Cannabis-impaired driving

Report to the Canadian Centre on Substance Use and Addiction

Mark Asbridge, PhD., Kathleen MacNabb, MSc., Alanna MacDonald, BSc.

Department of Community Health and Epidemiology, Faculty of Medicine, Dalhousie University

Executive Summary

In this report the issue of cannabis legalization in Canada and its potential impact on cannabis-impaired driving is examined. Drawing on the primary studies from the last fives years (2016-2021), as well as systematic reviews and meta-analyses, and reports from government/NGOs, four questions are addressed: (1) What is the prevalence of driving under the influence of cannabis (DUIC) in Canada pre- and post-legalization? (2) What is the state of knowledge on the relationship between cannabis use, driving ability, and crash risk? (3) What are the current trends in cannabis and driving risk perceptions and how do they vary across important demographic factors? and (4) How has legalization impacted the policing of cannabis-impaired driving?

Trends in behaviour point to a slight to moderate increase in DUIC in Canada and other jurisdictions following the legalization of recreational cannabis use. This increase was observed in survey and hospitalization data in Canada and the United States, and in roadside surveys in the United States. Canada has yet to complete a roadside survey post-legalization. However, the evidence on changes in fatal crash rates post-legalization is either unclear (United States) or unavailable (Canada). The belief that cannabis impairs driving also increased post-legalization. However other DUIC related perceptions or beliefs include the perception that drivers under the influence of cannabis would be caught or punished did not change.

Beyond trends in driver behaviour and beliefs, a key question of this report is whether cannabis impairs driving ability and increases collision risk. Both the experimental (laboratory) and observational (real work) epidemiologic literatures were reviewed, drawing on several systematic reviews and meta-analysis, as well as key individual studies. Collectively, the evidence points to significant, though small to moderate, impairing effects of cannabis on psychomotor and cognitive tasks related to driving, including memory, attention, information processing, tracking performance, fine motor coordination, and reaction time, and conflict control, among others, which are comparative to driving performance deficits produced by blood alcohol concentrations in the range of 0.04% to 0.06% BAC.

Epidemiologic studies confirm that acute cannabis consumption produces a significant increase in crash risk; however, many more recent studies have found a weaker association or no association at all. The risk increase is most salient at THC concentrations of 5ng/ml or higher, with lower concentrations showing inconsistent or no association. Collectively, cannabis produces only a *slight* or marginal increase in crash risk (relative risk: 1-3), similar to the impairing effects of alcohol at a BAC between 0.1 and 0.5 g/L, which is at or below provincial administrative sanctions for alcohol impaired driving in most jurisdictions in Canada. However, driver impairment and crash risk may be higher or lower across individuals as its is moderated by several important factors, including THC dose, THC chemotype, mode of delivery, recency of cannabis use, cannabis use history, body physiology, and the concurrent use of alcohol and other drugs.

Finally, in looking at the policing and enforcement of cannabis and driving related laws, there is a clear need to balance several important issues – accuracy, celerity, certainty, and public acceptability. The continued use of Drug Recognition Experts and the DECP evaluation protocol, must be weighed against broadening the application or use of point of contact assessment at the roadside using oral-fluid testing devices beyond its role as simply a screening tool (as is done in

Spain, for example). Each have pros and cons and their appropriate integration is necessary to effectively police cannabis and driving laws and gain public confidence. Equally important, are current THC legal limits set at an effective level? A review of the evidence suggests that threshold of ≥5ng THC/ mL of blood appear to be an appropriate point where increased driver impairment and crash risk are observed, with thresholds of ≥2.5ng THC/ mL of blood when used concurrently with alcohol.

Moving forward it is important that evidence continues to be collected to assess trends in DUIC, crash rates, and driver risk perceptions post-legalization. This requires well-designed case-control studies to assess crash risk, coupled with provincial roadside surveys and self-report surveys of Canadians to examine DUIC rates, and risk perception. This primary research must be coupled with the regular surveillance of cannabis-related injuries, hospitalizations and fatalities involving drivers. Together, this evidence will inform federal and provincial government agencies in the appropriate evaluation and review of former *Bills C-45 and C-46*.

Background

This report was drafted in Summer 2021, at the request of the Canadian Centre on Substance Use and Addiction (CCSA) and revised in Fall 2021 according to comments from the CCSA.

The purpose of this report is to inform discussions at the Public Safety Canada Policy Research Symposium by providing an overview of academic and grey literature on cannabis impairment and driving, paying particular attention to the implication of legalizing cannabis for recreational purposes in October 2018.

The impairing effects of cannabis and the current state of laws concerning cannabis use in Canada are noted first (Section 1), followed by; a discussion of the prevalence of driving under the influence of cannabis (DIUC), how it is measured, how prevalence may have changed since legalization, and which populations are most likely to DUIC (Section 2); examination of the association of cannabis use with crash risk (Section 3); an exploration of the perceptions of drivers and the general public towards DIUC (Section 4); and an overview of the implications of legalization on the policing DIUC (Section 5).

In preparing this report, we draw on academic and grey literature published in English located via database searches, Google searches, and from the first author's personal library. For the most part, the literature search focused on publications from 2016 and onwards to compliment systematic reviews on topics covered in this report.[1-4] While the report deals primarily with Canadian literature, international studies and reports are included when appropriate to fill gaps in the evidence.

Table of Contents

List of Tables

Section 1: Introduction

In this section, we introduce the drug cannabis by explaining how it is consumed and providing an overview of the pharmacological effects of cannabis, focusing on those which may impact drivers' ability to safety operate a motor vehicle. We also provide a background on the legalization of recreational cannabis in Canada in 2018 and the concurrent adoption of Bill C-46, which created criminal offense for driving under the influence of cannabis.

Cannabis and THC, pharmacokinetics, and dynamics

Cannabis is a commonly used drug around the world,[5] but particularity in Canada, where a fifth of people ages 15 years and older reported using cannabis during the last quarter of 2020. This is a stark increase from the 14% who reported cannabis use in the first quarter of 2018, prior to legalization.[6] The high, and increasing, level of cannabis consumption in Canada necessitates careful consideration of the impact of legalization on driving safety.

The impact of cannabis on psychomotor performance related to driving

Cannabis has the potential to impair drivers by triggering their natural cannabinoid receptor system which plays an important role in receiving and responding to sensory information, psychomotor function (i.e., coordination, dexterity, reaction speed, precision), memory, and emotional regulation.[7,8] Most relevant to driving, cannabis use may also impair cognition, perception,[9] motor function/ coordination[10] and reduces reaction time.[11] Together, these changes can impair driving skills.[12] Unsurprisingly, the negative impact of cannabis on driving performance increases with higher dose and decreases with time since use.[13] Cannabis appears to have a substantially decreased impairing affect on chronic users (as opposed to occasional users), likely because these individuals develop a tolerance to its impact or are better able to compensate in their driving.[14,15]

THC has been shown to decrease drivers' ability to remain in their lane (standard deviation of lateral position ['SDLP']), meaning cannabis-impaired drivers 'weave' in and out of lanes more frequently than non-impaired drivers.[16,17] By blunting general cognition, cannabis-impaired drivers are less able to react appropriately to adverse/ dangerous events. Cannabis has also been implicated in poorer time estimation (which, in turn, impacts stopping time and maintaining an appropriate following distance) and sustaining attention on the road.[7]

Cannabis use in combination with alcohol consumption greatly increases driving impairment,[17] particularly reaction time and lane weaving.[18] Driving under the influence of both drugs impairs drivers more than either substance alone. However, the exact nature of this relationship is difficult to assess.[18] While both have impairing affect on driving, their interaction is difficult to determine, as cannabis is typically associated with slower driving speed and alcohol is associated with speeding. Likewise, alcohol leads to more risky driving, while cannabis makes many drivers more cautious.[11,19,20]

How cannabis is measured related to driving

Defining how cannabis use is measured related to driving is central to understanding how physiological effects of cannabis consumption may impact driving ability. While some drivers are asked to self-report cannabis use while driving (typically for research purposes), this method logically results in the under-estimation of cannabis use while driving (see Section 2). More commonly, cannabis use while driving is measured using biological samples, which can identify *acute* consumption, meaning within the previous two hours. Blood, oral fluid (saliva), and urine can all be used to test for cannabis, however, a measure of THC concentration in a person's blood is considered the gold standard. Oral fluid and urine tests provide less accurate assessments of acute consumption. Urine contains inactive THC metabolites, which can show positive results in the body for days or weeks after consumption and has no clear relationship to motorists' impairment and ability to drive. Consequently, these measures have less utility in assessing cannabis use related to driving.

The measure that best captures recent use is by testing whole blood for THC or its psychoactive metabolites. However, this method too has challenges. Cannabis is fat soluble and metabolized substantially slower than most other drugs. Consequently, the (non-psychoactive) metabolite of THC (THC-COOH) is detectable in blood serum for three days after inhalation, long after any psychomotor effect,[21–23] and it can take up to five weeks to completely eliminate cannabis from lipid-rich tissues, meaning that repeated exposure within this period results in the accumulation of THC metabolites, which can result in a false positive.[23] Furthermore, unlike alcohol, there is no clear correlation between THC blood concentration and impairment or behaviour effects.[24] Consequently, this approach measures cannabis *use* rather than *impairment.*

Length of cannabis' impact on performance

There is no consensus regarding how long cannabis impacts driving performance, due both to dose, forms of ingestion, and frequency of use; and variation exists among studies that have investigated this question.[25].[26] THC is rapidly absorbed after inhalation of cannabis smoke and it is detectable in plasma within seconds. When cannabis is smoked, the effects start within seconds, reach a peak around 20 minutes and last for two to three hours. In contrast, if the drug is eaten, the effects are delayed and last longer, reaching a maximum about 3–4 hours after drug ingestion, and lasting up to 12 hours.[21] Drivers who consume cannabis orally are likely impaired longer (up to 12 hours) than those who consume it via inhalation, however, there is a dearth of evidence in this area.[25] Canada's 'Lower Risk Cannabis Use Guidelines' suggest abstaining from cannabis for a minimum of six hours prior to driving[27] and a meta-analysis concluded that drivers should wait at least five hours before driving.[25]

Driving under the influence of cannabis and the law in Canada

Detailed overview of how driving under the influence of cannabis is regulated

Driving under the influence of cannabis (DUIC) is a costly problem in Canada. Motor vehicle collisions attributable to cannabis impairment cost an estimated $1.09 billion in 2012 in the form of fatalities, injuries, and property damage.[28] Recognizing that DIUC might become an even greater economic and public health concern post-legalization, a bill was presented to the House of Commons in tandem with the *Cannabis Act*.

While the *Criminal Code of Canada* designated drug-impaired driving as a criminal offence long before the legalization of recreational cannabis, *Bill C-46: An Act to amend the Criminal Code (offences relating to conveyances) and to make consequential amendments to other Acts* intended to prevent DUIC driving by establishing per se limits for whole blood THC and enhancing police powers to obtain evidence of cannabis impaired driving. The new offenses are defined according to the following thresholds for THC blood concentrations within two hours of driving:

1. $2 \leq 5$ ng THC /mL of blood
2. ≥ 5ng THC/ mL of blood
3. ≥ 2.5ng THC/ mL of blood *and* ≥ 50 mg of alcohol/dL of blood

Exceeding the first threshold is punishable by a fine of up to $1000. The other thresholds are punishable by a mandatory fine of $1000 for the first offence and increasing penalties for subsequent offenses with a maximum penalty of 10 years and dangerous offender status. The third threshold exists because of the additive impact of cannabis and alcohol impairment discussed in Section 3.

