize recreational cannabis, adolescents perceived cannabis to be less harmful and reported more frequent use of cannabis (Cerda et al. 2017). The authors speculate the passage of the law may reduce stigmatization for using cannabis, thereby increasing use.

Such perceptions may also be expected to translate to more DUIC behavior. For example, Table 5 shows the perceptions of Washington State adults DUIC after the legalization of recreational cannabis (CHSC 2018). More than 18% of respondents agreed that the legalization of cannabis implied it was safe to drive after using cannabis. Such an assumption within society is not trivial. Those making this assumption were more than twice as likely to engage in DUIC behavior.

Table 5. Survey Response to Interpretation of Legalization of Cannabis in Washington State.
Regardless of whether you consume alcohol or cannabis, how much do you agree or disagree with the following statements?
"The legalization of cannabis implied that it is safe to drive under the influence of cannabis."

N	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
868	43.1%	18.1%	8.2%	12.2%	3.6%	7.1%	7.7%

Thus, care must be given when communicating the reason for passing a law to legalize cannabis that includes messaging to convey the inherent risk of driving after using cannabis, especially in combination with alcohol.

6 CONCLUSION

There is much debate and conflicting evidence about the effect of cannabis on fatal crash risk. However, an examination of international literature reviews and meta-analyses suggests that the preponderance of evidence indicates that driving under the influence of cannabis (DUIC) increases the risk of the driver being fatally injured in a motor vehicle crash, especially when combined with alcohol. Indeed, THC-positive drivers also appear more likely to be responsible for these crashes, probably because of insufficient attention or excessive speeding.

The mechanism for this increased crash risk appears to begin with the effect of THC on brain activity and functioning. These neural changes then impair cognitive functions that are necessary for driving, especially attention. The impairment of core cognitive functions translates to impairment of driver behaviors, most notably those not requiring conscious control. The absence on conscious control for these behaviors means that it is not possible for drivers to compensate for their impairment.

To the extent that decriminalization of cannabis increases access within a population – including drivers – it is logical to expect an increase in DUIC and associated motor vehicle crashes, especially those related to the behavior of impaired drivers. However, it is pragmatically difficult to isolate the causal effect of cannabis laws on traffic safety metrics. Moreover, there have been too few rigorous analyses of the effect of such laws on traffic safety using only a few states (CO, OR, WA) and relatively short post-legislation periods. Thus, it is insufficient evidence to make any conclusions about the legalization of cannabis on traffic safety.

Such conclusions may be disputed by individuals who believe they drive safely after using cannabis. However, evidence that tolerance to the acute effects of cannabis can be developed is inconclusive. Even those cannabis users professing they can compensate for the acute effects of cannabis are truly unable to compensate completely for their impairment. Regardless, laws regarding DUIC are a public health issue – and as such – need to reflect the risk imposed by the drug across the entire driving population, rather than reflect the unique circumstances of a small minority of individuals.

7 REFERENCES

Andrews, R., Murphy, K.G., Nahar, L., and Paterson, S. (2015). Cannabinoid concentrations detected in fatal road traffic collision victims compared with a population of other postmortem cases. Clinical Chemistry, 61(10), 1256 – 1264.

Aydelotte, J., Brown, L., Luftman, K., Mardock, A., Teixeira, P., Ben Coopwood, B., and Brown, C. (2017). Crash Fatality Rates After Recreational Marijuana Legalization in Washington and Colorado, American Journal of Public Health, 107, 1329 – 1331.

Berghaus, G., Scheer, N., and Schmidt, P. (1995). Effects of Cannabis on Psychomotor Skills and Driving Performance - a Metaanalysis of Experimental Studies. The 13th International Conference on Alcohol, Drugs and Traffic Safety (T'95) (August 13-18), Adelaide, Australia. Access January 2019: http://casr.adelaide.edu.au/T95/paper/s16p2.html

Berning, A., and Smither, D.D. (2014). Understanding the limitations of drug tests information, reporting and testing policies in fatal crashes. Traffic Safety Facts: DOT HS 812 072 NHTSA: Washington, DC. (pp1).

Boggs, D.L., Surti, T., and Gupta, A. (2018). The effects of cannabidiol (CBD) on cognition and symptoms in outpatients with chronic schizophrenia a randomized placebo-controlled trial. Psychopharmacology 235: 1923.

Brady, J.E., and 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.

