Cannabis Control Commission
COMMONWEALTH OF MASSACHUSETTS

A Baseline Review and Assessment of Cannabis Use and Public Safety

Part 1: Operating under the Influence of Cannabis: Literature Review and Preliminary Data in Massachusetts

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Massachusetts Cannabis Control Commission:
Report to the Massachusetts Legislature

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I. Executive Summary

In recent years, there have been increasing concerns over the potential consequences of cannabis use, including cannabis-impaired driving in the United States (U.S.)—categorized as a serious and growing threat to public safety. This concern is heightened with the enactment and implementation of cannabis policies across the U.S. However, the overall scope of the issue is difficult to assess. It has been challenging to get accurate estimates of cannabis use and driving as well as valid and reliable mechanisms to detect cannabis impairment or detect cannabinoids and their metabolites to infer a threshold of cannabis impairment.[1]

The 2017 National Survey on Drug Use and Health (NSDUH) study reports that after alcohol, cannabis ("marijuana") is the most widely used drug in the U.S.— with 44% of the population aged 12 years-old or older reporting lifetime cannabis use and 9.6% reporting past month ("current") cannabis use.[2] The Monitoring in the Future (MTF) study assesses substance use in youth and reports that 22.9% of 12th graders report current cannabis use and 5.9% report daily ("heavy use") while the rates of perception of harm have steadily decreased.[3]

Assessing and preventing cannabis-impaired driving is a top priority for Massachusetts with the recent implementation of licensed retail establishments permitting the sale of cannabis to adults aged 21 years-old or older in the Commonwealth. The Massachusetts Cannabis Control Commission (CNB) conducted a comprehensive review of the scope of the problem, including the state of the science and baseline data to better understand the complexity of this issue to make evidence-based policy and research considerations.

This report first provides a background on cannabis laws, law enforcement training(s), and varying associated issues of cannabis impairment as they relate to a driver's ability to safely operate a motorized vehicle. The background sections are followed by preliminary ("baseline") data, including: (1) Massachusetts State Police (MSP) Operating Under the Influence (OUI) trends, 2007-2017, (2) Drug Recognition Expert (DRE) trainings and evaluations in Massachusetts trends, 2010-2017, (3) Municipality Law Enforcement Agency (LEA) survey results on DREs, and (4) Massachusetts Public Awareness Campaign, *More About Marijuana*, as it relates to cannabis-impaired driving. Data results are followed by a comprehensive review of the state of science on: (1) detecting impairment, and (2) detecting cannabis cannabinoids and metabolites in varying human biological samples, the two key features needed to reliably detect and assess cannabis-impaired driving. Synthesizing the entirety of this data, the report concludes with varying: (1) research gaps in our knowledge to guide evidence-based policy with valid and reliable studies, and (2) policy considerations that Massachusetts could potentially implement to confront and potentially reduce adverse outcomes stemming from cannabis-impaired driving in the interim.

Purpose

This report has been prepared in response to the enabling legislation, Chapter 55 section 17a (ii) to assess the two items on the Cannabis Control Commission's research agenda on cannabis-impaired driving. This legislation section states that: "*the commission shall develop a research agenda in order to understand the social and economic trends of marijuana in the commonwealth, to inform future decisions that would aid in the closure of the illicit marketplace and to inform the commission on the public health impacts of marijuana*."

Two of the research agenda priority items enumerated include the assessment of:

(1) Incidents of impaired driving; and
(2) State of science around identifying a quantifiable level of marijuana-induced impairment of motor vehicle operation

Chapter 55 additionally asserts in section 17b that the Commission shall incorporate available data, annually report on the results of its research agenda, and if appropriate, make recommendations for further research or policy changes.

II. What is Cannabis?

Cannabis ("marijuana") is the term often used in the United States (U.S.) to define the components of several Cannabis plant varietals, including Cannabis Indica and Cannabis Sativa, the two most common varietals consumed in the U.S.[4] Although cannabis varietal names, which reflect marijuana's genealogy and chemical phenotype (*e.g. Cannabis sativa, Cannabis Indica, Cannabis ruderalis)* and the cultural terminology for cannabis (*e.g. marijuana, ganja, grass, hash, pot, weed*) are often used interchangeably, the term *cannabis* is used for purposes of this report. [See Section *XIV. State of Science: Detecting Cannabis Cannabinoids* for a detailed state of the science assessing detecting cannabinoids in varying human biological sample(s)].

III. Brief History of Cannabis Laws

International

Worldwide, cannabis has been used for religious, recreational, and therapeutic purposes for thousands of years,[5–8] although it has been predominantly illegal worldwide since the 1961 United Nations Single Convention on Narcotic Drugs,[9,10] it is no surprise that cannabis is currently the most frequently cultivated, trafficked, and abused illicit drug worldwide.[11]

National: United States

In the United States (U.S.), cannabis cultivation and use were legal under federal and state laws throughout most of American history. The first evidence of cannabis use in the U.S. was in 1611, when hemp was produced for its fiber and seed.[10] Its therapeutic use was introduced into Western medicine by Irish physician, William Brooke O'Shaughnessy, in 1839.[8,12] Cannabis's therapeutic potential was recognized by some U.S. physicians in the 1840s.[12] From 1850 to 1941, cannabis was included in the *United States Pharmacopeia*, an official public standards list of recognized medicinal drugs.[5,8] The use of medicinal cannabis decreased as the development of other pharmaceuticals increased (*e.g. aspirin, morphine, and other opium-derived drugs).*[8,12]

Social reform policies in the 20th century aimed to reduce recreational use of many substances, including cannabis.[13] An increase in cannabis use from 1910-1920, coupled with political hysteria, led twenty-nine states including Massachusetts[14] to pass laws prohibiting the possession or sale of cannabis.[6,15] State-level changes in cannabis policy led to its inclusion in the 1940's amendment to two federal policies: The Uniform Narcotic Drug Act of 1932 and the Marihuana Tax Act of 1937. The Marihuana Tax Act of 1937 moved toward federal criminalization through exorbitant fines for cannabis use, possession, and cultivation.[16]

The Federal Controlled Substance Act (CSA) of 1970 replaced the Marihuana Tax Act and made it additionally illegal under federal law for physicians to prescribe cannabis medicinally. Despite the increasing stringency of federal cannabis policies over time, the recreational use of cannabis increased.

In 1971, President Richard Nixon declared war on drugs, proclaiming: "*America's public enemy number one in the United States is drug abuse. In order to fight and defeat this enemy, it is necessary to wage a new, all-out offensive."* [17] The purpose of Nixon's "War on Drugs" policies were to combat drug abuse on both the supply and demand sides. However, a disproportionate number of these policies focused on criminal justice enforcement and punishment for drug offenses—creating systematic changes in the criminal justice system. These policies assisted to create both the "Law and Order" (*i.e. politicization of crime*) and "Crime and Punishment" (*i.e. a culmination of fear of street crime that created a "morally and justified" reason for the heavy punitive response to drug crime*) phenomena.[18] [See Section *XII. Social Equity: Prohibition and Disproportionate Impact* for additional information on the adverse effects of prohibition on minority cohorts].

Currently under the CSA, the United States Drug Enforcement Agency (DEA) classifies cannabis as a Schedule 1 drug, the most restrictive ranking, contending that it has: (1) a high potential for abuse, (2) no current accepted medical use in the U.S., and (3) a lack of accepted safety for use under medical supervision.[19,20] Since 1970, there have been multiple failed efforts to reschedule cannabis at the federal level, including most recently in August 2018.

The U.S. Food and Drug Administration (FDA) is responsible for the oversight and implementation of the 1906 Pure Food and Drug Act, which prevents the manufacture, sale, or transportation of adulterated, or misbranded, poisonous, or deleterious foods, drugs, medicines and liquors.[21] The FDA's role in the regulation of drugs, which includes cannabis and cannabis-derived products (*e.g. Marinol [dronabinol], Cesamet [nabilone], Syndros [dronabinol], Epidiolex [cannabidiol])*, includes a review to determine whether proposed drug products are safe and effective for their intended use before products can go to market. Currently under federal law, the FDA has not approved the cannabis plant for the treatment of any disease, symptom, or condition[22] external to Marinol, Cesamet, Syndros, and Epidiolex, which are FDA-approved medicines for specific medical conditions.

State-Level

There are three distinct types of cannabis legalization that have been enacted at the state or local level in the U.S. since its federal illegal status: (1) decriminalization, (2) medicinal cannabis, and (3) non-medical adult-use cannabis legalization.

The first wave of cannabis legalization was decriminalization, defined in 1972 by the National Commission on Marijuana and Drug Abuse,[23] as policies replacing criminal sanctions for the possession for personal use or casual distribution of cannabis in small amounts with civil fines.[24] Since 1972, 22 states and the District of Columbia (D.C.) have enacted varying policies decriminalizing small amounts of cannabis.[25] States with decriminalization designate offenses as low-level misdemeanors with no possibility of jail for qualifying offenses (5 states) or a civil infraction (17 states).[25]

Since 1996, 33 states, D.C., Guam, and Puerto Rico have enacted varying laws permitting comprehensive medicinal cannabis programs, which include four main features: (1) Protection from criminal penalties for using cannabis for a medical purpose; (2) Access to cannabis through home cultivation, dispensaries, or some other system; (3) Permits for a variety of strains, including strains more potent than "low THC"; and (4) Permits either smoking or vaporization of some type of cannabis product, plant material, or extract.[26] An additional 15 states permit use of "low THC, high cannabidiol (CBD)" products for medicinal reasons as a legal defense in limited situations.[26]

Since 2012, ten states and D.C. have enacted varying laws permitting small amounts of cannabis for non-medical adult-use for adults 21 years-old or older ("21≤").[25]

Legal Background: Massachusetts

Massachusetts has now enacted and implemented all three types of cannabis legalization in three disparate waves. All three waves of Massachusetts cannabis legalization have been enacted via ballot initiatives: cannabis decriminalization in 2008 with Question 2, "*The Sensible Marijuana Policy Initiative*," medicinal cannabis in 2012 with Question 3, "*An Initiative Petition for a Law for the Humanitarian Medical Use of Marijuana*," and non-medical adult-use cannabis legalization in 2016 with Question 4, "*Massachusetts Legalization, Regulation and Taxation of Marijuana Initiative.*"

Other important laws in the discussion on cannabis-impaired driving in Massachusetts are the implied consent law and the 2017 case law, *Commonwealth v. Thomas Gerhardt*, 477 Mass. 775, 81 N.E.3d 751 (2017).