Bill C-46 also authorizes the approval of oral fluid drug screening devices by police to test for drugs when officers have reasonable suspicion that a driver at a roadside stop have drugs present in their body, at which point they could request a drug evaluation by a Drug Recognition Expert (see Section 5) or request a blood sample for quantification.[29] The use of oral fluid screening devices facilitates timely, road-side testing, which is very important because of how fast THC is metabolized.[30]

Section 2: Driving under the influence of cannabis (DUIC)

In this section, we will review the evidence on the prevalence of driving under the influence of cannabis (DUIC) amongst drivers in Canada, focusing on trends in the five years prior to the legalization of recreational cannabis in Canada, and the post-legalization years to assess any impact on rates of DUIC. In addition, we will examine the primary psycho-social determinants associated with DUIC behaviour, with specific attention to youth and young adults. To assess DUIC, we must draw on data from several sources, each of which has its own inherent biases. These sources include population-level surveys, roadside surveys, data from presentations to emergency departments or hospitals following a traffic crash, and coroner/toxicological data following a fatal crash. We draw on data from Canada, as well as other jurisdictions where recreational cannabis use has been legalized. DUIC is defined as the use of cannabis just prior to driving a motor vehicle. In self-report surveys, the question that is typically asked is whether the person has driven a motor vehicle within 1-2 hours of using cannabis (in the past week/month/year), whereas for roadside surveys, emergency department/hospital studies, or coroner data, DUIC is determined based on the presence of THC and its metabolites in oral fluid, blood, or urine samples.

DUIC in Self-Report Surveys

Self-report surveys are the most common approach for assessing DUIC behaviour in the Canadian population. Self-report surveys can assess the whole population and examine prevalence rates for DUIC across broader social determinants and in harder to reach populations, such as youth, non-crash involved drivers, and those in more rural communities. Self-report surveys have limitations, including non-response bias and recall bias, where estimates of DUIC and cannabis use, more generally, are often under-reported or mis-reported. Moreover, self-report surveys often employ differing methodologies which do not always allow for comparability.

Several surveys assessing DUIC have been completed prior to the legalization of cannabis. For example, the Traffic Injury Research Foundation regularly completed the Road Safety Monitor survey of Canadian drivers and noted rates of DUIC over time. The percentage of drivers who reported DUIC fluctuated, with 1.5% in 2002, 2.8% in 2010, declining to 1.6% in 2013, and rising again to 2.1% in 2014 and 2.6% in 2015[31]. More recently, Rivera and Patten (2020) examined data from two national surveys (CCHS and CSTADS) in the years 2015 to 2018 and observed rates of past-year DUIC amongst individuals aged 15 and older that ranged from 1.8% to 3%, with higher rates observed for males and those aged 15 to 24.[32]

In 2017, Health Canada developed and implemented the Canadian Cannabis Survey (CCS)[33] with the aim of collecting detailed, baseline information about the habits of people who use cannabis and behaviours relative to cannabis use. In 2017 and 2018, the CCS defined DUIC by asking respondents about driving within 2 hours of using cannabis; in 2019 and 2020 DUIC was separated to assess driving within 2 hours of smoking/vaporizing cannabis and driving within 4 hours of consuming edible cannabis. In the two years prior to legalization, between 2.3 - 2.6% of

respondents aged 16 years and older reported past-year DUIC. This rate increased to 3.6% of past-year DUIC in 2019, the first full year after legalization, and to 3.4% in 2020. In each wave, rates were higher among males with inconsistent trends by age group.

Statistics Canada developed a similar survey called the Canadian National Cannabis Survey (NCS), with the objective of better understanding the frequency of cannabis use in Canada, and to monitor changes in behaviour resulting from legalization.[34] Data from the 2019 National Cannabis Survey indicates that 15% of individuals with a driver's licence who use cannabis admitted driving within two hours of using it at least once in the previous 12 months.[35] Males were more likely than females to report driving after using cannabis (17.5% and 9.5%, respectively), but there was no difference according to age group. Rotermann[36] examined data from the National Cannabis Survey (NCS) covering pre- and post-legalization periods and found no change (12.1% to 13.2%) in the rate of DUIC among cannabis users with a valid driver's license.

DUIC behaviour among youth and young adults (16 to 24 years of age) is consistently higher than adults pre-legalization, particularly among young males.[37 38 39] For example, a 2017 national study of youth 16 to 19 years of age, administered online, noted that 15.4% reported ever driving a car within 2 hours of using cannabis.[40] Drawing on the 2019 NCS, Brubacher and colleagues noted that among respondents aged 15 to 24 years, 14% reported driving within 2 hours of using cannabis.[41,42] However, among Canadian youth who use cannabis frequently, 64% of males and 33% of females reported being 'intoxicated' with cannabis while operating a vehicle.[43]

Several US studies have examined changes in DUIC rates pre- and post-legalization, and typically find that DUIC prevalence is higher in states where recreational cannabis consumption is legalized. A national study of adults 16 to 65 years of age revealed that the prevalence of DUIC was higher in those states that had legalized cannabis (past 30 days 7.3% versus 5.5%; past 12 months 10.4% versus 9%).[44] These results have been confirmed in state-specific studies drawing on driving while impaired (DUI) police data [45 46] where cannabis-related-DUI cases increased substantially post-legalization. As in Canada, rates of DUIC are consistently higher among young males relative to females.[47]

DUIC in Roadside Surveys

Roadside surveys establish checkpoints in a jurisdiction set at random times and days of the week, where drivers are randomly stopped and requested to provide an oral fluid (saliva) sample to be tested for the presence of drugs. Several roadside surveys have been completed in Canada. In 2008, 2010, 2012, and 2018, roadside surveys in British Columbia randomly stopped between 1500-2000 drivers to participate and provide an oral fluid sample, with a detection limit of 0.5 ng THC/ml in 2008, and 0.2 ng THC/ml in other years.[48–51] Between 7.0 and 10% of drivers tested positive for drugs, with cannabis being the drug most detected in each study. The proportion of drivers testing positive for cannabis varied slightly over time, from 4.6% and 4.5% in 2008 and 2010, to 3.7% in 2012, and 5.3% in 2018.

Ontario completed roadside surveys in 2014 and 2017. In the 2014 Ontario roadside survey, 2,142 drivers provided an oral fluid sample and 10.2% tested positive for drugs, while in 2017, 1738 drivers provided an oral fluid sample and 10.5% tested positive for drugs. In both surveys, cannabis was the most detected drug, representing a prevalence of cannabis use of 7% and 8.6% of participating drivers, respectively.[52,53] Similar roadside surveys were completed in Manitoba (2016), Yukon (2018), and the Northwest Territories (2018), where drugs were detected in 10%, 18%, and 13% of drivers who agreed to provide an oral fluid sample, respectively. In each case, cannabis was, overwhelmingly, the drug detected most often.[53]

Drivers testing positive for cannabis in roadside surveys are more likely to be male and tend to be spread evenly across age groups. This is notable in comparison to alcohol, where young people (24 years and younger) appear much less likely to drink and drive. Additionally, unlike drinking and driving, which tends to spike in the evening or at night, cannabis-positive driving occurs more consistently throughout the day.[51,52,54–57]

No jurisdictions in Canada have completed a roadside study post-legalization. Several US states have examined the impact of cannabis legalization on cannabis-positive driving via roadside surveys. A three-wave pre- post-legalization study was completed in Washington state and found that the proportion of THC-positive daytime drivers increased from 8% before retail sales to 23% 6 months after retail sales and 17% one year after retail sales; this proportion did not change among nighttime drivers (19% pre- and 20%, 19% post-legalization).[58] Similar studies in Washington and California on non-crash involved drivers before and after legalization found limited change among nighttime drivers, but significant increases in the proportion of cannabis-positive daytime drivers.[59] [60]

DUIC in hospital studies

Hospital-based studies capture patients presenting to the emergency department following a traffic crash. Typically, only major trauma or serious injury crashes are involved, as in such cases blood samples are drawn for clinical and/or research purposes; results are not generalizable to less serious crashes.[61] Due to the objective assessment of the presence of cannabis, hospital studies do not suffer recall bias that plagues self-report surveys; however, given that blood samples are typically captured hours after a traffic crash, estimates of cannabis levels are lower than at the time of the crash. Hospital studies also do not suffer from the high refusal rates and non-response bias common in self-report and roadside surveys.

Several hospital-based studies on cannabis positive drivers involved in a traffic crash have been completed in Canada in the years prior to legalization. A 2014 study from Ontario and Nova Scotia of over 800 drivers presenting to emergency departments (EDs) following a traffic crash, found that 11% were cannabis positive.[62] A British Columbia study examined 1097 drivers presenting to EDs between 2010 and 2012 and found cannabis metabolites present in 12.6% of drivers and Δ-9-tetrahydrocannabinol (Δ-9-THC) detected in 7.3%; in both cases, cannabis-positive drivers were more likely to be male and under the age of 30.[63] A follow-up study by the same research team in

British Columbia covering the years 2010 to 2016 noted that 8.3% of drivers presenting to the ED following a traffic crash were positive for THC.[64]

In terms of changes pre- and post-legalization, again Brubacher and colleagues[65] assessed the change in the proportion of positive-cannabis drivers presenting to emergency departments at multiple hospitals in British Columbia (between January 2013 and March 2020). They found that following legalization, there was a significant increase in the prevalence of drivers with THC>0 (33% increase) and with THC≥2ng/mL (129% increase), and a marginally significant increase for drivers with THC≥5ng/mL. The biggest increase post-legalization was observed among male drivers and those 50 years of age and older. Hospital based studies from the US similarly report increases in the rates of traffic-related presentations involving cannabis post legalization.[66-68]

DUIC in Fatal Crash Studies

Toxicological analysis of drivers involved in fatal crashes is regularly collected in each Canadian province, though testing rates are inconsistent between jurisdictions. The benefits of fatal crash studies are the objective assessment of the presence of cannabis and the ability to determine quantitative levels. Post-mortem blood THC concentrations more accurately reflect concentration at the time of crash relative to hospital studies, as circulation and metabolism ceases with death.[69,70]

Drawing on Transport Canada Data, the Traffic Injury Research Foundation examined trends in drug-positive fatal crashes between 2000 and 2012. They observed that the proportion of cannabis-positive (alone or in combination with other drugs) fatally injured drivers increased from 12.8% in 2000 to 19.7% in 2012. It is important to note that during the period, testing rates in fatal drivers hovered around 50%. Results showed varying characteristics with respect to gender and age among fatally injured drugged drivers.[31] An examination of fatally injured drivers in Canada between 2000 and 2010 revealed that 16.6% of those tested were positive for cannabis.[71] From 2011 to 2014, drug-testing rates increased substantially to over 80%. In 2014, 18.9% of those who were tested were found positive for THC.[72] A study from Ontario[73] looked at three-years of post-mortem blood samples (2016-2018) and observed that among the 921 cases examined, 27% tested positive for cannabis (THC), which exceeded the number of cases that tested positive for alcohol. Fatally injured drivers are more likely to be male, and under the age of 35, and THC-positive fatal crashes tend to be spread evenly across the days of the week and between nighttime and daytime.[73]

No studies have examined cannabis-positive fatal crashes in Canada post-legalization. This is, to a large extent, due to the lag time for the publishing of toxicological data in Canada. To examine the impact of legalization on fatal crashes involving cannabis, we can draw on results from other jurisdictions, including Uruguay and the United States, where several studies have examined changes in fatal crashes in legalized states such as Washington, Colorado, and Oregon. These studies typically involve pre- post-legalization comparisons of trends, or comparisons of fatality rates between states that have and have not legalized cannabis. Results from US studies in this area are mixed, in large part due to these methodological variations.

In the US, we can draw on several state-level studies that have examined fatal crash rates pre- and post-legalization. To date, however, findings have been mixed with several studies of Colorado, Washington State, and Oregon observing no discernable change in the rate of cannabis-positive (either alone or in combination with other drugs) fatal crashes post-legalization.[74][75][76] Conversely, a handful of studies of those same jurisdictions reported significant increases cannabis-positive fatal crashes post-legalization.[77][78] The most rigorous study, to date, was completed by Tefft and Arnold, who examined data on all drivers involved in fatal crashes in Washington in years 2008–2019 (n=8,282) to estimate prevalence of cannabis-positive fatal crashes before and after legalization. They employed multiple imputation to address the inconsistent fatal crash testing rates and noted that the proportion of drivers positive for THC was 9.3% before and 19.1% after legalization, while the proportion of drivers with high THC concentrations increased substantially.[79] These differing results are due, in large part, to the methods employed in each study, whether they include within-state studies or include control states, and the choice of outcome being measured.