Broyd, S.J. van Hell, H.H., Beale, C., Yucel, M., and Solowitz, N. (2016). Acute and chronic effects of cannabinoids on human cognition – Systematic review. Biological Psychiatry, 79, 557 – 567.

Brunet, P., Hauet, T., Hebrard, W., Papet, Y., Mauco, G., and Mura, P. (2011). Postmortem redistrubition of THC in the pig. Int J Legal Med, 124, 543 – 549.

Capler, R., Bilsker, D., Van Pelt, K., and MacPherson, D. (2017). Cannabis Use and Driving: Evidence Review. Canadian Drug Policy Coalition.

Cerdá, M., Wall, M., Feng, T., Keyes, K.M., Sarvet, A., Schulenberg, J., … Hasin, D.S. (2017). Association of State Recreational Marijuana Laws with Adolescent Marijuana Use. JAMA pediatrics, 171(2), 142–149.

Chihuri, S., Li, G., and Chen, Q. (2017). Interaction of marijuana and alcohol on fatal motor vehicle crash risk: a case-control study. Injury Epidemiology, 4(8), open access: https://injepijournal.biomedcentral.com/track/pdf/10.1186/s40621-017-0105-z.

Christenfeld, N.J., Sloan, R.P., Carroll, D., and Greenland, S. (2004). Risk factors, confounding, and the illusion of statistical control. Psychosomatic medicine,66(6), 868-875.

CHSC. (2018). Driving Under the Influence of Cannabis and Alcohol: Key Findings Report from 2018 Survey. Prepared for: Washington Traffic Safety Commission (621 8th Avenue SE, Suite 409, Olympia, WA 98501).

Cohen, K. and Weinstein, A. (2018). The effect of cannabinoids on executive functions, Brain Sciences, 40(8), 1 – 19.

Compton, R. and Berning, A. (2015). Drug and alcohol crash risk. Traffic Safety Facts (DOT HS 812 117). National Highway Safety Administration: Washington, DC.

Compton, R. (2017). Marijuana-Impaired Driving – A report to congress. (DOT HS 812 440) Washington, DC: National Highway Traffic Safety Administration.

Coyle, D. (2018). Recreational marijuana and traffic fatalities: Sensationalism or new safety concern. Graduate Student Thesis, Dissertation, and Professional Paper. ScholarWorks at University of Montana. Access January, 2019: https://scholarworks.umt.edu/cgi/viewcontent.cgi?article=12249andcontext=etd

Crean, R.D., Crane, N.A., and Mason, B.J. (2011). An evidence-based review of acute and long-term effects of cannabis use on executive functions. Journal of Addiction Medicine, 5(1), 1 – 8.

Desrosiers, N.A., Ramaekers, J.G., Chauchard, E., Gorelick, D.A. and Huestis, M.A. (2015). Smoked cannabis' psychomotor and neurocognitive effects in occasional and frequent smokers. Journal of Analytic Toxicology, 39, 251 – 261.

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

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

ElSohly, M.A., Mehmedic, Z., Foster, S., Gon, C., Chandra, S., and Church, J.C. (2016). Changes in Cannabis Potency Over the Last 2 Decades (1995-2014): Analysis of Current Data in the United States. Biological psychiatry, 79(7), 613-619.

FDA. (2017). Evaluating Drug Effects on the Ability to Operate a Motor Vehicle Guidance for Industry. U.S. Department of Health and Human Services Food and Drug Administration Center for Drug Evaluation and Research (CDER). Washington, DC.

GHSA. (2019). Traffic safety impacts of marijuana legalization. Accessed March 30th, 2019: https://www.ghsa.org/sites/default/files/2018-10/GHSA_SafetyImpacts_Final.pdf

Governing. (2019). State Marijuana Laws in 2018 Map. Accessed January 31, 2019: http://www.governing.com/gov-data/safety-justice/state-marijuana-laws-map-medical-recreational.html

Grotenhermen, F. (2003). Pharmacokinetics and pharmacodynamics of cannabinoids. Clinical Pharmacokinetics, 42(4), 327 – 360.

Hansen, B., Miller, K., and Weber, C. (2018). Early evidence on recreational marijuana legalization and traffic fatalities. NBER Working Paper Series. Access January, 2019: https://www.nber.org/papers/w24417

Hartman, R.L. and Huestis, M.A. (2013). Cannabis effects on drivng skills. Clinical Chemistry, 59(3), 478 – 492.