Implied Consent Law G.L. c. 90, § 24.

Under the Massachusetts implied consent law,[27] a driver arrested by a law enforcement officer who has probable cause to believe that he/she has been operating a motorized vehicle while impaired, must submit to a chemical test of blood or breath to determine their Blood Alcohol Content (BAC). If the suspected driver refuses to take the chemical test of the arresting officer's choice, their license is immediately suspended for a predetermined duration of time. The time of license suspension varies based on the age of the driver (*i.e. drivers aged 21 or older vs. minors aged 20 years-old or younger*) and the number of prior offenses. If the driver is an adult 21-years-old or older, the license suspension is 180 days for first offense (*i.e. refusal and with no prior offense*), three years for second offense (*i.e. refusal and a prior conviction for driving while under influence of intoxicating liquor*), five years for third offense (*i.e. refusal and two prior convictions*), and for life if three or more offenses (*i.e. refusal and three or more prior convictions).* If the driver is under the age of 21, the license suspension is three years for first offense, five years for the second offense, and for life for the third offense.

There is currently no similar implied consent law for cannabis-impairment in Massachusetts. This means if a driver is suspected of driving while impaired under the influence of cannabis, the driver can refuse a test with no license suspension implications. [See Section *XIII: State of Science: Detecting Impairment* subsections: *Can Standardized Field Sobriety Tests measure impairment by cannabis?* and *Can Drug Recognition Experts measure impairment by cannabis? Which parts of the process are more or less effective?* for validity studies on the SFST and DRE mechanisms].

Commonwealth v. Thomas Gerhardt

In a prosecution for operating while under the influence of cannabis ("OUI"), it is the Commonwealth's burden to prove beyond a reasonable doubt, that a defendant's consumption of cannabis impaired his or her ability to drive a motor vehicle safely. In a recent 2017 Supreme Judicial Court (SJC) case, *Commonwealth v. Gerhardt*, a motorist was charged in the District

Court with operating a vehicle under the influence of cannabis, in violation of G. L. c. 90, § 24. A motion was filed for a Daubert-Lanigan hearing, seeking to challenge the admissibility of evidence concerning his performance on field sobriety tests conducted after the stop.[28]

The Massachusetts SJC held that in a prosecution for operating a motor vehicle while under the influence of cannabis: "*police officers ("law enforcement officers [LEOs]") may not testify to the administration and results of field sobriety tests (FSTs) as they do in operating while under the influence of alcohol prosecutions*," but "*may testify to the administration of 'roadside assessments*;'" that a "*lay witness may not offer an opinion that another person is 'high' on marijuana* ("cannabis");" that a "*police officer may testify to observed physical characteristics of the driver such as blood shot eyes, drowsiness, and lack of coordination*," but may not "*offer an opinion that these characteristics mean that the driver is under the influence of marijuana* ("cannabis");" and that the jury may "*utilize their common sense*" in deciding if the driver's performance on the roadside assessments indicates his or her ability to operate a motor vehicle safely was impaired.[28]

Therefore, under this decision, a law enforcement officer ("police officer") may testify to observations made during the administration of roadside assessments to the extent that they are relevant to establish a driver's balance, coordination, mental acuity, and other skills required to safely operate a motor vehicle; However, an officer may not testify, on direct examination, that a driver's performance on an assessment established that the driver was under the influence of marijuana ("cannabis"), or that an individual "passed" or "failed" any assessment.[28]

Commonwealth of Massachusetts: Laws, Cases, Regulations, and Guidance

i. State Laws Governing Driving While Under the Influence (OUI) and Case Law

- Mass. General Law ch. 90, § 24, *Driving while under influence of intoxicating liquor, etc.; second and subsequent offenses; punishment; treatment programs; reckless and unauthorized driving; failure to stop after collision*
    - https://malegislature.gov/Laws/GeneralLaws/PartI/TitleXIV/Chapter90/Section24

      *Note: For additional information on all Massachusetts laws and regulations, please see: https://www.mass.gov/info-details/massachusetts-law-about-drunk-driving, which is a compilation of laws, regulations, cases, and web sources on drunk and drugged driving law.

ii. Commonwealth v. Gerhardt

- *Commonwealth v. Gerhardt,* 477 Mass. 775, 81 N.E.3d 751 (2017)
    - https://www.mass.gov/decision/commonwealth-v-gerhardt

iii. State Laws Governing the Cultivation, Production, Transportation or Sale of Medical and Adult-Use of Cannabis

- St. 2008, c. 387: *An Act Establishing A Sensible State Marihuana Policy*
    - https://malegislature.gov/Laws/SessionLaws/Acts/2008/Chapter387
- St. 2012, c. 369: *An Act for The Humanitarian Medical Use of Marijuana*
    - https://malegislature.gov/Laws/SessionLaws/Acts/2012/Chapter369
- St. 2016, c. 334: *The Regulation and Taxation of Marijuana Act*
    - https://malegislature.gov/Laws/SessionLaws/Acts/2016/Chapter334
- St. 2017, c. 55: *An Act to Ensure Safe Access to Marijuana*
    - https://malegislature.gov/Laws/SessionLaws/Acts/2017/Chapter55
- M.G.L. c. 94G: Regulation of the Use and Distribution of Marijuana Not Medically Prescribed
    - https://malegislature.gov/Laws/GeneralLaws/PartI/TitleXV/Chapter94G
- M.G.L. c. 94I: Medical Use of Marijuana
    - https://malegislature.gov/Laws/GeneralLaws/PartI/TitleXV/Chapter94I

iv. Regulations

- 935 CMR 500.00: *Adult Use of Marijuana*
    - https://www.mass.gov/files/documents/2018/03/27/935cmr500.pdf
- 935 CMR 501.000: *Medical Use of Marijuana*
- 935 CMR 502.000: *Colocated Adult-Use and Medical-Use Marijuana Operations*

v. Sub-Regulatory Guidance

- https://mass-cannabis-control.com/guidancedocuments/

IV. Law Enforcement Trainings

Public safety sectors of the Commonwealth are tasked with ensuring that constituents are safe, protected, and conducting themselves within the limits of the law(s). This task is exponentially more critical when there are changes in policy that may increase the quantity of a psychoactive ("impairing") substance, such as cannabis, which creates more exposure to and potential use of this substance.

The use of any substance with impairment potential can affect a person's ability to operate any motorized vehicle safely—which in turn, puts the driver, any passenger(s), and other person(s) who share the public space at risk. Different substances have different effects on the person consuming them depending on varying personal and environmental factors. Cannabis specifically can impair judgement, reaction time, and coordination.[29] [See *Section IX: Clinical Indicators* for additional information on the acute effects of cannabis intoxication].

The issue of law enforcement addressing impaired driving is not new. Mechanisms to detect alcohol impairment have been implemented since 1981 with the validation of the Standard Field Sobriety Test (SFST).[30] However, most law enforcement mechanisms (procedures and legislation) have focused on alcohol impairment. To address impaired driving on public roadways, it is imperative that both law enforcement and criminal justice professionals understand the signs of impairment and the available (science-validated) detection tools.

Additionally, differentiating between medical impairment and substance impairment is critical, as well as the ability to discern impairment from varying substances ("drugs") and categories of drugs, alcohol, and a varying combination of substances. With the legalization of cannabis for non-medical adult-use, Massachusetts is faced with detecting potentially increased rates of cannabis impairment on the road and discerning cannabis impairment from alcohol and/or other substances of impairment, all without having similarly validated tool(s) currently used for alcohol, the most commonly used substance of impairment.

To ensure the public safety of our roads, law enforcement officers (LEOs) may undergo training to better detect impairment and enforce the law regarding operating under the influence of alcohol and/or substances. There are three disparate trainings LEOs in the Commonwealth can undergo to advance this mission. In order of least to most comprehensive, these include:

- The Standard Field Sobriety Test (SFST) training;
- Advanced Roadside Impaired Driving Enforcement (ARIDE) training; and
- Drug Evaluation and Classification Program: Drug Recognition Expert (DRE) training.

The Standard Field Sobriety Test Training:

The Standard Field Sobriety Test (SFST) training is the most-widely used training for impaired driving detection and enforcement. SFST training is undertaken by all LEOs in the Police Academy. This training lays the groundwork for the more comprehensive Advanced Roadside Impaired Driving Enforcement (ARIDE) and Drug Recognition Expert (DRE) training. SFST training is conducted in accordance with National Highway Safety Administration (NHTSA) and International Association of Chiefs of Police (IACP) guidelines to administer, observe, and score drivers' performances on a series of three tests performed roadside during a traffic safety stop to assess a driver's impairment and probable cause for arrest. The tests include: (1) horizontal gaze nystagmus, (2) the walk and turn test, and (3) the one leg stand test.[31,32]

Horizontal Gaze Nystagmus Test:

The horizontal gaze nystagmus (HGN) test is typically conducted with a suspected driver standing, feet together and arms at the side and requires the driver to follow the movement of a stimulus with his/her eyes.[31] The officer observes the effects of stimulus movement, speed changes, and location, in both eyes. [Note: Among the three tests included in the SFST, the HGN is most often inadmissible in court].

Walk and Turn Test:

In the walk and turn test, the suspected driver is directed to take nine steps, touching heel-to-toe, along a straight line, turn on one foot completely and follow the same instructions in the opposite direction.[31] The officer observes eight indictors of impairment: (1) the driver cannot keep balance while listening to instructions, (2) begins before instructions are finished, (3) stops while walking to regain balance, (4) does not touch heel-to-toe, (5) uses arms to balance, (6) steps off the line, (7) takes an incorrect number of steps, and (8) makes an improper turn.

One Leg Stand Test:

In the one leg stand test, the driver is instructed to stand with one foot approximately six inches off the ground and count aloud by ones beginning with one thousand until told to put the foot down.[31] The officer observes the driver for 30 seconds and observes four indicators of impairment: (1) swaying while balancing, (2) using arms for balance, (3) hopping to maintain balance, and (4) putting his/her foot down.