Table 1 provides a summary of the evidence regarding DUIC behaviour and changes pre- versus post legalization. Evidence is consistent in self-report studies and hospital studies showing an increase in DUIC behaviour post-legalization. There are no post-legalization Canadian studies employing roadside surveys or fatal crash analyses; drawing on international evidence points to a post-legalization increase in the prevalence of DUIC in drivers examined at the roadside. The evidence of a post-legalization increase in cannabis-positive fatal crashes is unclear due to mixed findings across studies.

Table 1: Summary of DUIC behaviour pre- to post legalization

	Canada	International
	Change Pre- to Post Legalization	Change Pre- to Post- Legalization
Self-report surveys	Evidence of a slight increase +	Evidence of a slight increase +
Roadside surveys	No post-legalization surveys completed to date	Evidence of a moderate increase ++
Hospital data	Evidence of a moderate increase ++	Evidence of a slight increase +
Fatality data	No post-legalization fatal crash studies completed to date	Evidence is mixed

Section 3: Cannabis and Traffic Crash Risk

The aim of this section is to review the existing literature on estimates of crash risk associated with the acute consumption of cannabis. Key questions are:

1. Does acute cannabis consumption increase the risk of a traffic crash?
2. At what THC concentration (level or threshold) does crash risk increase?
3. Does the concurrent use of cannabis and alcohol produce additive or multiplicative effects on impairment, driving performance, and crash risk?

To examine this issue, we draw on studies from epidemiology, toxicology, pharmacological, and psychological literature, including both experimental and real-world (observational designs including case-control studies, case-crossover studies, culpability studies) studies.

Laboratory or Experimental Studies

Much of the early research assessing the effects of cannabis on driving performance involved experimental studies. These laboratory-based studies rely on driving simulators which attempt to provide a realistic and immersive driving experience where drivers are randomized into experimental and control groups to assess the effects of cannabis on driving performance. Experimental studies offer the benefit of assessing specific tasks related to driving and driver impairment, as well as the controlled THC dose and timing of consumption in relation to that impairment. The downside is that experimental studies occur in an artificial environment that, despite advances in simulator design, fail to fully replicate real-world driving and where participants are biased by the fact that they are often aware they are impaired, even in double-blinded, controlled studies.[80,81]

Several systematic reviews and meta-analyses of experimental studies have been completed. More than 25 years ago, Berghaus and colleagues completed a systematic review and meta-analysis of 60 laboratory studies and concluded that cannabis causes impairment of every performance area connected with safely driving a vehicle, with stronger effects at higher THC doses.[82] More recent systematic reviews continue to find that cannabis impairs attention, concentration, and psychomotor function as related to safe driving.[25,83–85] The most comprehensive of these reviews was completed by McCartney and colleagues,[25] who examined 80 experimental studies assessing cognitive and driving performance domains. They found that cannabis impairment ranged from small to moderate across nine cognitive areas (working memory, divided attention, sustained attention, information processing, tracking performance, fine motor coordination, reaction time, conflict control, and fluid intelligence). They also noted small to moderate increases in 'standard deviation of lane position (SDLP)', reaction time, and lane weaving. With respect to perception, some studies have observed that cannabis produces deficits in depth perception and visual acuity.[86,87] Simmons[85] noted that lateral position variability and rates of lane excursions were generally increased by cannabis, and speed was generally decreased by cannabis. *Indirect comparisons with alcohol indicate that the effects of cannabis on driving performance measures are akin to low blood alcohol concentrations (0.04% to 0.06% BAC)*.[85]

Sevigny's (2021) suggests that "certain driving abilities are significantly, albeit modestly, impaired in individuals experiencing the acute effects of THC"; however, these effects are moderated by THC dose (high vs. low dose), mode of delivery (smoked, vaporized, or ingested), and the recency of cannabis use.[88] [18,89,90] Reviews have noted that whether cannabis impairs driving performance is often contingent on the cannabis user experience of the driver and whether they smoked or ingested the cannabis.[25] Driving-related cognitive skills recover more slowly when cannabis is ingested compared to smoked. Equally important, Arkell and colleagues[16] examined cannabis chemotypes to compared the effects of Cannabidiol (CBD), used for pain relief as well as the treatment of epilepsy, anxiety, psychosis, and neurological disorders, and Δ9-Tetrahydrocannabinol (THC), used for intoxication, on driving performance. Only THC-dominate cannabis affected driving performance. These findings remind us that the effects of cannabis on driving performance are not universally consistent, and point to key factors that must be examined as we move forward in the expanding legal recreational cannabis market in Canada.[91]

Observational (Real-world) Studies

Observational epidemiological studies compare the proportion of THC positive drivers who are involved in a traffic crash (case) with drivers not involved in a crash (controls). Few standard case control studies of cannabis and crash risk have been completed, as they are difficult to carry out due to challenges in assessing THC in drivers *not* involved in a crash. Common biases for studies in this area include: 1) Variations in the adequacy of the non-collision controls employed to estimate relative risk and 2) inadequate control of confounding due to the presence of alcohol and/or other drugs, and other factors.[92–94]

There have been several systematic reviews and meta-analyses on this topic, which represent a natural starting point for this overview of acute cannabis consumption and crash risk. The systematic reviews were Asbridge et al (2012), Li et al (2012), Elvik (2013), Rogberg and Elvik (2016) and Houstic et al (2018),[1–4,95] each assessing similar sets of studies with some notable distinctions. Table 2 provides a summary of each of these studies. Estimates from each meta-analysis are generally consistent in showing that, overall, acute cannabis consumption is associated with an increase in traffic crash risk, ranging from an odds ratio of 1.36 to 2.66. Differences in estimates across reviews is due, in large part, to the choice of studies included. Some reviews include studies that measured cannabis in urine, saliva, or self-report, which are poor methods for assessing acute consumption, while others were more precise by only including studies measuring cannabis in whole blood, serum, or plasma. Additionally, there was considerable heterogeneity in estimates across reviews contingent on the study population, crash severity, and study design.

Several newer individual studies not included in the above reviews, or with important findings, necessitate comment. In 2015, a case-control study was carried out in Virginia by the US National Highway Traffic Safety Association.[96,97] Researchers measured THC in oral fluid samples of 2682 crash-involved drivers and in 6190 roadside control drivers, matched for time and place of crash. They found no associations between THC and crash risk (adjusted OR = 1.00); the study was limited by high refusal rates for crash-involved drivers and controls, and its focus on minor, non-

injury crashes. Brubacher and colleagues (2019)[64] completed a culpability study of 3005 drivers injured in motor vehicle collisions presenting to emergency departments in British Columbia. No association between cannabis and crash responsibility was observed. An Australian study by Drummer and colleagues (2020)[98] was conducted on 5000 drivers injured because of a vehicular collision who were taken to hospital and in whom comprehensive toxicology testing in blood was conducted. THC was detected in 11.1% of drivers tested, and those drivers with THC present showed only a modest increase in the odds of a culpable crash when all concentrations were assessed (OR=1.9, 95% CI 1.2–3.1). However, a dose-response effect was observed with higher odds of a culpable crash for THC levels ≥ 5ng/ml and ≥ 10 ng/ml.

Finally, three ecological studies from the United States and Great Britain have investigated the impact of April 20th, known as international '4/20' day, a popular counter-culture holiday where cannabis is celebrated and use rates are much higher than other days of the year, on fatal collision rates. All three [99] [100] [101] studies observed an increase in the relative risk of a fatal traffic crash after 4:20PM on April 20, compared with control times. While these studies are not able to examine cannabis-related crashes, nor assess cannabis as a direct cause in the traffic crash, they are able to infer association based on a natural experiment.

THC levels/thresholds and crash risk

A key legislative issue is the determination of the THC threshold at which cannabis impairs driving performance and increases crash risk. Bill C-46 set penalties, including criminal charges, for drivers with whole blood THC>2ng/mL (with more severe penalties for THC>5ng/mL or for THC>2.5ng/mL combined with BAC>0.05%). Most studies on cannabis and crash risk include drivers with any positive THC, and do not differentiate THC levels. However, Preuss and colleagues (2021)[102] provide an excellent review of those primary studies that examined the link between THC blood concentration and crash risk. They identified five studies,[64,98,103–105] two from Australia, two from France, and one from Canada, focusing either on drivers injured or killed in a traffic crash. Results across studies are generally consistent in showing a dose-response relationship, where the risk of a traffic crash increase with increasing THC concentrations. THC concentrations above 1-2 ng/ml and above 5 ng/ml were typically used and demonstrated the most robust cut points. Results were not consistent, however, with no association with crash observed at THC concentrations at or below 2ng/ml in three of the five studies. Consistent estimates of increased crash risk were observed at THC concentrations ≥ 5ng/ml in four of the five studies, with risk ratios (odds ratios) ranging from 2.1 to 6.6.

Crash Risk associated with the combined use of cannabis and alcohol

Limited research has examined the combined use of alcohol and cannabis on driving performance and crash risk. This research is relevant to Canadian law, as specific penalties exist for driving under the simultaneous influence of cannabis and alcohol, where lower thresholds for impairment are established. Collectively, the evidence on the interaction between alcohol and cannabis on crash risk is mixed, with some studies suggesting the interaction effect is multiplicative ,[94,106–111] while others suggest the effect is additive,[98,103,112–117] with limited research suggesting no

interaction.[118] Despite this heterogeneity, the consistent observation is that the combined use of cannabis and alcohol imposes greater deficits on driving performance and an increased crash risk, relative to the use of either substance alone.

Summary

In summary, there is near unanimous agreement across studies that acute cannabis use increases the risk for car crashes and impairs specific driving skills, and confidence in the results from several types of studies (case-control, culpability, and cohorts) are consistent. However, more recent observational epidemiologic studies are less consistent in showing an association between cannabis and crash risk, suggesting that additional, well-designed, primary studies, particularly case-control studies, are necessary to examine this association post-legalization. Drawing on Hels and colleagues (2012)[119] risk gradient (see Table 3), estimates from cannabis studies (including THC concentrations of 5ng/ml where risk estimates are highest) would suggest that the increase in crash risk be classified as "slight" (relative risk: 1-3), similar to the impairing effects of alcohol at a BAC between 0.1 and 0.5 g/L, which is at or below provincial administrative sanctions for alcohol impaired driving in most jurisdictions in Canada. While limited, studies on the concurrent use of alcohol and cannabis suggest that their combined crash risk burden is greater than the use of either substance alone, though the interaction between cannabis and alcohol is not multiplicative.

Table 2: Systematic review and meta-analyses of observational studies of acute cannabis consumption and traffic crash risk (adopted from Preuss et al., 2021[102])

Review	N		Acute Cannabis Measurement	Crash Risk Estimates Odds ratios (95% CIs)
	Participants	Studies		
Asbridge et al. 2012	51,783	9	Whole blood, serum or plasma Self-report (within 2 hrs crash)	Overall: 1.92 (1.35-2.73) Injury: 1.74 (0.88-3.46) Fatal: 2.10 (1.31-3.36)
Li et al., 2012	93,200	9	Whole blood, serum, or plasma Self-report Urine	Overall: 2.66 (2.07-3.41)
Elvik 2013	Not reported	27	Whole blood, serum, or plasma Self-report Urine Saliva	Injury: 1.10 (0.88-1.39) Fatal: 1.26 (0.88-1.81) Property: 1.26 (1.10-1.44)
Rogberg and Elvik 2016	239,739	46	Whole blood, serum, or plasma Self-report Urine Saliva Prescription	Overall: 1.36 (1.15-1.61) Fatal: 1.32 (1.08-1.62)
Houstic et al. 2018	245,591	24	Whole blood, serum, or plasma Self-report Urine Saliva	Overall: 1.89 (1.58-2.26) Collision: 1.95 (1.24-3.05) Injury: 2.16 (1.41-3.28) Fatal 1.73 (1.36-2.19)

Table 3: Relative risk of traffic-related serious injury or death for various substances with alcohol comparison (adapted from Hels et al. 2012[119]).