Holland, M.G., Schwope, D.M., Stoppacher, R., Gillen, S.B., and Huestis, M. (2011). Postmortem redistribution of THC, 11-OH-THC, and THCCOOH. Forensic Science International, 212, 247 – 251.

Hostiuc, S., Moldoveanu, Negoi, I., and Drima, E. (2018). The association of unfavorable traffic events and cannabis use: A meta-analysis. Frontiers in Pharmacy, 9(99), 1 – 14.

Houwing, S., Mathijssen, R., and Brookhuis, K.A. (2009). Case-control studies. In J.C. Verster, S.R. Pandi-Perumal, J.G. Ramaekers, and J.J. de Gier (Eds.) Drugs, Driving and Traffic Safety, Birkhauser Verlag, Switzerland.

Huestis, M., Mitchell, J., and Cone, E. (1996). Urinary Excretion Profiles of 11-Nor-9-Carboxy-Δ9-Tetrahydrocannabinol in Humans after Single Smoked Doses of Marijuana, Journal of Analytical Toxicology, 20, 441–452.

Huestis, M.A. (2007). Human cannabinoid pharmacokinetics. Chemistry and biodiversity, 4(8), 1770-804.

Huestis, M. (2015). Cannabis-impaired driving: A public health and safety concern. Clinical Chemistry, 61(10). Editorial.

Karila, L., Roux, P., Rolland, B., Benyamina, A. Reynaud, M., Aubin, H-J., and Lancon, C. (2014). Acute and long-term effects of cannabis use. Current Pharmaceutical Design, 20, 4112 – 4118.

Karschner, E.L., Schwilke, E.W., Lowe, R.H., Darwin, W.D., Pope, H.G., Herning, R.I., Cadet, J.L., and Huestis, M.A. (2009). Do Δ9-tetrahydrocannabinol concentrations indicate recent use in chronic cannabis users? Addiction 104(12), 2041-2048.

Kelley-Baker, T., Berning, A., Ramirez, A., Lacey, J. H., Carr, K., Waehrer, G., and Compton, R. (2017). 2013-2014 National Roadside Study of alcohol and drug use by drivers: Drug results (Report No. DOT HS 812 411). Washington, DC: National Highway Traffic Safety Administration.

Kraemer, H.C., Stice, E., Kazdin, A., Offord, D., and Kupfer, D. (2001). How do risk factors work together? Mediators, moderators, and independent, overlapping, and proxy risk factors.American journal of psychiatry,158(6), 848-856.

Kruger, H.P. and Berghaus, G. (1995). Behavioral Effects of Alcohol and Cannabis: Can Equipotencies be Established? ICADS International Conference. Access January, 2019: http://www.icadtsinternational.com/files/documents/1995_061.pdf.

Leafly. (2019). What are the strongest cannabis strains? Accessed May 2019: https://www.leafly.com/news/strains-products/what-are-the-strongest-cannabis-strains

Lemos, N.P. and Ingle, E.A. (2011). Cannabinoids in postmortem toxicology, Journal of Analytical Toxicology, 35, 394 – 401.

Li, M-C, Brady, J.E., DiMaggio C., Lusardi, Tzong, K.Y., and Li, G. (2011). Marijuana use and motor vehicle crashes. Epidemiological Reviews, 34, 65 – 72.

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

Logan, B.K. (2007). Marijuana and Driving Impairment. In: ElSohly M.A. (Eds) Marijuana and the Cannabinoids. Forensic Science And Medicine. Humana Press.

Monfort, S.S. (2018). Effect of recreational marijuana sales on police-reported crashes in Colorado, Oregonc and Washington. Washington, DC: Insurance Institute for Highway Safety.

Morgan, C.J.A, Freeman, T.P., Hindocha, C., Shafer, C., Gardner, C., and Curran, H.V. (2018). Individual and combined effects of acute delta-9-tetrahydrocannabinol and cannabidiol on psychotomimetic symptoms and memory function. Translational Psychiatry, 8(1), 181.

NCSL. (2015). Drugged Driving per se Laws. National Conference of State Legislatures. Accessed January, 2019: http://www.ncsl.org/documents/transportation/persechart_April2015.pdf

NHTSA (2010). Drug involvement in fatally injured drivers. Traffic Safety Facts: DOT HS 811 415. NHTSA: Washington, DC.