Since SFSTs are reliant on the validity and reliability of each test in prosecution, this report provides a comprehensive review of each training and test conducted. [Note: it has been argued that if any detail of roadside use of the SFST departs from the NHTSA guidelines, that variation invalidates the test results and is inadmissible as evidence in court].[33] [See Section *XIII. State of the Science: Can Standardized Field Sobriety Tests measure impairment by cannabis? Which parts of the test are more or less effective?* for a literature review assessing the validity of the SFST training and tests].

Advanced Roadside Impaired Driving Enforcement Training

The Advanced Roadside Impaired Driving Enforcement (ARIDE) training was developed by the National Highway Traffic Safety Administration (NHTSA) with collaboration and expertise from the International Association of Chiefs of Police (IACP), Technical Advisory Panel, and the Virginia Association of Chiefs of Police. ARIDE is considered the "bridge" training between the SFST and DRE training. ARIDE provides an additional level of training for LEOs to detect drug impairment in drivers— to either get these drivers off the road for public safety, or for further examination by a Drug Recognition Expert (DRE) officer and potential prosecution.[34] The term, "drug," in this training refers to any substance that, when taken into the human body, can impair the ability of the person to operate a vehicle safely.[34,35]

The ARIDE training in Massachusetts is taught by DRE instructors and conducted under the administrator and approval of Sergeant Don Decker, Massachusetts's DRE program coordinator.[36] The overall goals of the course are twofold:

- Train LEOs to observe, identify and articulate signs of impairment related to drugs, alcohol or the combination of both in order to reduce the number of impaired driving incidents, serious injury, and fatal crashes; and
- Train other criminal justice professionals *(e.g. prosecutors, toxicologists)* to both:
    - Understand the signs of impairment related to drugs, alcohol, or a combination of the two substances, and;
    - Effectively work with law enforcement in order to reduce the number of impaired driving incidents, serious injury, and fatal crashes.

The course objectives are to train law enforcement and criminal justice professionals to:[35]

- Properly administer and articulate the SFST [Note: The most important aspect of the ARIDE training is the officer's ability to display proficiency in SFST];
- Define and describe the relationship of drugs to impaired driving incidents;
- Observe, identify, and articulate the observable signs of drug impairment with the established seven categories associated with the DRE Program;
- Identify, document, and describe indicators observed and information obtained related to impairment which leads to arrest/release decision; and
- Articulate through testimony, impairment related to alcohol, drugs, or a combination of the both based on a complete investigation.

This 16-hour classroom sessions includes the following:[35]

- Introduction and Overview of "Drugs and Highway Safety;"
- SFST update and review;
- SFST proficiency exam;
- Drugs in the human body;
- Observations of eyes and other sobriety tests;
- Seven drug categories;
- Effects of drug combinations; and
- Pre-and post-arrest procedures.

Drug Evaluation and Classification Program Drug Recognition Expert Training

The Drug Evaluation and Classification (DEC) Program, often referred to as the Drug Recognition Expert (DRE) Training Program, is a research-based program developed in the 1970's by the Los Angeles California Police Department in conjunction with medical professionals to detect impairment in drivers and help prevent crashes and avoid deaths and injuries by improving enforcement of drug impaired driving investigations.[37,38] [See Section *XIII. Can Drug Recognition Experts measure impairment by cannabis? Which parts of the process are more or less effective?* for a literature review assessing the validity of the DRE mechanisms].

The International Association of Chiefs of Police (IACP) report that The National Highway Traffic Safety Administration (NHTSA) has supported the DEC ("DRE") Training Program since 1984.[39] In 1987, the Highway Safety Committee of the IACP was requested by NHTSA to participate in the development and national expansion of the DEC Program and oversee the credentialing of certified DREs. Since that time, the program has grown both nationally and internationally.[39] In the U.S., each of the 50 states has operating DRE-trained officers. In Massachusetts specifically, the DRE program has existed and been recognized by NHTSA and the IACP since 1998.[34,40]

A LEO who successfully completes all phases of the DEC Program is known as a DRE. To become a DRE, a law enforcement professional or other related professional has to successfully complete all training requirements for certification as established by the IACP and the NHTSA.[41]

Training includes:

- 72 hours of classroom training;
- Field certification; and
- Comprehensive final knowledge examination.

For DREs to retain their certification, the DRE must:

- Participate in continuing education courses;
- Complete a recertification training course every two years; and
- Maintain a log of all evaluations completed in training and as part of any enforcement activities.

Additionally, state DEC/DRE program coordinators may place other standards on DREs that is specific to their state.

The DRE officer is trained to both conduct a detailed evaluation of a suspected driver's impairment and interpret the results of the evaluation accurately. When a DRE is called for an assessment, this DRE-trained LEO follows a protocol of twelve standardized steps in order to reach a reasonably accurate conclusion concerning the category or categories of drug(s), or medical conditions causing the impairment observed in the driver (See 12-steps and 7-drug categories below). Based on these informed conclusions, in the last step, the DRE can request the collection and analysis of an appropriate biological sample to obtain corroborative, scientific

evidence of the driver's substance use. In Massachusetts this specimen is a urine sample. After the full assessment, the DRE provides the law enforcement agency (LEA) of the arresting LEO a full report and the LEA can take action on how to proceed given the information.[34]

To register to become a DRE in Massachusetts: Please contact Massachusetts's DRE Coordinator Sergeant Don Decker, Drug Recognition Expert. Contact information and additional information can be found at: https://www.mass.gov/how-to/register-for-drug-recognition-expert.

The twelve-steps for DRE Assessments as Outlined by the IACP:

Breath Alcohol Test:

The arresting law enforcement officer reviews the driver's breath alcohol concentration (BrAC) test results and determines if the driver's suspected impairment is consistent with their BrAC.[42] If the impairment is not explained by the BrAC, the officer requests a DRE evaluation.

Interview of the Arresting Officer:

The DRE begins the investigation by reviewing the BrAC test results and discussing the circumstances of the arrest with the arresting law enforcement officer.[42] The DRE asks about the driver's behavior, appearance, and driving.

Preliminary Examination and First Pulse:

The DRE conducts a preliminary examination, in large part, to ascertain whether the driver may be suffering from a medical or mental health condition unrelated to substances.[42] Accordingly, the DRE asks a series of standard questions relating to the driver's health and recent ingestion of food, alcohol, and drugs, including prescribed medications. The DRE observes the driver's attitude, coordination, speech, breath, and face. The DRE also determines if the driver's pupils are of equal size and if their eyes can follow a moving stimulus and track equally. The DRE also looks for horizontal gaze nystagmus (HGN) and takes the drivers pulse for the first of three times. If the DRE believes that the driver may be suffering from a significant medical condition, the DRE will seek medical assistance immediately. If the DRE believes that the driver's condition is drug-related, the evaluation continues.

Eye Examination:

The DRE examines the driver for horizontal gaze nystagmus (HGN), vertical gaze nystagmus (VGN), and a lack of convergence (inability to cross eyes).[42]

Divided Attention Psychophysical Tests:

The DRE administers four psychophysical tests: (1) The Modified Romberg Balance, (2) Walk and Turn, (3) One Leg Stand, and (4) Finger to Nose test.[42]

Vital Signs and Second Pulse:

The DRE takes the driver's blood pressure, temperature, and pulse.[42]

Dark Room Examinations:

The DRE estimates the driver's pupil sizes under three different lighting conditions with a measuring device called a pupilometer.[42] The device assists the DRE in determining whether the pupils are dilated, constricted, or normal.[42]

Examination for Muscle Tone:

The DRE examines skeletal muscle tone. Certain categories of drugs may cause the muscles to become rigid.[42] Other categories may cause the muscles to become loose and flaccid.

Check for Injection Sites and Third Pulse:

The DRE examines the driver for injection sites, which may indicate recent use of certain types of drugs.[42] The DRE also takes the pulse for a third and final time.

Subject's Statements and Other Observations:

The DRE typically reads Miranda, if not done so previously, and asks the subject a series of questions regarding drug use.[42]

Analysis and Opinions of the Evaluator:

Based on the totality of the evaluation, the DRE forms an objective-based opinion as to whether or not the driver is impaired and indicates what category or categories of drugs may have contributed to the driver's impairment.[42]

Toxicological Examination:

The toxicological examination is a chemical test or tests that provide additional scientific, admissible evidence to support the DRE's opinion.[42] In Massachusetts, the sample is urine.

The Seven Drug Categories DREs are Trained to Recognize as Outlined by the IACP

There are seven categories of substances ("drugs") the DRE is trained to recognize and discern from other substances of impairment. It was noted by Massachusetts's DRE Coordinator, Sergeant Don Decker, DRE, in his presentation to the Massachusetts OUI Commission that the DRE training is helpful in determining the category of substance causing impairment, but not helpful in determining the exact substance of impairment (*e.g. a DRE-trained officer can determine a central nervous system depressant, but not be able to determine the specific depressant, such as: Valium, Xanax, Zoloft etc*.).[34]

1. **Central Nervous System (CNS) Depressants:** CNS depressants slow down the operations of the brain and the body. Examples include alcohol, barbiturates, anti-anxiety tranquilizers (*e.g. Valium, Librium, Xanax, Prozac, and Thorazine*), GHB (gamma hydroxybutyrate), Rohypnol, and many other anti-depressants (*e.g. Zoloft, Paxil*).[43]

2. **CNS Stimulants:** CNS stimulants accelerate the heart rate and elevate the blood pressure and "speed-up," or over-stimulate, the body. Examples include cocaine, "crack" cocaine, amphetamines, and methamphetamine ("crank").[44]

3. **Hallucinogens:** Hallucinogens cause the user to perceive things differently than they actually are in reality. Examples include LSD, peyote, psilocybin and MDMA (Ecstasy).[44]

4. **Dissociative Anesthetics:** Dissociative anesthetics include drugs that inhibit pain by cutting off or dissociating the brain's perception of the pain. Examples include Phencyclidine (PCP), its analogs, and dextromethoraphan.[44]

5. **Narcotic Analgesics "Opioids":** Narcotic analgesics relieve pain, induce euphoria, and create mood changes in the user. Examples include opium, codeine, heroin, demerol, darvon, morphine, methadone, Vicodin, and Oxycontin.[44]

6. **Inhalants:** Inhalants include a wide variety of breathable substances that produce mind-altering results and effects. Examples include Toluene, plastic cement, paint, gasoline, paint thinners, hair sprays, and various anesthetic gases.[44]

7. **Cannabis:** Cannabis is the scientific name for marijuana. The active ingredient in cannabis is delta-9 tetrahydrocannabinol, or THC. This category includes cannabinoids and synthetics like Dronabinol.[44]

There are varying limitations to these tests and reasons unrelated to substance use where a LEO may designate impairment for a person on a particular test when that person is not actually impaired. For example, a driver who has an eye disease or condition that affects his/her ability to see could confound the test and results of the HGN test, or age, disability, injury, or disease could affect the ability of a person to perform the one leg stand test or the walk and turn test. Additionally, persons with certain physical and/or mental health disorder(s) or disabilities may be unable to successfully complete these tasks, impaired by substances or not. It is a general rule that LEOs ask drivers whether there is any reason why they cannot perform the test and their answer should be noted in the officer's report. [See Section *VI. Baseline Data*, subsections: *Massachusetts Drug Recognition Expert (DRE) Data and Drug Recognition Expert (DRE) Municipality and State Law Enforcement Survey* for data regarding law enforcement trainings and evaluations in Massachusetts].