Risk level	Relative risk	Substance
Slightly increased risk	1-3	0.1 g/L ≤ alcohol in blood < 0.5 g/L Cannabis (THC ~ 5 ng/ml) Benzodiazepines Antidepressants Antihistamine\s (weak) Sedative Hypnotics
Medium increased risk	2-10	0.5 g/L ≤ alcohol in blood < 0.8 g/L Opiates
Highly increased risk	5-30	0.8 g/L ≤ alcohol in blood < 1.2 g/L Multiple prescription medicine use
Extremely increased risk	20-2000	Alcohol in blood ≥ 1.2 g/L Alcohol (lower levels) in combination with drugs Multiple prescription medicine use

Section 4: Perceptions of DIUC

In this section, the literature on the attitudes and public perceptions of Canadians about the risks associated with DUIC is reviewed, and potential changes in attitudes and perceptions before and after cannabis legalization are assessed. Beyond a recognition that cannabis can impair driving performance and increase the chance of a crash, it is important to understand that DUIC also carries the potential for legal consequences, including fines, license suspension, and jail time. Why do public attitudes and perceptions matter? Scott et al. (2021) modeled the system of beliefs that can predict DUIC and found that intention to DUIC (or not to) was the largest predictor of future DUIC behaviour. In turn, this intention was influenced by participant attitudes towards cannabis, past engagement in DUIC, perceptions of whether it is the norm and their overall value system.[120] As people develop attitudes and perceptions of cannabis, they form beliefs about what is safe and acceptable. If people believe that DUIC is unsafe, they are less likely to engage in this behaviour.[121] By understanding public attitudes towards DUIC, we can better understand which beliefs can lead to a higher rate of driving under the influence.

Pre-Legalization Attitudes

Public attitudes towards DUIC have been examined several times over the last 10 years.[39,122–124] In a survey conducted by Public Safety Canada in 2017, 81% of respondents reported that they believed that cannabis could impair driving abilities.[124] The Canadian Cannabis Survey in 2017 included questions on attitudes and found that 75% of Canadians believed that recreational cannabis impaired driving performance, which rose to 81% in 2018.[125] Other surveys, such as ones commissioned by insurance companies or MADD, have found that between 68% and 86% of the public believed that cannabis impairs driving ability.[126–129] When selecting reasons why Canadians believe that cannabis may impair driving, the most frequently selected reason was that cannabis slows reaction time and reduces one's ability to concentrate.[124]

Canadians were also concerned with the prevalence of DUIC. In the 2017 Public Safety Canada survey, 53% of respondents noted they were concerned about other drivers engaging in DUIC, and 70% indicated that they believed DUIC would increase after legalization.[124] Online polls reported higher numbers, with 86% of Canadians, indicating concern about increasing DUIC.[130] In an online survey by the Angus Reid Institute in 2017, 65% reported that they believed there would be more cases of DUIC after legalization.[131]

Changes in Attitudes Post Legalization

Post legalization, limited research has examined changes in attitudes towards DUIC in Canada. In the iterations of the Canadian Cannabis Survey following legalization, there were some small changes in opinions on DUIC. In the 2019 Canadian Cannabis Survey, 85% of Canadians reported believing that cannabis impairs driving, which then decreased to 83% of respondents in 2020.[33,42] An online survey found that 86% of Canadians felt that DUIC was unsafe.[132] Generally, there was

little change in attitudes before and after legalization, where estimates ranged from 68% to 86%, although this variation before legalization was likely due to more data and surveys being available. The act of legalization itself was observed to influence attitudes among users of cannabis. In a qualitative study containing interviews with people convicted of DUIC, it was noted that participants felt that legalization was an indication that the government and many Canadians now see cannabis as being low or lower risk, not only to health, but also to driving.[133] Similar findings have been observed in qualitative studies with youth.[134]

Studies from the United States also offer insight on attitudes and perceptions linked to legalization. In Washington State, roadside surveys were conducted before legalization and one year afterward. Among drivers who tested positive for cannabis, before legalization 45% stated that cannabis was very likely to impair driving, compared to 17% one year after legalization. In comparison, among drivers who tested negative for cannabis, the perception that cannabis was very likely to impair driving increased from 52% before legalization to 56% after legalization.[58] Finally, a study of youth perceptions noted that adolescents in states with legalized recreational cannabis held lower risk perceptions of cannabis.[135]

Perceptions that Cannabis does not Impair Driving

Although many Canadians believe that cannabis can impact a person's ability to drive, there are many who believe that there is little to no risk in DUIC. Prior to legalization, surveys find that between 8 and 15% of Canadians disagreed with the statement that DUIC impeded one's ability to drive. [122,125 136,137] Following legalization, a slight decrease in these beliefs have been reported, where 9% of respondents in the 2019 Canadian Cannabis Survey reported that cannabis does not impair driving, and 7% in 2020.[33,42] Related to this, in a 2019 survey, the most common reason Canadians engaged in DUIC was that they did not feel impaired by cannabis (80.4%). The second most common reason was that respondents believed they could drive carefully while under the influence (19.7%).[42] Other reasons for DUIC included the need to go somewhere and there was no other transit available.[124]

Another justification for engaging in DUIC is that cannabis affects people differently, such that regular users would not be impaired by cannabis, but that it would affect others who use less regularly.[133,138] This comparative optimism can sometimes lead to the result where respondents admit to considering DUIC a concern, while also reporting DUIC themselves.[124] Another factor is normative influences, where people who DUIC consider whether DUIC is acceptable and prevalent among their family and friends. People who engage in DUIC are also more likely to disregard the opinions of those who do not use cannabis.[133] Finally, some Canadians believe that cannabis improves their driving, indicating that they believed cannabis made a person a more careful driver.[124,133 124,139134,140]

Attitudes towards Law Enforcement of DUIC

Before cannabis legalization, Canadians expressed concern that police were not prepared for DUIC cases, and few Canadians indicated confidence in the ability of police to enforce DUIC laws. One online survey found only 19% of respondents believed that police would have the resources or equipment to catch drivers who were engaged DUIC after legalization.[130] Another poll by the Angus Reid Institute noted that only 32% of Canadians were confident that police were prepared to catch drivers under the influence of cannabis.[141] Similarly, only 26% of Canadians believed it was very likely someone would be stopped for DUIC,[128] while an online survey found a high proportion of Canadians who were unsure if police could catch those engaging in DUIC.[127] The Canadian Cannabis Survey noted a small increase in people reporting that they believed it likely, or extremely likely that a driver would be caught driving under the influence of cannabis, going from 23% in 2018 to 25% in 2019 immediately after legalization; however, this then dropped to 24% in 2020.[33,42,125] Similar patterns have been observed in other studies, including drivers previously convicted for DUIC. [129] [142] [58]

Finally, research has noted that people believe it is harder to tell if someone is under the influence of cannabis relative to alcohol.[44] Often, comparisons are made between cannabis and alcohol, with people often indicating that they believe people are far more likely to be caught driving under the influence of alcohol and more likely to be punished.[112,143] As such, it is unsurprising that 21% of Canadians indicated in an online survey that they believed that DUIC laws should be more relaxed compared with drinking and driving laws and, notably, 50% of cannabis users indicated this belief.[137]

Factors Affecting Attitudes and Perceptions

As with DUIC, many factors influence attitudes and risk perceptions towards DUIC. The main factors include age, sex, and cannabis use experiences. With respect to age, most studies find that youth and young adults (16 to 24 years) are much less likely to believe, relative to older adults, that cannabis either did not increase the chances of a collision or only increased it a little or was not a "big deal".[144] [145] [122] [126] [129] These perceptions may translate into future behaviour among youth. Colonna et al. (2021)[146] investigated determinants of DUIC in youth and found several predictors of intention to DUIC in the future based on attitudes held by the youth. Youth who perceived DUIC as increasing collision risk or as being dangerous were less likely to have intentions to engage in it relative to those who perceived little or no risk.[146] [147]

Attitudes towards DUIC also vary between the sexes.[47,148] Explanations for these differences draw on biology and the role of genetics, hormones, or anatomy which may impact absorption and mitigate the effects of THC. Rates of DUIC across genders may also be influenced by social and cultural determinants shaped by differences in upbringing, societal gender roles, and differences in identity.[47] DUIC risk perceptions are typically higher among females, whereas risk taking behaviours have been noted to be higher in young males, which may contribute to higher rates of

DUIC in males.[37][122] This has been a consistent finding in other surveys in Canada, as well as the United States.[128,129,143,149]

Finally, attitudes towards DUIC are shaped by the respondents' frequency of cannabis use. In the 2017 Canadian Cannabis Survey, users who reported using cannabis three or more times a week were the least likely to believe that cannabis impaired driving (31%), whereas among occasional users, consisting of those who used more than once a month but less than three times a week, nearly 50% held this belief. Infrequent users, who used cannabis once a month or less, were the most likely to believe that cannabis impairs driving, at 75% agreement.[122] This finding has been replicated elsewhere. [33,143][136]

Summary
Overall, most Canadians believe that cannabis impairs driving to some degree, and the proportions holding these beliefs have not changed dramatically following legalization, with most estimates between 75% and 86% of Canadians indicating this belief. Perceptions, across surveys, showed greater variance within a given year than between years and can be viewed in Table 4, below. Confidence in the ability of police to enforce DUIC laws has remained low pre and post legalization. Opinions on cannabis and driving are influenced by demographic factors and patterns of cannabis use. Males, youth and young adults, and regular cannabis users are more likely than females, older adults and seniors, and occasional users, to believe DUIC is safe, and that cannabis does not impair driving performance. Those who perceive DUIC to impair their driving are less like to engage in DUIC than those who believe it has little or no effect or that they can manage the effects. Those who believe that there could be legal consequences to DUIC are less likely to DUIC than those who believe they will go unpunished. These attitudes and perceptions are important to understand as they influence how people will behave and will aid us in understanding what influences people to engaged in DUIC.

Table 4: Summary of DIUC risk perceptions pre- to post legalization

	Pre Legalization (% of Canadians)	Post Legalization (% of Canadians)
Belief that Cannabis Impairs Driving	68 - 86 %	83 – 86%
Belief that Cannabis does not impair driving	4 - 14 %	7-9%
Belief that Police would be ready to catch drivers under the influence of cannabis after legalization	19 - 47%	

Belief that drivers under the influence of cannabis would be caught / stopped	23 - 26%	24 – 25%

Section 5: Implications of legalization on cannabis-impaired driving and policing

This section provides an overview of the impact of legalizing recreational cannabis on policing cannabis-impaired driving. Information in this area is constantly evolving and, as such, lacks clear answers; here we simply provide evidence to consider to inform discussion on this issue.

After providing details on how DIUC is identified and policed in Canada, we then present factors to consider related to setting per se limits for blood cannabis concentrations while driving. We conclude with a short discussion about the optimal model for policing cannabis-impaired driving.

The current policing model for cannabis-impaired driving in Canada

Broadly, there are two possible ways police initially identify drivers who may be under the influence of Cannabis: by observation of erratic driving behaviour (i.e., slow driving, failure to maintain an appropriate following distance, swerving) leading to a more in-depth investigation (often employing the Drug Evaluation and Classification Program) or through random or targeted roadside screening of a drivers' bodily fluids (blood, urine, saliva).

The Drug Evaluation and Classification Program

The Drug Evaluation and Classification Program (DECP), which was first used in Canada prior to the legalization of recreational cannabis, involves specially trained police officers called Drug Recognition Experts (DRE) employing a standardized and systematic procedure for determining whether a driver is impaired, whether impairment is due to the consumption of drug(s), and which drug(s) were consumed. All DRE are certified by the International Association of Chiefs of Police.[150]

Police can demand drivers whom they reasonably believe to have drugs and/or alcohol in their body (not necessarily impaired) do a Standardized Field Sobriety Test (SFST),[151] which includes three tests (walk and turn, one-legged stand, and ability to follow the officer's finger with their eyes) and has previous been shown to reliably identify driver *impairment* by cannabis.[152]

Drivers who fail the SFST may then be evaluated by a DRE or in some instances police may opt to apply a provincial administrative penalty and avoid a criminal law process.[153,154] The 12-step procedure evaluates drivers according to physical, psychological, and clinical parameters.[155] Specifically, the DRE evaluation involves an: alcohol breath test, interview the arresting officer, interview with driver about health status, observation of physical characteristics including pulse and, balance test, walking/turning heel to toe, coordination, blood pressure, temperature, and pulse, pupil size under different light conditions, examination of muscle tone, and checking for injection sites. The results of the DECP evaluation must be validated by a positive blood, urine, or oral fluid test.[22] If the DECP assessment suggests impairment, a blood, urine, or saliva sample is collected to confirm using toxicological analysis. A review of laboratory-based and field-based use of the DECP program found that DRE are generally able to accurately identify cannabis-impaired drivers.[156] The process of conducing the SFST and DECP requires about two hours to complete.[157]

New laws and practices post-legalization

As noted above, Bill C-46 amended sections of the *Criminal Code* related to drug-impaired driving, including creating a new criminal charge for driving with a blood drug concentration that is equal to or higher than a permitted concentration (the 'per se limit') for ten drugs, including cannabis, authorized roadside oral fluid testing, enabled law enforcement to more easily demand blood samples from drivers, and to permit police to demand breath samples for alcohol without suspicion.[29] Additionally, funding was directed to increase the number of trained DREs across Canada with increased capacity to address potential changes in DUIC post-legalization.