Quickfall, J. and Crockford, D. (2006). Brain neuroimaging in Cannabis Use: A review. Journal of Neuropsychiatry and Clinical Neuroscience, 18(3), 318 – 332.

Pearlson, G.D., Repoli, L., King, D., Novotny, S., Ward, N., Boer, E., Calhoun, V.D., and Stevens, M.C. (2017). Functional MRI Changes During Marijuana-Intoxicated Driving. Poster presented at the American College of Neuropsychopharmacology 56th annual meeting, Palm Springs, CA

Ramaekers, J.G., Robbe, H.W.J., and O'Hanlon. (2000). Marijuana, Alcohol and Actual Driving. Human Psychopharmacology, 15, 551 – 558.

Ramaekers J.G., Berghaus G., van Laar M., and Drummer O.H. (2004). Dose related risk of motor vehicle crashes after cannabis use. Drug and alcohol dependence, 73(2), 109-119.

Ramaekers J.G, Kauert G., Theunissen E.L, Toennes S.W, and Moeller M.R. (2009). Neurocognitive performance during acute THC intoxication in heavy and occasional cannabis users. Journal of Psychopharmacology, 23(3), 266-77.

Ramaekers, J.G., van Wel, J.H., Spronk, D.B., Toennes, S.W., Kuypers, K.P., Theunissen, E.L., and Verkes, R.J. (2016). Cannabis and tolerance: acute drug impairment as a function of cannabis use history. Scientific reports, 6, 26843.

Ramaekers, J.G. (2018). Driving under the influence of cannabis – An increasing public health concern. Journal of the American Medical Association, 319(14), 1433 – 1434.

Ramaekers, J.G. (2019). Personal communication and written comments during technical review of this report.

Reisfield, G.M., Goldberger, B.A., Gold, M.S., and DuPont, R.L. (2012). The mirage of impairing drug concentration thresholds: A rationale for zero tolerance per se driving under the influence of drug laws. Journal of Analytical Toxicology, 2(36), 353 – 356.

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

Romano, E., and Voas, R.B. (2011). Drug and alcohol involvement in four types of fatal crashes. Journal of studies on alcohol and drugs, 72(4), 567-76.

SAMHSA. (2017). Key Substance Use and Mental Health Indicators in the United States: Results from the 2017 National Survey on Drug Use and Health. Substance Abuse and Mental Health Services Administration (SAMHSA), U.S. Department of Health and Human Services (HHS). Accessed April 14, 2019: https://www.samhsa.gov/data/sites/default/files/cbhsq-reports/NSDUHFFR2017/NSDUHFFR2017.pdf

Sewell, R.A., Poling, J.P., and Sofouglu, M. (2009). The Effect of Cannabis Compared with Alcohol on DrivingAmerican Journal of Addiction, 18(3), 185 – 193.

Solowitz, N. and Pesa, N. (2012). Cannabis and cognition: Short and long-term effects. In D. Castle, M. Murray, and D.C. D'Souza (Eds.) Marijuana and Madness, Cambridge University Press.

Stevens, M., Ward, N., Boer, R., King, D., Boyle, C., Bullock, A., Calhoun, V., and Pearlson, G. (2018). fMRI-Measured Brain Network Connectivity Changes After Acute Cannabis Challenge.

Poster presented at the American College of Neuropsychopharmacology 57th annual meeting, Hollywood, FL.

Swift, W., Jones, C., and Donnelly, N. (2010). Cannabis use while driving: A descriptive study of Australian cannabis users, Drugs: Education, Prevention and Policy, 17:5, 573-586

Theunissen, E.L., Kauert, G.F., Toennes, S.W. (2012). Neurophysiological functioning of occasional and heavy cannabis users during THC intoxication. Psychopharmacology, 220, 341 – 350.

Urfer, S., Morton, J., Beall, V., Feldmann, J., and Gunesch, J. (2014). Analysis of Δ9-tetrahydrocannabinol Driving Under the Influence of Drugs Cases in Colorado from January 2011 to February 2014. Journal of Analytical Toxicology, 38(8), 575–581.

USDA. (2019). Plants Database. Access March 28, 2019: https://plants.usda.gov/core/profile?symbol=casa3

Wong, K., Brady, J.E., and Li, G. (2014). Establishing legal limits for driving under the influence of marijuana. Injury epidemiology, 1(1), 26.