V. Other Legalized States

Non-medical adult-use of cannabis is legal in ten states and the District of Columbia (D.C.), but comprehensive strategies to prevent, detect, and confront driving under the influence of cannabis remain a challenge for all jurisdictions. In all states, it is illegal to drive under the influence of cannabis; However, states differ in their provisions and mechanisms used to confront cannabis-impaired driving (*e.g. zero-tolerance, per se laws, implied consent laws, etc.*). This section provides case studies from key states related to legislation and detection of cannabis-impaired driving. Future reports will look closely at different strategies to prevent cannabis-impaired driving.

Table V.1: States with Non-Medical Adult-Use Cannabis Laws

State	Implied consent for cannabis?	# Certified DREs in State (2017)	Per se laws	Legal THC Limit in blood
Alaska	No	40[39]	None	
California	Yes (blood and urine)	1,579[39]	None	
Colorado	Yes (breath, blood, or urine)	211[39] (228 as of May 2018[45])	Permissible inference	5 ng/ml
District of Columbia (D.C.)	Yes (breath, blood, urine)	9[39]	None	
Maine	Yes (breath, blood, urine)	98[39]	None	
Massachusetts	No	133[39]	None	
Michigan	Yes (unknown)	97[39]	Zero tolerance – except for medicinal cannabis patients	0 ng/ml
Nevada	Yes (blood, urine)	113[39]	Per se (blood and urine)	2 ng/ml (10ng/ml in urine)
Oregon	Yes (breath, blood, urine)	213[39]	None	
Vermont	Yes (breath, blood, urine)	53[39]	None	
Washington	Yes (breath, blood)	202[39]	Per se	5 ng/ml

Data from: https://www.ghsa.org/state-laws/issues/drug%20impaired%20driving as of 10/4/18
Implied consent data from https://www.leafly.com/news/cannabis-101/cannabis-dui-laws-by-state

Spotlight Issues

Colorado: Law Enforcement Cannabis Training Lab

Understanding Legal Marijuana, LLC[a] ("The Green Lab") provides a hands-on training experience for LEOs to detect impairment that is analogous to alcohol wet labs in Colorado.[45] Through interactions with cannabis users, LEOs are able to better understand cannabis use and impairment.[45] Training includes detection exercises with volunteers who have or have not used cannabis as well as training related to reporting, toxicology, and court processes.[45]

In the 2018 report, *Driving Under the Influence of Drugs and Alcohol*, Bui et al. 2018 reports that 410 Colorado LEOs had participated in the Green Lab since its opening in 2015.[45]

Washington: Polydrug User Issues and Data Tracking

A 2016 report, *Marijuana Use, Alcohol Use, and Driving in Washington State*, from the Washington Traffic Safety Commission identified poly-drug drivers as the most frequent type of impaired driver in Washington (WA) compared to single substance impaired drivers (*e.g. only alcohol* or *only cannabis*).[46] Co-use or poly-drug drivers refer to those who have consumed two or more impairing substances.[46] In WA, rates of poly-drug drivers have trended upward since 2012.[46] This report compiled various data sources including WA Roadside Self-Report Marijuana ("cannabis") Survey, Behavioral Risk Factor Surveillance, and Heavy Use Survey as well as state toxicology reports and random roadside sampling data.[46] The report identified concerns related to tracking these trends as national roadside sampling conducted by NHTSA will no longer be funded.[46]

Oregon: Driving Under the Influence of Cannabis Process

Law enforcement processes related to driving under the influence of cannabis can be difficult to access and understand. In the 2016 report to Congress, *Marijuana Report: Marijuana use, attitudes and health effects in Oregon*, prepared by Oregon Health Authority Program Design and Evaluation Services, the roadside process for suspected drivers under the influence of cannabis is clearly described:

> "*A person commits the offense of driving under the influence of intoxicants (DUII) if the person drives a vehicle with 0.08 percent or more by weight of alcohol in their blood, or under the influence of any intoxicating liquor, controlled substance or inhalant. Unlike alcohol, in Oregon there is no specific threshold for determining cannabis-related driving impairment based on physical measures (e.g. concentrations of specific cannabis chemicals in blood or urine). DUII for cannabis is determined based on an evaluation by officers certified as drug recognition experts (DREs). Impairment assessment includes*

[a] https://www.understanding420.com/Default.aspx

both questioning and physical tests. Based on their assessment, the DRE delivers a formal opinion on whether the driver is impaired, and by what type of drug. If a person is investigated for impaired driving and breathalyzer test results indicate an alcohol DUII (e.g., blood alcohol concentration [BAC] is 0.08 or greater), further investigation of drug impairment is rarely conducted. If the BAC is less than 0.08, and the officer believes that the level of driver impairment is greater than expected based on whatever BAC level is measured, then a DRE assessment is conducted. This procedure means that a person driving while impaired by both alcohol and cannabis is likely to be categorized as only an alcohol impaired DUII case, resulting in an under-count of actual cannabis-impaired or other drug-impaired driving" (pg. 61).[47]

VI. Baseline Data

Massachusetts Drug Recognition Expert (DRE) Data

In 2017, Drug Evaluation and Classification (DEC) Program state coordinators reported that there were 8,606 Drug Recognition Experts (DREs) certified in the U.S. through December 31, 2017. Of these DREs, 2,343 were employed by state police or highway patrol agencies, 4,351 were affiliated with city police or municipal agencies, 1,283 were with sheriff's departments, and 357 were with other agencies (*e.g. U.S. Park Police, U.S. Military Police, U.S. Fish and Wildlife Service, motor carrier, etc.*).[39]

In 2017, 30,989 DRE evaluations for enforcement purposes were completed nationally. Cannabis was the most frequently identified drug category overall (13,435), followed by: central nervous system (CNS) stimulants (10,879), CNS depressants (9,656), and narcotic analgesics "opioids" (9,641). Multiple states in the U.S. had notable increases in DRE enforcement evaluations from 2016-2017, including Massachusetts with a 35% increase.[39] In Massachusetts, narcotic analgesics were the most reported drug category by DREs in 2017, although cannabis was the most reported drug category in 29 other states.[39]

DREs are a valuable tool for combating the adverse impact of drugs on the communities that law enforcement agencies serve. Additionally, DREs are frequently called upon to differentiate unsafe driving behaviors stemming from drug ("substance") influence and medical and/or mental health conditions.[48]

State DRE coordinators are required to collect and submit an annual report for the International Association of Chiefs of Police (IACP). Tables VI.A.1.-VI.A.3. below were constructed from Massachusetts's law enforcement training and evaluations data compiled by Massachusetts's DRE Coordinator, Sergeant Don Decker.

Table VI.A.1. Drug Recognition Experts (DREs) in Massachusetts (MA), 2010-2017

DRE YEAR END REPORTS	2010	2011	2012	2013	2014	2015	2016	2017
Current Drug Recognition Experts (DREs)								
Number of evaluators (DREs) in MA	63	79	72	61	87	100	116	133
Number of DRE Instructors in MA	28	26	21	19	19	18	17	20
Number of State Police/HP[1] DREs	NA+	NA+	NA+	NA+	NA+	30	31	33
Number of City Police Department DREs	NA+	NA+	NA+	NA+	NA+	70	82	96
Number of Sheriff's Department DREs	NA+	NA+	NA+	NA+	NA+	0	0	0
Number of Other Agency DREs	NA+	NA+	NA+	NA+	NA+	2	3	4
Number of LEAs with certified DREs	NA+	NA+	NA+	NA+	NA+	55	60	71
Number of agencies that have DREs	41	31	34	35	54	NA+	NA+	NA+

*Note: All data reflects the Massachusetts Annual Report coordinated by Massachusetts's Drug Recognition Expert (DRE) Coordinator, Sergeant Don Decker for the International Association of Chiefs of Police (IACP)

-"Police Department" terminology is used in place of "Law Enforcement Agency (LEA)" terminology used in text throughout this report to be consistent with IACP reporting mechanisms.