DUIC is currently defined on a 'per se' basis, meaning there are criminal charges associated with operating a motor vehicle within two hours of having a blood cannabis concentration of 2-5 ng THC /mL, greater than 5ng THC/mL, and greater than 2.5ng/mL *with* greater than 50mg alcohol/dL. Blood concentrations at or above the stipulated limits is considered a criminal offence. (This is the same way as driving under the influence of alcohol is defined in Canada.) Per se limits define the offence of DIUC as operating a motor vehicle with a blood concentration of THC above certain thresholds, *not* whether the presence of the drug in a driver's body is known to have caused impairment. This is unlike DRE detection, which requires both identifying the presence of a drug (like per se limits) *and* that the drug has caused impairment, as evidence by validated behavioural and physiological characteristics.

Individual per se limits stipulate the maximum permissible blood drug concentration for each of the seven types of drugs: cannabis, depressants, stimulants, inhalants, hallucinogens, dissociative anaesthetics, and narcotic analgesics. Anyone found to have a blood concentration more than the limits set for drugs, the existing limit for alcohol (80mg/100mL blood), or a combination of alcohol and drug(s) within two hours of driving can be charged with an offence, irrespective of whether the drug has impaired their ability to drive safely.[29] While these limits are evidence-based, as discussed below, the variation in impairing affects of cannabis due to a variety of factors means that these limits do not correspond to the same level of impairment (if at all) for all drivers.

Furthermore, the new legislation authorizes police to compel a bodily fluid sample, currently an oral fluid sample, from drivers with a reasonable suspicion of having prohibited drugs in their body. Refusal to provide a bodily sample, an SFST demand, DRE demand, or any unlawful demand is considered commensurate with impairment and therefore carries the same punishment as exceeding per se limits. The Draeger DrugTest 5000 and the Abbot SoToxa™ Oral Fluid Collection Device were approved for testing saliva for cannabis by the Department of Justice on the advice of a panel of toxicologists and traffic safety experts.[158] Police can use this device to collect saliva from drivers and quickly tests for the presence of some drugs, typically within 10 to 15 minutes. This 'point-of-contact' (POC) test can be administered on the roadside under direct supervision (unlike urine tests) and without medical training (unlike blood tests), much like breathalyzer tests are used to detect alcohol impairment.[157] Consequently, there is minimal risk of contamination.[159] The POC oral fluid testing regime is (comparatively) easily administered and

able to identify drivers that may have exceeded per se limits, due to the strong correlation between oral fluid and blood drug concentrations.[160]

What should the cut-points for detection of cannabis be?

Cut-points are the concentration that distinguish positive drug tests from negatives. A THC concentration of 25ng/mL of oral fluid or greater is positive and the cut-point for blood samples is 2ng/mL of blood. Neither oral fluid nor blood drug testing measures impairment per se, but simply the concentration of THC in a driver's body. Logically, cut-points *should* correspond to driver impairment, but this is difficult for reasons explained below. Consequently, there are several considerations when choosing appropriate cut-points.

Cut-points for cannabis (the limits defined by per se laws) are chosen by balancing the need for sensitivity (the ability to correctly identify drivers impaired by cannabis) and specificity (the ability to correctly identify drivers not impaired by cannabis). Detection levels that are too high lack sensitivity, meaning that drivers who consumed enough cannabis to be impaired would test negative (false negatives) and levels that are too low lack specificity, meaning drivers who have low concentration of cannabis (i.e., too low to cause impairment, residual cannabis due to chronic use) would be unduly penalized (false positives). Put another way, detection levels must balance the public health risks posed by cannabis-impaired drivers with the risk of unduly charging individuals with DIUC when they are not impaired, even though they have a non-zero concentration of THC (or psychoactive metabolite).

Like alcohol, detection levels for cannabis vary by jurisdiction and driver class (e.g. Learners license holder).[161] It is difficult to determine appropriate per se limits (those which reliably indicate impairment) because of the poor correlation blood cannabis concentration and level of impairment.[21] The level of impairment appears to peak after drivers' blood THC concentration peaks,[162,163] further complicating the implicit link between per se limits (based on blood THC concentrations) and impairment. The complex pharmacokinetic processes that govern cannabis metabolism and variation among drivers; age, sex, body size, mode of use, history of use, concentration of THC, amount consumed, etc. make it difficult to identify minimum THC concentrations that are associated with impairment. To further complicate the issue, THC and metabolites have been detected in the brain tissue of individuals involved in fatal motor vehicle collisions when no longer detectable in blood.[164] This suggests that cannabis *may* have impairing affects after it is no longer detectable in the blood, however, researchers did not examine whether these individuals were responsible for the collision or the (potential) impact that cannabis played in the collision.

What is the optimal model?

There is no clear evidence of which model of detection and policing DIUC is preferable at present.[22] As such, we simply summarize the strengths and weaknesses of DECP versus road-side oral fluid testing (Table 5) and highlight two factors to consider related to optimizing policing of cannabis-impaired driving. It is essential that blood be drawn as soon as possible after the

appropriate legal threshold for taking blood has been met.[165] Importantly, there is much needed evidence on the length of time required for THC and metabolites to clear the body when cannabis is consumed via methods other than smoking (i.e., edibles, butane hash oil, shatter).[165] What impact does the consumption of cannabis via these methods have on driver impairment and our ability to detect cannabis in drivers?

Table 5: Strengths and weaknesses of Drug Evaluation and Classification Program and roadside oral fluid testing

	Strengths	Weaknesses
Drug Evaluation and Classification Program	• Assesses driver impairment, rather than simply the presence of a drug • Can assess a range of impairing substances across seven drug classes	• Requires specially trained and certified officers to administer program, which are lacking in rural areas • Costly in terms of training and officers' time • Long potential lag time between substance use and officer assessment of driver impairment • Challenges obtain court convictions
Roadside oral fluid testing	• Quick process, point-of-contact (10-15 minutes) • No specialized training or medical expertise required	• Limited number of drugs included • Does not measure impairment (drug presence only)

Conclusion

This report examined the issue of cannabis legalization in Canada and its potential impact on cannabis-impaired driving. Primary studies from the last five years (2016-2021), as well as systematic reviews and meta-analyses, and reports from government/NGOs, informed this report. Our review of the evidence indicates the following in response to the research questions:

- Trends in driving behaviour point to a slight to moderate increase in DUIC in Canada and other jurisdictions following the legalization of recreational cannabis use.

- The belief that cannabis impairs driving increased, slightly, post-legalization. However, other DUIC related perceptions or beliefs, including the belief that drivers under the influence of cannabis have a low likelihood of being caught or punished, remained.

- Collectively, the epidemiological evidence points to significant, though small to moderate, increase in crash risk resulting from acute cannabis use. The experimental literature confirms the impairing effects of cannabis on psychomotor and cognitive tasks related to driving, including memory, attention, information processing, tracking performance, fine motor coordination, and reaction time, among others, which are comparative to driving performance deficits produced by blood alcohol concentrations in the range of 0.04% to 0.06% BAC.

- The threshold of ≥5ng THC/ mL of blood appears to be an appropriate point where increased driver impairment and crash risk are observed, with thresholds of ≥2.5ng THC/ mL of blood when used concurrently with alcohol.

Moving forward it is important that evidence continues to be collected to assess trends in DUIC, crash rates, and driver risk perceptions post-legalization. This requires well-designed case-control studies to assess crash risk, coupled with provincial roadside surveys and self-report surveys of Canadians to examine DUIC rates, and risk perception. This primary research must be coupled with the regular surveillance of cannabis-related injuries, hospitalizations and fatalities involving drivers. Together, this evidence will inform federal and provincial government agencies in the appropriate evaluation and review of former *Bills C-45 and C-46*.

References

1. Asbridge M, Hayden JA, Cartwright JL. Acute cannabis consumption and motor vehicle collision risk: Systematic review of observational studies and meta-analysis. *BMJ*. 2012;344(7846). doi:10.1136/bmj.e536

2. Elvik R. Risk of road accident associated with the use of drugs: A systematic review and meta-analysis of evidence from epidemiological studies. *Accid Anal Prev*. 2013;60:254-267. doi:10.1016/j.aap.2012.06.017

3. Rogeberg O, Elvik R. The effects of cannabis intoxication on motor vehicle collision revisited and revised. *Addiction*. 2016;111(8):1348-1359. doi:10.1111/add.13347

4. Li MC, Brady JE, DiMaggio CJ, Lusardi AR, Tzong KY, Li G. Marijuana use and motor vehicle crashes. *Epidemiol Rev*. 2012;34(1):65-72. doi:10.1093/epirev/mxr017

5. United Nations Office on Drugs and Crime. *World Drug Report 2019- Booklet 5 Cannabis and Hallucinogens*. Vienna; 2019. https://wdr.unodc.org/wdr2019/prelaunch/WDR19_Booklet_5_CANNABIS_HALLUCIN OGENS.pdf.

6. Statistics Canada. Prevalence of cannabis use in the past three months, by time relative to legalization and quarter, and selected demographics, household population aged 15 and older, Canada (provinces only), first quarters of 2018 and 2019, and fourth quarter of 2020. https://www150.statcan.gc.ca/n1/pub/82-003-x/2021004/article/00001/tbl/tbl01-eng.htm. Published 2021. Accessed August 10, 2021.

7. Huestis MA. Effect of drug use on the performance of drivers and other road users. In: *Report of the Second Technical Consultation on Drug Use and Road Safety*. Mallorca; 2015:11. https://www.who.int/violence_injury_prevention/publications/road_traffic/Drug_use_and_ road_safety_meeting_report_21June2017.pdf.

8. Desrosiers NA, Ramaekers JG, Chauchard E, Gorelick DA, Huestis MA. Smoked cannabis' psychomotor and neurocognitive effects in occasional and frequent smokers. *J Anal Toxicol*. 2015;39(4):251-261. doi:10.1093/jat/bkv012

9. Broyd SJ, Van Hell HH, Beale C, Yücel M, Solowij N. Acute and chronic effects of cannabinoids on human cognition - A systematic review. *Biol Psychiatry*. 2016;79(7):557-567. doi:10.1016/j.biopsych.2015.12.002

10. Volkow ND, Baler RD, Compton WM, Weiss SRB. Adverse Health Effects of Marijuana Use. *N Engl J Med*. 2014;370(23):2219-2227. doi:10.1056/nejmra1402309

11. Lenné MG, Dietze PM, Triggs TJ, Walmsley S, Murphy B, Redman JR. The effects of cannabis and alcohol on simulated arterial driving: Influences of driving experience and task demand. *Accid Anal Prev*. 2010;42(3):859-866. doi:10.1016/j.aap.2009.04.021

12. Ramaekers JG, Kauert G, Van Ruitenbeek P, Theunissen EL, Schneider E, Moeller MR. High-potency marijuana impairs executive function and inhibitory motor control. *Neuropsychopharmacology*. 2006;31(10):2296-2303. doi:10.1038/sj.npp.1301068

13. Khiabani HZ, Bramness JG, Bjørneboe A, Mørland J. Relationship between THC concentration in blood and impairment in apprehended drivers. *Traffic Inj Prev*. 2006;7(2):111-116. doi:10.1080/15389580600550172

14. Bosker WM, Kuypers KPC, Theunissen EL, et al. Medicinal Δ 9-tetrahydrocannabinol (dronabinol) impairs on-the-road driving performance of occasional and heavy cannabis users but is not detected in Standard Field Sobriety Tests. *Addiction*. 2012;107(10):1837-1844. doi:10.1111/j.1360-0443.2012.03928.x

15. Colizzi M, Bhattacharyya S. Cannabis use and the development of tolerance: A systematic review of human evidence. *Neurosci Biobehav Rev*. 2018;93:1-25. doi:10.1016/j.neubiorev.2018.07.014

16. Arkell TR, Vinckenbosch F, Kevin RC, Theunissen EL, McGregor IS, Ramaekers JG. Effect of cannabidiol and Δ9-tetrahydrocannabinol on driving performance: A randomized clinical trial. *JAMA*. 2020;324(21):2177-2186. doi:10.1001/jama.2020.21218

17. Hartman RL, Brown TL, Milavetz G, et al. Cannabis effects on driving lateral control with and without alcohol. *Drug Alcohol Depend*. 2015;154(2015):25-37. doi:10.1016/j.drugalcdep.2015.06.015

18. Hartman RL, Huestis MA. Cannabis effects on driving skills. *Clin Chem*. 2013;59(3):478-492. doi:10.1373/clinchem.2012.194381

19. Ronen A, Gershon P, Drobiner H, et al. Effects of THC on driving performance, physiological state and subjective feelings relative to alcohol. *Accid Anal Prev*. 2008;40(3):926-934. doi:10.1016/j.aap.2007.10.011

20. Ronen A, Chassidim HS, Gershon P, et al. The effect of alcohol, THC and their combination on perceived effects, willingness to drive and performance of driving and non-driving tasks. *Accid Anal Prev*. 2010;42(6):1855-1865. doi:10.1016/j.aap.2010.05.006

21. Skopp G, Richter B, Potsch L. Serus cannabinoid levels 24 to 48 hours after cannabis smoking. *Arch Kriminol*. 2003;212(3):83-95.

22. Asbridge M. Driving after marijuana use: The changing face of "impaired" driving. *JAMA Pediatr*. 2014;168(7):602-604. doi:10.1001/jamapediatrics.2014.83

23. Corrigan D. The pharmacology of cannabis: Issues for understanding its use. In: *A Cannabis Reader: Global Issues and Local Experiences*. Lisbon: European Monitoring Centre for Drugs and Drug Addiction; 2008:27-38.

24. Agurell S, Halldin M, Lindgren JE, et al. Pharmacokinetics and metabolism of Δ1-tetrahydrocannabinol and other cannabinoids with emphasis on man. *Pharmacol Rev*. 1986;38(1):21-43.

25. McCartney D, Arkell TR, Irwin C, McGregor IS. Determining the magnitude and duration of acute Δ9-tetrahydrocannabinol (Δ9-THC)-induced driving and cognitive impairment: A systematic and meta-analytic review. *Neurosci Biobehav Rev*. 2021;126:175-193. doi:10.1016/j.neubiorev.2021.01.003

26. Arkell TR, Spindle TR, Kevin RC, Vandrey R, McGregor IS. The failings of per se limits

to detect cannabis-induced driving impairment: Results from a simulated driving study. *Traffic Inj Prev*. 2021;22(2):102-107. doi:10.1080/15389588.2020.1851685

27. Fischer B, Russell C, Sabioni P, et al. Lower-risk cannabis use guidelines: A comprehensive update of evidence and recommendations. *Am J Public Health*. 2017;107(8):e1-e12. doi:10.2105/AJPH.2017.303818

28. Wettlaufer A, Florica RO, Asbridge M, et al. Estimating the harms and costs of cannabis-attributable collisions in the Canadian provinces. *Drug Alcohol Depend*. 2017;173:185-190. doi:10.1016/j.drugalcdep.2016.12.024

29. Department of Justice Canada. Bill C-46: An Act to amend the Criminal Code (offences relating to conveyances) and to make consequential amendments to other Acts, as enacted. 2018. https://www.parl.ca/LegisInfo/BillDetails.aspx?Language=en&Mode=1&billId=8886286.

30. Grotenhermen F. The pharmacokinetics and the pharmacodynamics of cannabinoids. *Clin Pharmacokinet*. 2003;42(4):327-360. doi:10.2165/00003088-200342040-00003

31. Robertson RD, Mainegra Hing M, Pashley CR, Brown SW, Vanlaar WGM. Prevalence and trends of drugged driving in Canada. *Accid Anal Prev*. 2017;99:236-241. doi:10.1016/j.aap.2016.12.008

32. Rivera LA, Patten SB. Driving Under the Influence of Cannabis in Canada, 2015 to 2018. *Can J Psychiatry*. 2020;65(9):674-675. doi:10.1177/0706743720922655

33. Health Canada. Canadian Cannabis Survey 2020: Summary. https://www.canada.ca/en/health-canada/services/drugs-medication/cannabis/research-data/canadian-cannabis-survey-2020-summary.html. Published 2020. Accessed August 11, 2021.

34. Statistics Canada. National Cannabis Survey. https://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5262. Published 2020. Accessed August 10, 2021.

35. Statistics Canada. National Cannabis Survey 1st quarter, 2019. https://www150.statcan.gc.ca/n1/pub/11-627-m/11-627-m2019032-eng.htm. Published 2019. Accessed August 10, 2021.

36. Rotermann M. Analysis of trends in the prevalence of cannabis use and related metrics in Canada. *Heal Reports*. 2019;30(6):3-13. doi:10.25318/82-003-x201900600001-eng

37. Wallingford S, Konefal S, Young MM, Student Drug Use Surveys Working Group. *Cannabis Use, Harms and Perceived Risks among Canadian Students Cannabis Use, Harms and Perceived Risks among Canadian Students*. Ottawa; 2019. https://www.ccsa.ca/sites/default/files/2019-04/CCSA-Canadian-Students-Cannabis-Harms-Risks-Report-2019-en.pdf.

38. Health Canada. Canadian Alcohol and Drug Use Monitoing Survey: Summary of Results for 2012. https://www.canada.ca/en/health-canada/services/health-concerns/drug-prevention-treatment/drug-alcohol-use-statistics/canadian-alcohol-drug-use-monitoring-survey-summary-results-2012.html. Published 2014. Accessed August 11, 2021.

39. Cantor N, Kingsbury M, Hamilton HA, Wild TC, Owusu-Bempah A, Colman I. Correlates of driving after cannabis use in high school students. *Prev Med (Baltim)*. 2021;150:106667. doi:10.1016/j.ypmed.2021.106667

40. Wadsworth E, Hammond D. International differences in patterns of cannabis use among youth: Prevalence, perceptions of harm, and driving under the influence in Canada, England & United States. *Addict Behav*. 2019;90:171-175. doi:10.1016/j.addbeh.2018.10.050

41. Brubacher JR, Chan H, Staples JA. Cannabis-impaired driving and Canadian youth. *Paediatr Child Health (Oxford)*. 2020;25(15):S21-S25. doi:10.1093/pch/pxaa017

42. Statistics Canada. National Cannabis Survey 2019- Summary. https://www.canada.ca/en/health-canada/services/publications/drugs-health-products/canadian-cannabis-survey-2019-summary.html. Published 2019. Accessed August 10, 2021.

43. Leadbeater BJ, Ames ME, Sukhawathanakul P, Fyfe M, Stanwick R, Brubacher JR. Frequent marijuana use and driving risk behaviours in Canadian youth. *Paediatr Child Health (Oxford)*. 2017;22(1):7-12. doi:10.1093/pch/pxw002

44. Lensch T, Sloan K, Ausmus J, et al. Cannabis use and driving under the influence: Behaviors and attitudes by state-level legal sale of recreational cannabis. *Prev Med (Baltim)*. 2020;141:106320. doi:10.1016/j.ypmed.2020.106320

45. Couper FJ, Peterson BL. The prevalence of marijuana in suspected impaired driving cases in Washington State. *J Anal Toxicol*. 2014;38(8):569-574. doi:10.1093/jat/bku090

46. Urfer S, Morton J, Beall V, Feldmann J, Gunesch J. Analysis of Δ9-tetrahydrocannabinol driving under the influence of drugs cases in Colorado from January 2011 to February 2014. *J Anal Toxicol*. 2014;38(8):575-581. doi:10.1093/jat/bku089

47. Lloyd SL, Lopez-Quintero C, Striley CW. Sex differences in driving under the influence of cannabis: The role of medical and recreational cannabis use. *Addict Behav*. 2020;110:106525. doi:10.1016/j.addbeh.2020.106525

48. Beirness DJ, Beasley EE. *Alcohol and Drug Use Among Drivers: British Columbia Roadside Survey 2008*. Ottawa; 2009.

49. Beirness DJ, Beasley EE. A roadside survey of alcohol and drug use among drivers in British Columbia. *Traffic Inj Prev*. 2010;11(3):215-221. doi:10.1080/15389581003735626

50. Beirness DJ, Beasley EE. An Evaluation of Immediate Roadside Prohibitions for Drinking Drivers in British Columbia: Findings from Roadside Surveys. *Traffic Inj Prev*. 2014;15(3):228-233. doi:10.1080/15389588.2013.813628

51. Beasley EE, Beirness DJ. *Alcohol and Drug Use Among Drivers Following the Introduction of Immediate Roadside Prohibitions in British Columbia: Findings from the 2012 Roadside Survey*. Ottawa; 2012.

52. Beirness DJ, Beasley EE, McClafferty K. *Alcohol and Drug Use among Drivers in Ontario: Findings from the 2014 Roadside Survey*.; 2015.

53.   Public Safety Canada. *Annual National Data Report to Inform Trends and Patterns in Drug-Impaired Driving*. Ottawa; 2020. https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/2020-did-fad/index-en.aspx#s6.

54.   Beirness DJ, Beasley EE. *Drug Use Among Driver- British Columbia Roadside Survey 2010*. Ottawa; 2011. doi:10.1787/9789282102763-6-en

55.   Matzopoulos R, Lasarow A, Bowman B. A field test of substance use screening devices as part of routine drunk-driving spot detection operating procedures in South Africa. *Accid Anal Prev*. 2013;59:118-124. doi:10.1016/j.aap.2013.05.015

56.   Alcañiz M, Guillen M, Santolino M. Differences in the risk profiles of drunk and drug drivers: Evidence from a mandatory roadside survey. *Accid Anal Prev*. 2021;151:150947. doi:10.1016/j.aap.2020.105947

57.   Mills L, Freeman J, Davey J, Davey B. The who, what and when of drug driving in Queensland: Analysing the results of roadside drug testing, 2015–2020. *Accid Anal Prev*. 2021;159:106231. doi:10.1016/j.aap.2021.106231

58.   Eichelberger AH. Marijuana use and driving in Washington State: Risk perceptions and behaviors before and after implementation of retail sales. *Traffic Inj Prev*. 2019;20(1):23-29. doi:10.1080/15389588.2018.1530769

59.   Ramirez A, Berning A, Carr K, et al. *Marijuana, Other Drugs, and Alcohol Use by Drivers in Washington State*. Washington, DC; 2016.

60.   Pollini RA, Romano E, Johnson MB, Lacey JH. The impact of marijuana decriminalization on California drivers. *Drug Alcohol Depend*. 2015;150:135-140. doi:10.1016/j.drugalcdep.2015.02.024

61.   Brubacher JR, Chan H, Erdelyi S, et al. Police documentation of drug use in injured drivers: Implications for monitoring and preventing drug-impaired driving. *Accid Anal Prev*. 2018;118:200-206. doi:10.1016/j.aap.2018.02.018

62.   Asbridge M, Mann R, Cusimano MD, et al. Cannabis and traffic collision risk: Findings from a case-crossover study of injured drivers presenting to emergency departments. *Int J Public Health*. 2014;59(2):395-404. doi:10.1007/s00038-013-0512-z

63.   Brubacher JR, Chan H, Martz W, et al. Prevalence of alcohol and drug use in injured British Columbia drivers. *BMJ Open*. 2016;6:e009278. doi:10.1136/bmjopen-2015-009278

64.   Brubacher JR, Chan H, Erdelyi S, et al. Cannabis use as a risk factor for causing motor vehicle crashes: A prospective study. *Addiction*. 2019;114:1616-1626. doi:10.1111/add.14663

65.   Brubacher JR, Chan H, Erdelyi S, Staples JA, Asbridge M, Mann RM. The impact of cannabis legalization on the prevalence of tetrahydrocannabinol in injured drivers. *New Engl J Med*.