[1]Highway Patrol

NA+ refers to a lapse of data *(i.e. years when the IACP did not require a specific statistic reported by the state DRE Coordinators*)

Table VI.A.2. Categories of drugs and poly-drug suspected/confirmed by DRE evaluations in Massachusetts, 2010-2017

DRE YEAR END REPORTS	2010	2011	2012	2013	2014	2015	2016	2017
Drug Category (DRE Opinion)	Frequency [Percent (%)] of total enforcement evaluations							
Depressant	85 (34.7)	149 (38.1)	96 (29.6)	22 (16.8)	89 (30.9)	104 (30.2)	122 (32.3)	170 (33.3)
Stimulant	42 (17.1)	49 (12.5)	30 (9.3)	30 (22.9)	47 (16.3)	42 (12.2)	47 (12.4)	63 (12.4)
Hallucinogen	0 (0.0)	3 (0.8)	6 (1.9)	0 (0.0)	2 (0.7)	2 (0.6)	0 (0.0)	7 (1.4)
Disassociate Anesthetic	4 (1.6)	5 (1.3)	8 (2.5)	3 (2.3)	4 (1.4)	8 (2.3)	13 (3.4)	18 (3.5)
Narcotic Analgesic	111 (45.3)	209 (53.5)	112 (34.6)	28 (21.4)	104 (36.1)	155 (45.1)	147 (38.9)	198 (38.8)
Inhalant	0 (0.0)	1 (0.3)	1 (0.3)	0 (0.0)	3 (1.0)	3 (0.9)	3 (0.8)	2 (0.4)
Cannabis	74 (30.2)	79 (20.2)	74 (22.8)	28 (21.4)	96 (33.3)	85 (24.7)	93 (24.6)	168 (32.9)
Poly-Drug Use	Frequency [Percent (%)] of total enforcement evaluations							
Total number of evaluations	89 (26.3)	147 (37.6)	100 (30.6)	55 (42.0)	72 (25.0)	111 (32.3)	129 (34.1)	165 (32.4)
Alcohol Rule Out	5 (2.0)	23 (5.9)	58 (17.9)	5 (3.8)	26 (9.0)	37 (10.8)	10 (2.6)	8 (1.6)
Medical Rule Out	0 (0.0)	7 (1.8)	8 (2.5)	8 (6.1)	5 (1.7)	12 (3.5)	12 (3.2)	5 (1.0)
No Opinion of Impairment	12 (4.9)	25 (6.4)	22 (6.8)	19 (14.5)	31 (10.8)	25 (7.3)	20 (5.3)	27 (5.3)
Results Pending	Unknown	Unknown	Unknown	25 (19.1)	25 (8.7)	59 (17.2)	36 (9.5)	124 (24.3)
Tox Found No Drugs	2 (0.8)	4 (1.0)	4 (1.2)	2 (1.5)	10 (3.5)	5 (1.5)	0 (0.0)	2 (0.4)
All DRE Evaluations	Frequency [Percent (%)] of total enforcement evaluation toxicology refusals							
Refused	45 (14.3)	149 (38.1)	149 (46.0)	33 (25.2)	67 (23.3)	157 (45.6)	177 (46.8)	200 (39.2)

*Note: All data reflects the Massachusetts Annual Report coordinated by Massachusetts's Drug Recognition Expert (DRE) Coordinator, Sergeant Don Decker for the International Association of Chiefs of Police (IACP)

Table VI.A.3. Varying law enforcement (LE) and related professional training statistics to detect substance ("drug")-impaired driving in Massachusetts, 2010-2017

DRE/ARIDE Trainings in Massachusetts	2010	2011	2012	2013	2014	2015	2016	2017
DRE Training								
Number of DRE Schools	1	0	0	1	1	2	2	3
Number students/trained	16	0	5 (OOS~)	15	17	29	31	38
Number of DREs certified	16	4	4	0	29	29	30	36
Number of DRE Instructor school/courses	1	0	0	0	0	0	0	1
Number of students/trained	27	0	0	0	0	0	0	8
Number of DRE Instructors certified	36	0	0	0	0	0	0	6
Number of 8-Hour Recertification courses	1	1	1	1	1	1	1	1
Number of students	36	39	39	35	35	48	37	32
ARIDE Training								
Number of ARIDE classes	3	7	7	7	7	10	8	7
Number trained	Unknown	111	111	137	137	234	202	184
SFST Training								
Number of SFST Classes	9	11	11	12	12	12	Unknown	Unknown
Number of Students	364	Unknown	Unknown	Unknown	Unknown	480	Unknown	Unknown
Number of SFST Instructor Classes	0	0	0	0	0	0	0	0
Number of Students	0	0	0	0	0	0	0	0
Other Training								
Prosecutor Training	2	NA+	NA+	NA+	NA+	NA+	NA+	NA+
SFST refresher	4	NA+	NA+	NA+	NA+	NA+	NA+	NA+
Drug Training for Health Care Professionals	5	5 (classes)	5 (classes)	4 (classes)	3 (classes)	NA+	NA+	NA+
Number of EMTs	NA+	57	57	72	64	NA+	NA+	NA+
Number of Paramedics	NA+	42	42	37	22	NA+	NA+	NA+

District Attorney's Training	NA+	NA+	NA+	NA+	NA+	4 (classes)	NA+	NA+
EMS Drug Class	NA+	NA+	NA+	NA+	NA+	5	NA+	NA+

*Note: All data reflects the Massachusetts Annual Report coordinated by Massachusetts's Drug Recognition Expert (DRE) Coordinator, Sergeant Don Decker for the International Association of Chiefs of Police (IACP)

-There were additional training conducted in these years not specific to combatting drug-impaired driving, such as Drug Impairment Training for Educational Professionals (DITEP) (*e.g. School Resource Officers [SROs]*) that are not reported here.

NA+ refers to a lapse of data *(i.e. years when the IACP did not require a specific statistic reported by the state DRE Coordinators*)

~OOS refers to students sent to trainings out of state (*i.e. out of Massachusetts*)

Drug Recognition Expert (DRE) Municipality and State Law Enforcement Survey

The Drug Recognition Expert (DRE) Survey ("DRE Survey") was sent internally to all of Massachusetts's 351 municipality Law Enforcement Agencies (LEAs) as well as the Massachusetts State Police (MSP) on June 12, 2018. Since June, the Cannabis Control Commission has received 83 completed surveys from different municipalities (23.6% of all MA municipalities) and one from the MSP. The goal of this survey was to assess the existing procedures and resources accessible to local LEAs and the MSP to assess and confront cannabis-impaired driving, especially regarding Drug Recognition Expert (DRE) and Advanced Roadside Impaired Driving Enforcement (ARIDE)-trained law enforcement officers (LEOs) on staff and/or availability and use of DREs via other LEAs. Determining the current procedures and resources, and assessing best practices are important initial goals of the Cannabis Control Commission. This assessment will provide information to determine loopholes and examine how to most efficiently and effectively work with collaborating LEAs in the future to confront cannabis-impaired driving in the Commonwealth. All participating LEAs that completed the survey can be found in Table VI.B.2.

Table VI.B.1. Breakdown of law enforcement agencies completing the "DRE Survey"

Law enforcement agency ("police department") survey respondents	
Total Number of Potential Respondents [survey sent to]	352
Total Massachusetts Municipalities Responding	83
Massachusetts State Police	1

Table VI.B.2. List of law enforcement agencies that completed the "DRE Survey"

Participating law enforcement agencies: Massachusetts State Police or municipality		
Mass State Police	Fairhaven	North Brookfield
Acton	Fitchburg	Northampton
Amesbury	Franklin	Norwood
Amherst	Georgetown	Peabody
Andover	Gill	Pittsfield
Arlington	Granby	Plymouth
Auburn	Groveland	Randolph
Beverly	Hadley	Rockport
Brockton	Hampden	Scituate
Bedford	Hanson	Somerville
Belchertown	Holbrook	Southborough
Billerica	Ipswich	Southwick
Bourne	Lanesborough	Stoneham
Boxford	Leicester	Stoughton
Bridgewater	Lenox	Taunton
Carlisle	Lynn	Templeton
Chelsea	Lynnfield	Tewksbury
Chicopee	Middleton	Sherborn
Dedham	Manchester by the Sea	Uxbridge
Dalton	Marblehead	Walpole
Dartmouth	Marion	West Bridgewater
Deerfield	Medfield	West Springfield
Douglas	Melrose	Westminster
Dover	Milford	Westwood
Dudley	Millville	Sutton
Eastham	Nahant	Swampscott
East Bridgewater	Natick	Westminster
Easthampton	North Andover	Wilbraham

*Note: Webster, MA did complete the survey, but after survey analyses were complete, thus, data from this municipality are not included in this report.

Forty-six percent of LEAs reported tracking OUI-Cannabis arrests. The range of years that LEAs reported tracking OUI arrests ranged from zero (71.4%) to ten years (10.7%).

Table VI.B.3. Years (frequency and percent [%]) of participating LEAs tracking OUI-Cannabis arrests

Years	Frequency	Percent (%) of LEAs
0 Years	60	71.4
1 Year	6	7.1
2 Years	3	3.6
3 Years	4	4.8
5 Years	1	1.2
7 Years	1	1.2
10+ Years	9	10.7

Drug Recognition Experts (DREs) Results

Seventy-three percent of LEAs reported having at least one Drug Recognition Expert (DRE) on staff (41.7%) or access to one via another LEA (72.6%). Only one LEA, the MSP, reported having more than three DREs per 1,000 residents.

Chart VI.B.1. LEAs with at least one-DRE trained officer in their Department

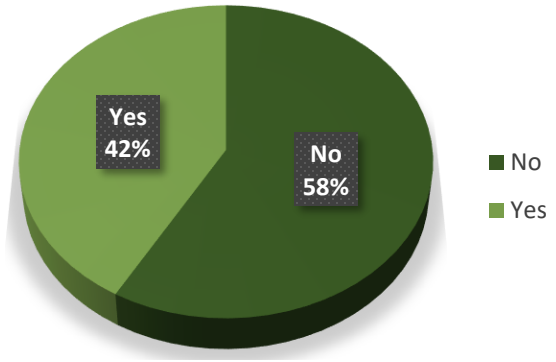
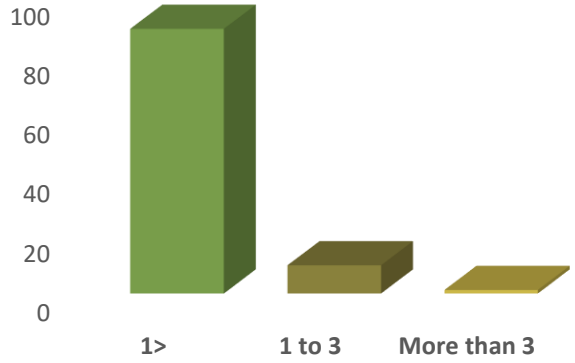
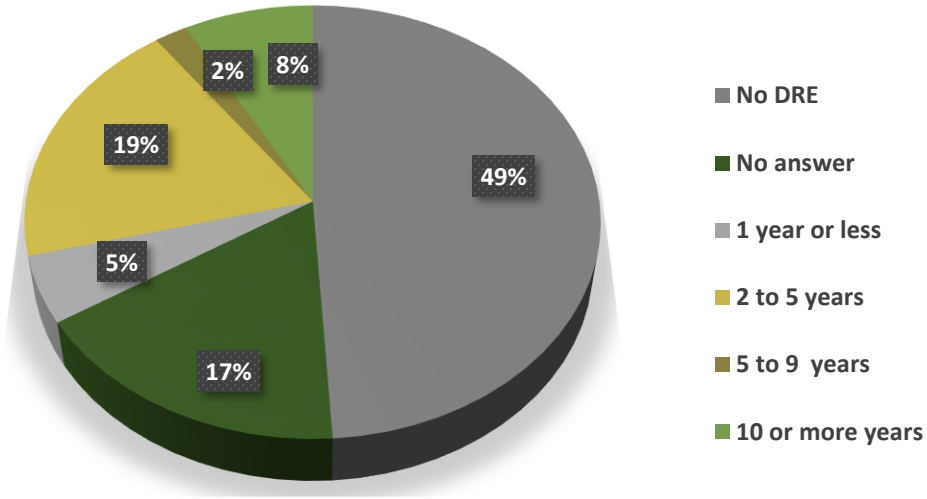