66.   Roberts BA. Legalized cannabis in Colorado emergency departments: A cautionary review of negative health and safety effects. *West J Emerg Med*. 2019;20(4):557-572.

doi:10.5811/westjem.2019.4.39935

67.   Leung J, Chiu V, Chan GCK, Stjepanović D, Hall WD. What Have Been the Public Health Impacts of Cannabis Legalisation in the USA? A Review of Evidence on Adverse and Beneficial Effects. *Curr Addict Reports*. 2019;6(4):418-428. doi:10.1007/s40429-019-00291-x

68.   Colorado Department of Public Health and Environment. *Monitoring Health Concerns Related to Marijuana in Colorado: 2016*. Denver; 2017.

69.   Beckson M, Jones AW, Els C, Hagtvedt R. Cannabis, crashes and blood: challenges for observational research. *Addiction*. 2020;115(3):589-590. doi:10.1111/add.14891

70.   Hoffman MA, Trochta A, Gary RD, Fitzgerald RL, McIntyre IM. An evaluation of postmortem concentrations of Δ9-tetrahydrocannabinol (THC) and 11-nor-9-carboxy-Δ9-tetrahydrocannabinol (THCCOOH). *Forensic Sci Int*. 2020;315(2020):110414. doi:10.1016/j.forsciint.2020.110414

71.   Beirness DJ, Beasley EE, Boase P. Drug use amoung fatally injured drivers in Canada. In: *20th International Conference on Alcohol, Drugs and Traffic Safety*. Brisbane; 2013.

72.   Brown S, Vanlaar WGM, Robertson R. *The Alcohol and Drug-Crash Problem in Canada. 2014 Report*. Ottawa; 2017.

73.   Beirness DJ, Gu KW, Lowe NJ, et al. Cannabis, alcohol and other drug findings in fatally injured drivers in Ontario. *Traffic Inj Prev*. 2020;22(1):1-6. doi:10.1080/15389588.2020.1847281

74.   Tefft BC, Arnold LS, Grabowski JG. *Prevalence of Marijuana Involvement in Fatal Crashes: Washington, 2010-2014*. Washington, DC; 2016.

75.   Aydelotte JD, Brown LH, Luftman KM, et al. Crash fatality rates after recreational marijuana legalization in Washington and Colorado. *Am J Public Health*. 2017;107(8):1329-1331. doi:10.2105/AJPH.2017.303848

76.   Highway Loss Data Institute. *Recreational Marijuana and Collision Claim Frequencies*. Vol 35. Ruckersville; 2018.

77.   Lee J, Abdel-Aty A, Park J. Investigation of associations between marijuana law changes and marijuana-involved fatal traffic crashes: A state-level analysis. *J Transp Heal*. 2018;10(`):194-202. doi:10.1016/j.jth.2018.05.017

78.   Lane TJ, Hall W. Traffic fatalities within US states that have legalized recreational cannabis sales and their neighbours. *Addiction*. 2019;114(5):847-856. doi:10.1111/add.14536

79.   Tefft BC, Arnold LS. Estimating cannabis involvement in fatal crashes in Washington state before and after recreational cannabis legalization using multiple imputation of missing values. *Am J Epidemiol*. 2021;Forthcomin. doi:10.1093/aje/kwab184

80.   Robbe HWJ, O'Hanlon JF. *U.S. Department of Transportation. Marijuana and Actual Driving Performance: Final Report.* Washington, DC; 1993.

http://ntl.bts.gov/lib/25000/25800/25867/DOT-HS-808-078.pdf.

81. Walsh JM, Verstraete AG, Huestis MA, Mørland J. Guidelines for research on drugged driving. *Addiction*. 2008;103(8):1258-1268. doi:10.1111/j.1360-0443.2008.02277.x

82. Berghaus G, Scheer N, Schmidt P. Effects of cannabis on psychomotor skills and driving performance- A metanalysis of experimental studies. In: *13th International Conference on Alcohol, Drugs and Traffic Safety*. Adelaide; 1995:403-409.

83. Prashad S, Filbey F. Cognitive motor deficits in cannabis users. *Curr Opin Behav Sciece*. 2017;13(1). doi:10.1016.j.cobeha.2016.07.001

84. Chow RM, Marascalchi B, Abrams WB, Peiris NA, Odonkor CA, Cohen SP. Driving under the Influence of Cannabis: A Framework for Future Policy. *Anesth Analg*. 2019;128(6):1300-1308. doi:10.1213/ANE.0000000000003575

85. Simmons SM. The Effects of Cannabis and Alcohol on Driving Performance and Driver Behaviour: A Systematic Review and Meta-Analysis. 2020. doi:10.11575/PRISM/38092

86. Ortiz-Peregrina S, Ortiz C, Castro-Torres JJ, Jiménez JR, Anera RG. Effects of smoking cannabis on visual function and driving performance. A driving-simulator based study. *Int J Environ Res Public Health*. 2020;17(23):9033. doi:10.3390/ijerph17239033

87. Ortiz-Peregrina S, Ortiz C, Casares-López M, Jiménez JR, Anera RG. Effects of cannabis on visual function and self-perceived visual quality. *Sci Rep*. 2021;11:1655. doi:10.1038/s41598-021-81070-5

88. Sevigny EL. Cannabis and driving ability. *Curr Opin Psychol*. 2021;38:75-79. doi:10.1016/j.copsych.2021.03.003

89. Bergamaschi MM, Karschner EL, Goodwin RS, et al. Impact of prolonged cannabinoid excretion in chronic daily cannabis smokers' blood on per se drugged driving laws. *Clin Chem*. 2013;59(3):519-526. doi:10.1373/clinchem.2012.195503

90. Dahlgren MK, Sagar KA, Smith RT, Lambros AM, Kuppe MK, Gruber SA. Recreational cannabis use impairs driving performance in the absence of acute intoxication. *Drug Alcohol Depend*. 2020;208:107771. doi:10.1016/j.drugalcdep.2019.107771

91. Cole TB, Saitz R. Cannabis and Impaired Driving. *JAMA*. 2020;324(21):2163-2164. doi:10.1001/jama.2020.18544

92. Ramaekers JG, Moeller MR, van Ruitenbeek P, Theunissen EL, Schneider E, Kauert G. Cognition and motor control as a function of Δ9-THC concentration in serum and oral fluid: Limits of impairment. *Drug Alcohol Depend*. 2006;85(2):114-122. doi:10.1016/j.drugalcdep.2006.03.015

93. Chipman ML, Macdonald S, Mann RE. Being "at fault" in traffic crashes: Does alcohol, cannabis, cocaine, or polydrug abuse make a difference? *Inj Prev*. 2003;9(4):343-348. doi:10.1136/ip.9.4.343

94. Perez-Reyes M, Hicks RE, Bumberry J, Jeffcoat R, Cook E. Interaction between marihuana and ethanol: Effects on psychomotor performance. *Alcohol Clin Exp Res*.

1988;12(2):268-276.

95. Hostiuc S, Moldoveanu A, Negoi I, Drima E. The association of unfavorable traffic events and cannabis usage: A meta-analysis. *Front Pharmacol*. 2018;9. doi:10.3389/fphar.2018.00099

96. Compton RP, Berning A. *Drug and Alcohol Crash Risk*. Washington, DC; 2015.

97. Lacey JH, Kelley-Baker T, Berning A, et al. *Drug and Alcohol Crash Risk: A Case-Control Study*. Washington, DC; 2016.

98. Drummer OH, Gerostamoulos D, Di M, et al. Odds of culpability associated with use of impairing drugs in injured drivers in Victoria, Australia. *Accid Anal Prev*. 2020;135. doi:10.1016/j.aap.2019.105389

99. Staples JA, Redelmeier DA. THe April 20 cannabis celebration and fatal traffic crashes in the United States. *JAMA Intern Med*. 2018;178(4):569-572. doi:10.1001/jamainternmed.2017.8298

100. Harper S, Palayew A. The annual cannabis holiday and fatal traffic crashes. *Inj Prev*. 2019;25(5):433-437. doi:10.1136/injuryprev-2018-043068

101. Vandoros S, Kawachi I. The relative risk of motor vehicle collision on cannabis celebration day in Great Britain. *Accid Anal Prev*. 2019;128:248-252. doi:10.1016/j.aap.2019.02.013

102. Preuss UW, Huestis MA, Schneider M, et al. Cannabis Use and Car Crashes: A Review. *Front Psychiatry*. 2021;12:643315. doi:10.3389/fpsyt.2021.643315

103. Drummer OH, Gerostamoulos J, Batziris H, et al. The involvement of drugs in drivers of motor vehicles killed in Australian road traffic crashes. *Accid Anal Prev*. 2004;36(2):239-248. doi:10.1016/S0001-4575(02)00153-7

104. Laumon B, Gadegbeku B, Martin JL, Biecheler MB. Cannabis intoxication and fatal road crashes in France: Population based case-control study. *Br Med J*. 2005;331(7529):1371-1374. doi:10.1136/bmj.38648.617986.1F

105. Martin JL, Gadegbeku B, Wu D, Viallon V, Laumon B. Cannabis, alcohol and fatal road accidents. *PLoS One*. 2017;12(11):1-16. doi:10.1371/journal.pone.0187320

106. Bates MN, Blakely TA. Role of cannabis in motor vehicle crashes. *Epidemiol Rev*. 1999;21(2):222-232. doi:10.1093/oxfordjournals.epirev.a017998

107. Biecheler MB, Peytavin JF, SAM Group, Facy F, Martineau H. SAM survey on "drugs and fatal accidents": Search of substances consumed and comparison between drivers involved under the influence of alcohol or cannabis. *Traffic Inj Prev*. 2008;9(1):11-21. doi:10.1080/15389580701737561

108. Ramaekers JG, Robbe HWJ, O'Hanlon JF. Marijuana, alcohol and actual driving performance. *Hum Psychopharmacol*. 2000;15(7):551-558. doi:10.1002/1099-1077

109. Ramaekers JG, Berghaus G, Van Laar M, Drummer OH. Dose related risk of motor vehicle crashes after cannabis use. *Drug Alcohol Depend*. 2004;73(2):109-119.

doi:10.1016/j.drugalcdep.2003.10.008

110. Sewell RA, Poling J, Sofuoglu M. The effect of cannabis compared with alcohol on driving. *Am J Addict*. 2009;18(3):185-193. doi:10.1080/10550490902786934

111. Chihuri S, Li G, Chen Q. Interaction of marijuana and alcohol on fatal motor vehicle crash risk: a case–control study. *Inj Epidemiol*. 2017;4(8). doi:10.1186/s40621-017-0105-z

112. Kelly E, Darke S, Ross J. A review of drug use and driving: Epidemiology, impairment, risk factors and risk perceptions. *Drug Alcohol Rev*. 2004;23(3):319-344. doi:10.1080/09595230412331289482

113. Dubois S, Mullen N, Weaver B, Bédard M. The combined effects of alcohol and cannabis on driving: Impact on crash risk. *Forensic Sci Int*. 2015;248:94-100. doi:10.1016/j.forsciint.2014.12.018

114. Gjerde H, Normann PT, Christophersen AS, Samuelsen SO, Mørland J. Alcohol, psychoactive drugs and fatal road traffic accidents in Norway: A case-control study. *Accid Anal Prev*. 2011;43(3):1197-1203. doi:10.1016/j.aap.2010.12.034

115. Chihuri S, Li G. Direct and indirect effects of marijuana use on the risk of fatal 2-vehicle crash initiation. *Inj Epidemiol*. 2020;7:49. doi:10.1186/s40621-020-00276-9

116. Li G, Chihuri S, Brady JE. Role of alcohol and marijuana use in the initiation of fatal two-vehicle crashes. *Ann Epidemiol*. 2017;27(5):342-347. doi:10.1016/j.annepidem.2017.05.003

117. Bramness JG, Khiabani HZ, Mørland J. Impairment due to cannabis and ethanol: Clinical signs and additive effects. *Addiction*. 2010;105(6):1080-1087. doi:10.1111/j.1360-0443.2010.02911.x

118. Lamers CTJ, Ramaekers JG. Visual search and urban city driving under the influence of marijuana and alcohol. *Hum Psychopharmacol*. 2001;16(5):393-401. doi:10.1002/hup.307

119. Hels T, Bernhoft IM, Lyckegaard A, et al. *Risk of Injury by Driving with Alcohol and Other Drugs*.; 2011.

120. Scott B, Ward N, Otto J, Finley K. Modeling the system of beliefs that influence driving under the influence of cannabis (DUIC) in Washington State. *Accid Anal Prev*. 2021;151:105988. doi:10.1016/j.aap.2021.105988

121. Davis KC, Allen J, Duke J, et al. Correlates of marijuana drugged driving and openness to driving while high: Evidence from Colorado and Washington. *PLoS One*. 2016;11:1-13. doi:10.1371/journal.pone.0146853

122. Koundakjian K, Maslov A, Ellingwood H. *Behaviours and Beliefs Related to Cannabis before Legalization: A Public Safety Perspective. Research Report: 2018-R005*. Ottawa; 2018. https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/2018-r005/index-en.aspx.

123. Patton D, Brown D. Driving Drunk, Driving High: A Comparison of Student Attitudes Towards Driving while Drunk Versus Driving while High on Cannabis. In: *16th International Council on Alcohol, Drugs and Traffic Safety*. Montreal; 2002:5.

124. EKOS Research Associates Inc. *Public Opinion Research on Drug Impaired Driving*. Ottawa; 2017. https://epe.lac-bac.gc.ca/100/200/301/pwgsc-tpsgc/por-ef/public_safety_canada/2018/019-17-e/index.html.

125. Statistics Canada. Canadian Cannabis Survey 2018 Summary. https://www.canada.ca/en/services/health/publications/drugs-health-products/canadian-cannabis-survey-2018-summary.html. Published 2018. Accessed August 10, 2021.

126. Ekos Research Associates Inc. Baseline Survey on Awareness, Knowledge and Behaviour Associated with Recreationsl Use of Marijuana- Final Report. https://epe.lac-bac.gc.ca/100/200/301/pwgsc-tpsgc/por-ef/health/2016/046-15-e/report-rapport-eng.html. Published 2016. Accessed August 10, 2021.

127. Canadian Underwriter. One in 10 polled Canadians admit to driving under the influence of marijuana, State Farm Canada survey finds. https://www.canadianunderwriter.ca/insurance/one-10-polled-canadians-admit-driving-influence-marijuana-state-farm-canada-survey-finds-1004111937/. Published 2017. Accessed August 10, 2021.

128. Jonah B. *CCMTA Public Opinion Survey of Drugs and Driving in Canada, Summary Report*.; 2013. http://ccmta.ca/images/publications/pdf/CCMTA_Public_Opinion_Survey_of_Drugs_and_Driving_in_Canada_revised_2014_04_14_FINAL_ENGLISH.pdf.

129. Simpson S. Some Canadian Drivers are Driving While Knowingly Impaired from Alcohol, Cannabis or an Illicit Drug. 2017. https://www.ipsos.com/sites/default/files/2017-05/7631-dt2_0.pdf.

130. Desjardins. Drug-impaired driving: Canadians worry as marijuana-impaired fatalities go up. https://blogues.desjardins.com/press_release/2018/10/drug-impaired-driving-survey.php. Published 2018. Accessed August 10, 2021.

131. Kurl S. *4/20 Friendly? Canadian Support for Pot Legalization Grows, but Most Don't View It as a National Priority*. Vancouver; 2016. http://angusreid.org/wp-content/uploads/2016/04/2016.04.20-Marijauna.pdf.

132. PSB Research. *Spring 2019 Cannabis Culture Poll*. Vol 26. Washington, DC; 2019. https://s3.documentcloud.org/documents/5956725/Cannabis-Culture-Poll-TOPLINE-April-2019-4-19-19.pdf.

133. Wickens CM, Watson TM, Mann RE, Brands B. Exploring perceptions among people who drive after cannabis use: Collision risk, comparative optimism and normative influence. *Drug Alcohol Rev*. 2019;38(4):443-451. doi:10.1111/dar.12923

134. Greene KM. Perceptions of Driving after Marijuana Use Compared to Alcohol Use among Rural American Young Adults. *Drug Alcohol Rev*. 2018;37(5):637-644. doi:10.1111/dar.12686

135. Wall MM, Poh E, Cerdá M, Keyes KM, Galea S, Hasin DS. Adolescent Marijuana Use from 2002 to 2008: Higher in States with Medical Marijuana Laws, Cause Still Unclear. *Ann Epidemiol*. 2011;21(9):714-716. doi:10.1016/j.annepidem.2011.06.001

136. PEI Chief Public Health Office, Badr H, Baidoobonso S, et al. *2018 PEI Cannabis Survey Report: Knowledge, Attitudes and Behaviours before Legalization*. Charlottetown; 2019. https://www.princeedwardisland.ca/sites/default/files/publications/cpho_2018_pei_cannabis_survey_report.pdf.

137. Bricker D, Ipsos. Canadian believe occurance of impaired driving (58%), addiction (45%) will increase as a result of legalizing marijuana. 2017. https://www.ipsos.com/sites/default/files/2017-05/7631-dt2_0.pdf.

138. Carpino M. Associations of perceived risk of regular cannabis use with cannabis-related driving and passenger behaviours among Canadian high school students. 2019.

139. Fischer B, Rodopoulos J, Rehm J, Ivsins A. Toking and driving: Characteristics of Canadian university students who drive after cannabis use - An exploratory pilot study. *Drugs Educ Prev Policy*. 2006;13(2):179-187. doi:10.1080/09687630500512335

140. Arkell TR, Lintzeris N, Mills L, Suraev A, Arnold JC, McGregor IS. Driving-Related Behaviours, Attitudes and Perceptions among Australian Medical Cannabis Users: Results from the CAMS 18-19 Survey. *Accid Anal Prev*. 2020;148:105784. doi:10.1016/j.aap.2020.105784

141. Angus Reid Institute. Anxiety lingers over impact on impaired driving, organized crime and use among minors. https://angusreid.org/wp-content/uploads/2018/09/2018.09.24_marijuana_prelegalization.pdf. Published 2018. Accessed August 10, 2021.

142. Watson TM, Mann RE, Wickens CM, Brands B. Deterring driving under the influence of cannabis: Knowledge and beliefs of drivers in a remedial program. *Can J Criminol Crim Justice*. 2019;61(3):1-20. doi:10.3138/cjccj.2018-0020

143. McCarthy DM, Lynch AM, Pederson SL. Driving after use of alcohol and marijuana in college students. *Psychol Addict Behav*. 2007;21(3):425-430. doi:10.1037/0893-164X.21.3.425

144. Erin Goodman S, Leos-Toro C, Hammond D. Risk perceptions of cannabis- vs. alcohol-impaired driving among Canadian young people. *Drugs Educ Prev Policy*. 2020;27(3):205-212. doi:10.1080/09687637.2019.1611738

145. Marcoux K, Robertson R, Vanlaar W. *The Road Safety Monitor 2010— Youth Drinking and Driving*. Ottawa; 2011. https://tirf.ca/wp-content/uploads/2017/01/RSM_2010_Young_Drivers_4.pdf.

146. Colonna R, Hand CL, Holmes JD, Alvarez L. Young drivers' determinants of driving under the influence of cannabis: Findings from the Youth Cannabis and Driving Survey (YouCanDS). *J Safety Res*. doi:10.1016/j.jsr.2021.05.001

147. Aston ER, Merrill JE, McCarthy DM, Metrik J. Risk factors for driving after and during marijuana use. *J Stud Alcohol Drugs*. 2016;77(2):309-316. doi:10.15288/jsad.2016.77.309

148. Carpino M, Langille D, Ilie G, Asbridge M. Cannabis-related driving and passenger behaviours among high school students: a cross-sectional study using survey data. *C Open*. 2020;8(4):E754-E761. doi:10.9778/cmajo.20200081

149. Arnold LS, Tefft BC. *Driving under the Influence of Alcohol and Marijuana: Beliefs and Behaviours, United States, 2013-2015 (Technical Report)*. Washington, DC; 2016. https://aaafoundation.org/driving-influence-alcohol-marijuana-beliefs-behaviors-united-states-2013-2015/.

150. IACP. The International Drug Evaluation & Classificatio Program. https://www.theiacp.org/projects/the-international-drug-evaluation-classification-program. Published 2021. Accessed August 10, 2021.

151. Stuster J, Burns M. *Validation of the Standardized Field Sobriety Test at BACs below 0.10 Percent—Final Report*. Santa Barbara; 1998. http://www.drugdetection.net/NHTSA docs/BurnsValidationofSFSTatBACbelow0.10percentSanDiego.pdf.

152. Porath-Waller AJ, Beirness DJ. An Examination of the Validity of the Standardized Field Sobriety Test in Detecting Drug Impairment Using Data from the Drug Evaluation and Classification Program. *Traffic Inj Prev*. 2014;15(2):125-131. doi:10.1080/15389588.2013.800638

153. Owusu-Bempah A. Cannabis impaired driving: An evaluation of current modes of detection. *Can J Criminol Crim Justice*. 2014;56(2):219-240. doi:10.3138/CJCCJ.2014.ES05

154. Solomon R, MacLeod J, MADD Canada, Dumschat E. *The Shifting Focus of Canadian Impaired Driving Enforcement : The Increased Role of Provincial and Territorial Administrative Sanctions*.; 2020. https://madd.ca/pages/wp-content/uploads/2020/05/MADD-Canada_The-Shifting-Focus-of-Canadian-Impaired-Driving-Enforcement_FINAL.pdf.

155. Vaillancourt L, Viel E, Dombrowski C, Desharnais B, Mireault P. Drugs and driving prior to cannabis legalization: A 5-year review from DECP (DRE) cases in the province of Quebec, Canada. *Accid Anal Prev*. 2021;149:105832. doi:10.1016/j.aap.2020.105832

156. Beirness DJ, LeCavalier J, Singhal D. Evaluation of the drug evaluation and classification program: A critical review of the evidence. *Traffic Inj Prev*. 2007;8(4):368-376. doi:10.1080/15389580701525651

157. Asbridge M, Ogilvie R. *A Feasibility Study of Roadside Oral Fluid Drug Testing*.; 2015.

158. Beirness DJ, Smith DR. An assessment of oral fluid drug screening devices. *J Can Soc Forensic Sci*. 2017;50(2):55-63. doi:10.1080/00085030.2017.1258212

159. Cirimele V, Villian M, Mura P, Bernard M, Kintz P. Oral fluid testing for cannabis: On-site OraLine IV s.a.t. device versus GG/MS. *Forensic Sci Int*. 2006;161(2):180-184. doi:10.1016/j.2006.01.020

160. Kintz P, Brunet B, Muller J-F, et al. Evaluation of the Cozart DDSV Test for Cannabis in Oral Fluid. *Ther Drug Monit*. 2009;31(1):131-134. doi:10.1097/FTD.0b013e3181947916

161. Wong K, Brady JE, Li G. Establishing legal limits for driving under the influence of marijuana. *Inj Epidemiol*. 2014;1(26). doi:10.1186/s40621-014-0026-z

162. Compton RP. *Marijuana-Impaired Driving: A Report to Congress*. Washington, DC;

2017. https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/812440-marijuana-impaired-driving-report-to-congress.pdf.

163.   Ramirez A, Berning A, Kelley-Baker T, et al. *2013 – 2014 National Roadside Study of Alcohol and Drug Use by Drivers: Alcohol Results*. Washington, DC; 2016.

164.   Mura P, Kintz P, Dumestre V, Raul S, Hauet T. THC can be detected in brain while absent in blood. *J Anal Toxicol*. 2005;29(8):842-843. doi:10.1093/jat/29.8.842

165.   Wood E, Brooks-Russell A, Drum P. Delays in DUI blood testing: Impact on cannabis DUI assessments. *Traffic Inj Prev*. 2016;17(2):105-108. doi:10.1080/15389588.2015.1052421