Chart VI.B.2. Number of DREs per 1,000 residents (for LEAs with at least one-DRE)



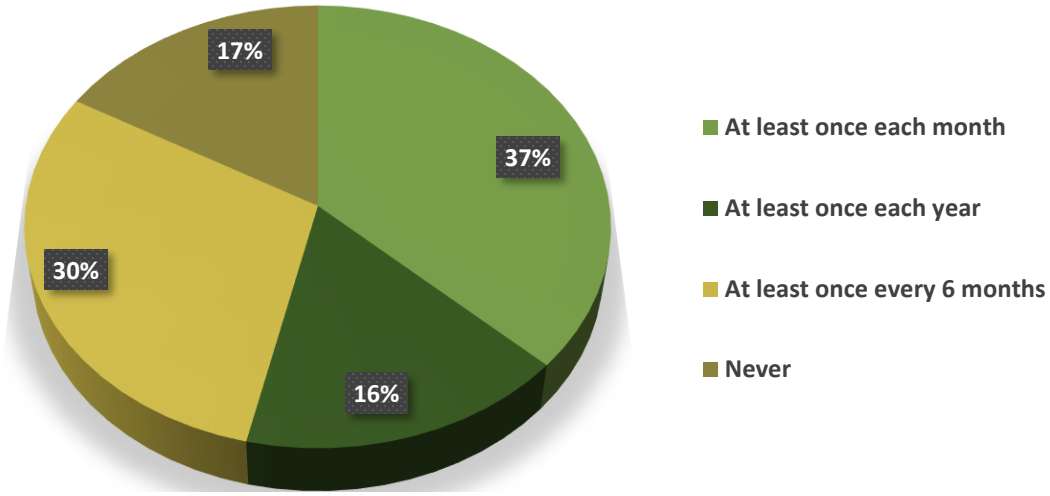
The length of time municipalities reported having a DRE ranged from "never" to "15+ years." Sixty-four percent of LEA respondents reporting not having at least one officer trained as a DRE, reported access to a DRE through another LEA. Only two LEAs reported that they have used a Massachusetts's State Police DRE, although only four respondents answered this question.

Chart VI.B.3. All LEA responses to the length of time (years) that they have had at least 1 DRE on staff



When asked how regularly LEAs use DRE services: 36.9% reported "at least once each month," 29.8% reported "at least once every 6-months, 16.7% reported "never," and 16.7% reported "at least once a year." Ninety-five percent of LEAs without a DRE reported interest in training officers to become DREs to detect cannabis-impaired driving.

Chart VI.B.4. How regularly LEAs with DREs report engaging their services



The most frequently reported impediment to providing DRE certification through their LEA were: "resources to pay for the training" (61%)—either as the sole reason or in combination with varying other impediments, including: (1) staffing, (2) requirements to stay current with

certification, or (3) not useful. Only 6.3% reported that "not useful" was the only impediment to providing DRE training through their agency.

Advanced Roadside Impaired Driving Enforcement (ARIDE) Results

Fifty-four percent of respondents reported that their agency employs one or more LEOs trained in Advanced Roadside Impairment Driving Enforcement (ARIDE). The number of LEOs in the varying Massachusetts LEAs with ARIDE training ranged from: 0 ARIDE-trained officers or No answer (56.0%), 1 to 5 ARIDE trained officers (28.6%), 6 to 9 ARIDE officers (7.1%), 10 to 19 ARIDE trained officers (4.8%), and 20 or more ARIDE trained officers (3.6%).

Chart VI.B.5. LEAs reporting employment of one or more ARIDE-trained officers

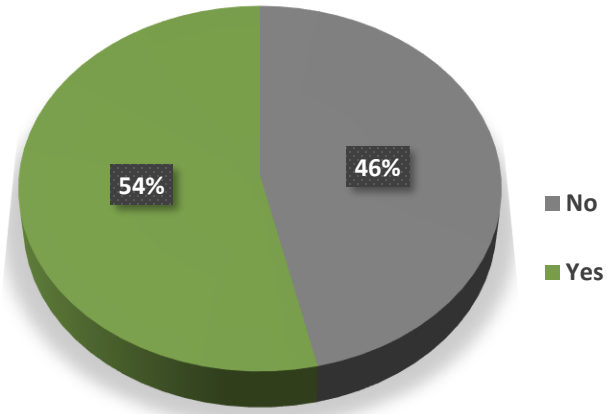
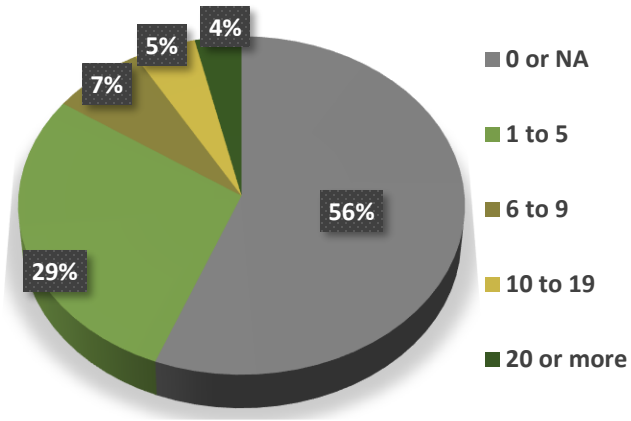


Chart VI.B.6. LEAs reporting the number of ARIDE-trained officers in their Department



Qualitative Data

In a qualitative, open-ended response question, respondents were asked how their LEA currently addressed drivers suspected of OUI-Marijuana. Answers ranged (categories and examples included below):

- DRE response(s) or a mix of DRE/other mechanisms (example responses included):
  - *"Currently there are no standards beyond SFSTs like alcohol. If the DRE is working, he will assist if it's not his stop."*
  - *"We have 3 trained DREs and numerous other officers trained in ARIDE."*
  - *"DRE, if no DRE they rely on the totality of evidence at the scene."*
  - *"Stop for impairment. If an officer presumes alcohol related, resort to their training. If drugs are factor, a DRE is called in."*
  - *"Observation and SFST and If we can locate a DRE, we will use one."*
  - *"Officer makes arrest based on probable cause and a DRE is called in."*
  - *"SFST testing, along with DRE analysis, if one of our six DREs are available to respond."*
  - *"As best we can with the resources we have. If the area DRE is available, we would ask him to respond, otherwise we use the SFST we have and try to gather as much evidence as to marijuana usage as possible."*

- On scene evidence/observation(s) and operation(s) (example responses included):
  - "*Standardized field side sobriety tests (SFSTs)."*
  - *"Roadside assessments including the use of SFSTs along with academy training on drug impaired drivers."*
  - *"Utilize standard SFSTs and officers conduct roadside observations of marijuana use, ask if develop reasonable suspicion."*
  - *"Through interviews, field sobriety tests, and overall observations."*
  - *"SFST, Observations, Questioning."*
  - *"Form opinions based upon SFSTs, officer observations, subject statements, and evidence at scene."*

- Observations like alcohol (example response included):
  - *"We try to apply our knowledge of alcohol impairment and field sobriety tests to detect marijuana. Improvement is needed if we are to be effective in reducing marijuana impaired operation."*

- Mentions of other detection mechanism(s) (example responses included):
  - *"Standardized field sobriety, interviewing operator, ARIDE trained officers, if an accident with injury and transport to hospital then we completed blood preservation order followed up by a search warrant and lab analysis of the blood."*

    - *"Negotiating with Union to begin a pilot program to use body cameras strictly to document sobriety testing."*

Other responses of note raised by LEAs about DREs included the ability to prosecute and lack of education/training to detect cannabis impairment etc.

Example responses included:

- *"Based on general observations. The use of DRE doesn't really have any standing in court. If OUI drugs can be based on the slightest of probably cause, an arrest is made. Complete waste of police resources with no benefit to prevent this from occurring again. Almost impossible to get a conviction."*
- *"We try to apply our knowledge of alcohol impairment and field sobriety tests to detect marijuana. Improvement is needed if we are to be effective in reducing marijuana impaired operation."*
- *"Our Department members are not properly educated and/or trained to detect persons under the influence or marijuana."*
- *"It is a great cause of frustration for municipal law enforcement officers. Currently, DREs are very few and far between. If available, they may consult over the phone after an arrest has already been made. Our officers rely on the training they received to detect impairment for OUI- Alcohol. As we know, this is not the best method and presents multiple challenges during prosecution."*
- *"We need the training and resources to educate our officers. This is a huge blind spot in Massachusetts. We have had discussions with our DA in Middlesex County to develop a county-wide training so that we at a minimum take an impaired driver from drugs off the road. Some officers might see that with no easy way to detect an impaired driver from drugs; they will NOT make an arrest. We are working to give the tools required to our officers to prevent this from happening.*
    - *Currently, in our county we have anecdotal evidence that judges are not even accepting expert testimony from police trained DRE's unless they have a medical background.*
    - *This is all very frustrating and a blind spot in keeping our roadways free of drug impaired operators.*
- *Regarding using an external-DRE: "It is my strong opinion that having that option is not practical. PD's cannot rely on outside resources to effectively police their communities."*
- *"Based on probable cause and driving behavior. Our courts in Barnstable County do not allow DRE use. This is a big issue for us especially now with the proliferation of marijuana in the Commonwealth. Any assistance would be appreciated."*
- *"If we can get an officer from another department that is trained in DRE, we can assess the driver's impairment, However, this is not always possible. In those instances where we cannot get a DRE the driver is not charged because we lack the necessary evidence for a prosecution."*
- *"We don't. Now, it is my understanding that there is an issue with a DRE being recognized in court."*

- *"With traditional standardized field sobriety testing, a preservation letter for blood and warrant, and the use of a DRE at the time of arrest. Unfortunately, Lowell District Court does not recognize DREs and won't allow their testimony at trial. This limits the ability to succeed with prosecution for OUI-drugs. We are really in trouble unless technology quickly develops some type of roadside testing device like a PBT and/or a breathalyzer equivalent that establishes impairment from substances like opioids, benzos, and marijuana. We have really been left without the tools to manage this new legislation."*

Massachusetts State Police (MSP) Operating under the Influence (OUI) Data

General Overview

The Massachusetts State Police (MSP) collects data in accordance with Massachusetts G. L. c. 90, § 24., *Driving while under influence of intoxicating liquor, etc.*, which permits law enforcement and researchers to monitor operating under the influence (OUI) cases. In this database, incidents of OUIs are stratified out by "OUI-Alcohol," "OUI-Drugs," and "OUI-Unknown Substance." The alcohol category indicates incidents where alcohol was the main or only noted substance of impairment. The drug(s) category indicates incidents where a drug was the main substance of impairment; However, it does not differentiate between type of drug category (*i.e. central nervous system [CNS] depressants, CNS stimulants, hallucinogens, dissociative anesthetics, narcotic analgesics, inhalants, and cannabis*) or specific drug(s) under these categories (*e.g. Valium, Cocaine, Ecstasy, Vicodin etc*.), thus, this report is unable to discern "cannabis" from any other drug ("substance"). The unknown substance category is more limited and includes alcohol, drugs, or any impairing substance, which were unknown to the officer or unspecified in the report.

For purposes of this report, data from 2007-2017 were examined as "baseline" data to begin to assess potential changes in incidents of impaired driving in Massachusetts prior to the opening of non-medical adult-use retail cannabis establishments and to make considerations ("recommendations") for future data collection. Tables stratify out substances by category included in the MSP data: "OUI-Alcohol," "OUI-Drugs," and "OUI-Unknown Substance." However, due to the low numbers in the "OUI-Unknown Substance" category, only results from the alcohol and drug categories are the focus of discussion.

Table VI.C.1. show the statistics (frequency [%]) of incidents of OUI cases involving alcohol, drugs, and unknown substance(s) stratified by year, 2007-2017. The incidents of OUI-alcohol cases have been steadily decreasing from 2007 (93.9%) to 2017 (86.0%), while incidents of OUI-drugs have been steadily increasing since 2007 (6.0%) to 2017 (14%). Not much can be inferred by unknown substances. Chart VI.C.1 visually shows the percent change in OUI-alcohol (blue) and OUI-drugs (green), 2007-2017.

Table VI.C.1: MSP OUI substance categories stratified by year (frequency [%]), 2007-2017

Year	OUI-Alcohol (%)	OUI-Drugs (%)	OUI-Unknown (%)
2007	3,504 (93.9)	222 (6.0)	3 (0.1)
2008	5,204 (95.4)	241 (4.4)	11 (0.2)
2009	4,691 (93.6)	320 (6.4)	1 (0.02)
2010	4,452 (92.3)	373 (7.7)	1 (0.02)
2011	3,522 (90.8)	355 (9.2)	1 (0.02)
2012	4,704 (92.7)	366 (7.2)	0 (0.0)
2013	3,923 (90.3)	418 (9.6)	2 (0.05)
2014	4,126 (87.2)	603 (12.8)	1 (0.02)
2015	3,371 (84.8)	598 (15.0)	6 (0.2)
2016	3,877 (85.5)	658 (14.5)	0 (0.0)
2017	2,769 (86.0)	450 (14.0)	0 (0.0)

*Note: Percentages (%) reflect % within year of data and not all years overall

Chart VI.C.1 Percent change in OUI-Alcohol (blue) and OUI-Drugs (green), 2007-2017

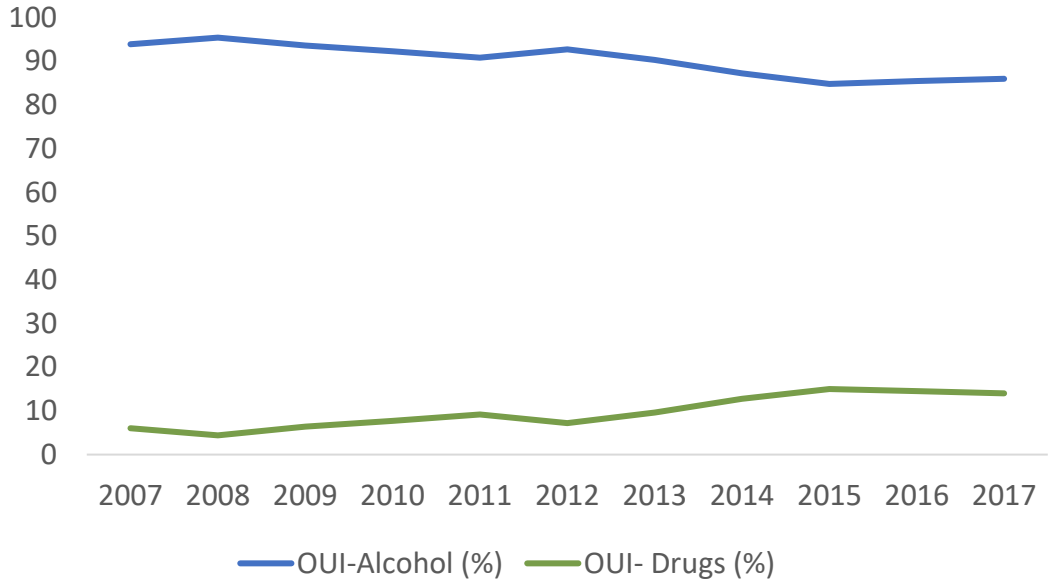


Table VI.C.2. show the varying action(s) taken by the MSP law enforcement officers for all OUI incidents from 2007-2017, which include: (1) arrest, (2) citation, (3) no action, (4) protective custody, (5) summons, and (6) under investigation. Most of all categories resulted in an arrest. In total incidents that resulted in an arrest: 91.5% were from alcohol impairment vs. 8.4% from drug impairment. All other categories of actions followed similar patterns with alcohol impairment contributing to the majority of each action—a result stemming from the disproportionate higher frequency of incidents resulting from OUI-alcohol impairment in comparison to drug or unknown substance OUI impairment.

Table VI.C.2. MSP OUI categories by action taken (frequency [%]), 2007-2017

Acton Taken	OUI-Alcohol (%)		OUI-Drugs (%)		OUI-Unknown (%)	
Arrest	42,143	(91.5)	3,863	(8.4)	25	(0.1)
Citation	12	(100)	0	(0.0)	0	(0.0)
No Action	112	(88.9)	14	(11.1)	0	(0.0)
Protective Custody	1	(100)	0	(0.0)	0	(0.0)
Summons	1,849	(71.8)	723	(8.1)	1	(0.04)
Under Investigation	26	(86.7)	4	(13.3)	0	(0.0)
Total	44,143	(90.5)	4,604	(9.4)	26	(0.1)

*Note: Percentages reflect % within action taken (OUI-Alcohol, OUI-Drugs, OUI-Unknown) and not all actions taken overall

Table VI.C.3. stratifies the MSP reported OUIs from all Massachusetts counties from 2007-2017. This is important to monitor because counties may differ in population and substance use, an area of potential public health and public safety prevention and intervention amidst cannabis legalization. In comparison to the Massachusetts average of all annual rates of OUI-drug incidents overall (9.7%) across all years, 2007-2017, four counties average higher: Barnstable (25.7%), Dukes (14.3%), Essex (12.1%), and Plymouth (17.4%). Since the drug category includes all potential drugs, research is unable to discern the category of drug(s) of impairment in these cases. This is important to note since there has been an increase in opioid analgesic use in recent years in Massachusetts and specific counties. The National Institute on Drug Abuse (NIDA) states that Massachusetts was among the top ten states with the highest opioid-related use mortality.[49]

Table VI.C.3. MSP OUI substance categories by Massachusetts County (frequency [%]), 2007-2017

County	OUI-Alcohol (%)		OUI-Drugs (%)		OUI-Unknown (%)	
Barnstable	1,210	(74.2)	419	(25.7)	1	(0.1)
Berkshire	872	(94.7)	48	(5.2)	1	(0.1)
Bristol	4,375	(92.2)	369	(7.8)	0	(0.0)
Dukes	24	(85.7)	4	(14.3)	0	(0.0)
Essex	5,411	(87.8)	748	(12.1)	3	(0.1)
Franklin	646	(91.2)	62	(8.8)	0	(0.0)
Hampden	4,496	(94.4)	265	(5.6)	1	(0.02)
Hampshire	673	(91.4)	61	(8.3)	1	(0.1)
Middlesex	7,599	(91.5)	707	(8.5)	1	(0.01)
Nantucket	26	(96.3)	1	(3.7)	0	(0.0)
Norfolk	3,547	(91.8)	319	(8.3)	0	(0.0)
Plymouth	2,452	(82.1)	519	(17.4)	16	(0.5)
Suffolk	5,588	(93.3)	400	(6.7)	0	(0.0)
Worcester	7,224	(91.3)	682	(8.6)	2	(0.03)

*Note: Percentages (%) reflect % within county and not all counties in Massachusetts overall

Crash Status

A potential consequence of impaired driving is increased risk of crash and resulting injury. From 2007 to 2017, the majority of OUI incidents the MSP responded to did not result in a crash (82.5%). Out of the 8,582 (17.5% of OUIs) that did result in a crash, 87.9% were alcohol OUIs and 12.0% were drug OUIs. Alcohol OUIs contributed to a higher percentage of OUIs resulting in crashes; However, within the subcategories “OUI-alcohol” vs. “OUI-drugs,” OUI-drugs contributed to more crashes than OUI-alcohol. Out of all OUI-alcohol incidents, 17.1% were the result of a crash versus OUI-drugs incidents, where 22.4% were the result of a crash. Differing drug categories and drugs within those categories have varying effects on a person’s ability to operate a motorized vehicle. An increased quantity of cannabis, a formerly illegal substance, may

increase the rates of driving after use and potential injury, which is important for law enforcement to be prepared for in the Commonwealth.

It is important to note that not all people who use cannabis will drive and not all drivers who have used cannabis are impaired. [See Sections: *XIII. State of the Science: Detecting Impairment* and *XIV State of Science: Detecting Cannabis Cannabinoids* for literature reviews assessing the validity of assessing cannabis-impairment and cannabinoids].

Table VI.C.4. All reported OUIs resulting in crash vs. non-crash, 2007-2017

Crash vs. Non-Crash	Frequency (%)	
Crash	8,582	(17.5)
Non-Crash	40,396	(82.5)
Total	48,978	

Table VI.C.5. OUI categories stratified by crash vs. non-crash, (frequency [%]) by crash category, 2007-2017

Crash Status	OUI-Alcohol (%)+		OUI-Drugs (%)+		OUI-Unknown (%)+		Total (%)+	
Crash	7,545	(87.9)	1,029	(12.0)	4	(0.1)	8,582	(17.5)
Non-Crash	36,598	(90.6)	3,575	(8.9)	22	(0.1)	40,396	(82.5)

*Note: +Percentages (%) reflect % within OUI category and not crash category
~ Total % refers to crash vs. non-crash category

Table VI.C.6. OUI categories by crash vs. non-crash, (frequency [%]) by OUI category, 2007-2017

Crash Status	OUI-Alcohol (%)+		OUI-Drugs (%)+		OUI-Unknown (%)+	
Crash	7,545	(17.1)	1,029	(22.4)	4	(15.4)
Non-Crash	36,598	(82.9)	3,575	(77.7)	22	(84.6)
Total	44,143		4,604		26	

Note: +Percentages (%) reflect % within crash category (crash vs. non-crash) and not OUI category

Demographics

i. Race/Ethnicity

Table VI.C.7. stratifies out OUI incidents (frequency [%]) by the varying racial and ethnicity cohorts represented in the MSP data. Across all racial cohorts, alcohol OUIs are consistently the larger percentage of OUI incidents. Drug impairment OUIs are highest among White and Black cohorts and lowest among Asian/Pacific Islander and American Indian/Alaskan Native cohorts.

Table VI.C.7. Race/ethnicity cohorts stratified by total OUI categories within each race/ethnicity (frequency [%]), 2007-2017

Race/Ethnicity	OUI- Alcohol	(%)	OUI- Drugs	(%)	OUI- Unknown	(%)	Total
White	32,941	(89.6)	3,812	(10.4)	22	(0.1)	36,753
Black	3,793	(91.6)	345	(8.3)	3	(0.1)	4,141
Hispanic	6,455	(94.7)	359	(5.3)	1	(0.0)	6,815
Asian OR Pacific Islander	1,191	(97.9)	26	(2.1)	0	(0.0)	1,217
Middle Eastern or East Indian	464	(95.3)	23	(4.7)	0	(0.0)	487
American Indian or Alaskan Native	38	(97.4)	1	(2.6)	0	(0.0)	39
Unknown	360	(90.5)	38	(9.6)	0	(0.0)	398

*Note: Percentages reflect the percent of OUIs (alcohol, drug, unknown) within each race/ethnicity cohort, not across all race/ethnicity cohorts.

Table VI.C.8. stratifies out racial/ethnicity cohorts consistent with 2017 Massachusetts census data to compare the percent of Massachusetts population by racial cohort and each OUI category. Notable variations are seen in specific cohorts, including: White, Hispanic, and Asian. Most of the Massachusetts's population is White, non-Hispanic (81.3%), but only account for 74.6% of the alcohol OUIs, a lower percentage than would be expected. Additionally, White was the only racial cohort whose OUI drug percentage was greater than their percent of the population overall (82.8% OUI-drugs vs. 81.3% of population). The percent of OUI-drugs of Black, Hispanic, Asian and American Indian/Alaskan Native cohorts were all lower than their overall percentage of the Massachusetts population. Conversely, the Hispanic cohort accounts for 11.9% of the population, but 14.6% of alcohol OUIs, a higher percentage, and 7.8% of OUI-drugs, a lower percentage than their overall percent of the state population. The Asian cohort had notable lower percentages of both alcohol and drug-related OUIs in relation to their percent of the state population.

Table VI.C.8. Race/ethnicity cohorts stratified by percent of total population and OUI categories overall, 2007-2017

Race/Ethnicity	Cohort as percent of state population (2017)	OUI-Alcohol (%)	OUI-Drugs (%)	OUI-Unknown (%)
[a]White	81.3	74.6	82.8	84.6
[b]Black	8.8	8.6	7.5	11.5
[c]Hispanic	11.9	14.6	7.8	3.9
[d]Asian*	7.0	3.8	1.1	0.0
[e]American Indian or Alaskan Native	0.5	0.1	0.2	0.0

*Note: To be consistent with Census data categories, Asian in this category has combined Pacific Islander and Middle Eastern or East Indian together.
[a-e]: Racial/ethnic categories for Census tracking in Appendix: Table 3. U.S. Census Data definitions of inclusion for race/ethnicity

ii. Gender

Table VI.C.9. stratifies gender by OUI category. In 2007-2017, females accounted for 21.1% of all alcohol OUIs and 21.9% of all drug OUIs. In comparison, males accounted for 78.4% of all alcohol OUIs and 77.8% of all drug OUIs.

Table VI.C.9. OUI categories by gender: female, male, and unknown gender (frequency [%]), 2007-2017

Gender	OUI-Alcohol (%)		OUI-Drugs (%)	
Female	9,322	(21.1)	1,010	(21.9)
Male	34,616	(78.4)	3,581	(77.8)
Unknown	205	(0.5)	13	(0.3)
Total	44,143		4,604	

*Note: Percentages (%) reflect the % of OUIs (alcohol, drug) for each gender cohort (females vs. male) as total of OUI category overall
-OUI-Unknown substances not included due to low numbers

iii Massachusetts Residents vs. Out-of-State Visitors

Massachusetts was the first East Coast state to enact and implement non-medical adult-use cannabis policy and regulations. It will be important to monitor incidents of impaired driving from residents of the Commonwealth as well as those of visitors, who may be purchasing and/or consuming legalized cannabis within Massachusetts's jurisdiction. Table VI.C.10. show the frequency and percent of OUI incidents of Massachusetts residents (86.2%) and non-residents (13.8%).

Table VI.C.10. Drivers' state of residence: Massachusetts vs. out-of-state residence (frequency [%])

Driver State of Residence (address)	Massachusetts (%)	Non- Massachusetts (%)
Resident vs. Non- Resident	44,090 (86.2)	7,037 (13.8)

VII. Public Health Framework for Cannabis-Impaired Driving Prevention

Public Awareness Campaigns

A public awareness campaign is a comprehensive effort to educate a large audience to act toward a specified goal. A public awareness campaign rooted in a public health framework serves to promote public health by creating synergy between short-term mass media campaigns and long-term localized action.[50]

The public health prevention model is an inclusive model targeting the overall health of the public at large rather than an individualized or small group prevention model. Nurse and Edmondson-Jones 2007 discuss the importance of a framework in public health delivery.[51] Authors state that a framework assists in providing shape, structure, clarity of purpose, and direction for a combination of constructs to improve the health of a population, which includes a complex combination of skills, methods, relationships, and interactions.[51] Public health frameworks work within varying systems that surround an individual and affect individuals' behaviors, aiming to impact his/her choice(s) to partake in a behavior.[51–54]

Key Standards of Public Health

The 10 key standards of public health[51]

- *Surveillance and assessment of the population's health and well-being;*
- *Promoting and protecting the population's health and well-being;*
- *Developing quality and risk management within an evaluative culture;*
- *Collaborative working for health;*
- *Developing health programs and services and reducing inequalities;*
- *Policy and strategy development and implementation;*
- *Working with and for communities;*
- *Strategic leadership for health;*
- *Research and development; and*
- *Ethically managing self, people, and others.*

*Note: Highlighted in green are the standards of public health incorporated into the Massachusetts Public Awareness Campaign, *More About Marijuana*.

For the prevention of disease, the Centers for Disease Control and Prevention (CDC), published a framework outlining critical elements, which includes:

- Strong public health fundamentals;
- High-impact intervention; and
- Sound health policies.

This public health framework is routinely applied to varying public health and public safety issues. In this framework, strong public health fundamentals refer to surveillance, detection, and investigation of the issue, such as cannabis-impaired driving. For the Commonwealth, this would

occur at both the local and state levels. High-impact interventions refer to focused efforts to prevent cannabis-impaired driving within a short time-frame, such as identifying and validating new tools for prevention and expediting the broad use of validated interventions to reduce impaired driving. Sound health policies refers to developing and advancing policies to prevent, detect, and control rates of impaired driving, which include: ensuring sound scientific data to support evidence-based policies, working with local state and local public health and public safety departments to both prevent, control, and respond to this potential "emerging threat," helping community leaders improve local response and readiness, and educating the public.[55]

Cannabis Public Awareness Campaigns: All States

Massachusetts is one of seven states that have implemented a comprehensive public awareness campaign to either inform constituents of the non-medical adult-use cannabis laws and provisions within their states and/or educate youth or parents on the harms of cannabis use for adolescents whose brains are still maturing. [See Table VII.D.1. for a list of states with cannabis public awareness campaigns, their campaign slogan, and website to their campaign].

Table VII.D.1: States with Non-Medical Adult Cannabis Laws and Public Awareness Campaigns

State	Campaign Name	Website
Massachusetts	*More About Marijuana*	*https://www.mass.gov/learn-about-marijuana* or *www.moreaboutmj.org*
Alaska	*Get The Facts About Cannabis*	*http://dhss.alaska.gov/dph/Director/Pages/cannabis/default.aspx*
California	*Let's Talk Cannabis*	*https://www.cdph.ca.gov/Programs/DO/letstalkcannabis/Pages/LetsTalkCannabis.aspx*
Colorado	*Good to Know*	*https://www.colorado.gov/good-know*
Nevada	*Good to Know*	http://goodtoknownv.com/
Oregon	*Stay True To You*	*http://www.staytruetoyou.org/#home*
Washington	*Listen2YourSelfie*	*https://www.youcanwa.org/*

Cannabis Public Awareness Campaign: Massachusetts

Based within a public health framework, Massachusetts's cannabis public awareness campaign, *More About Marijuana*, is a collaboration between The Massachusetts Cannabis Control Commission (CNB), The Department of Public Health (DPH), and The Bureau of Substance Abuse Services (BSAS) within DPH, who contracted with MORE Advertising to collaboratively research, devise, and implement *More About Marijuana* in the Commonwealth.

The goals of the campaign are threefold:

1. Conduct research to assess the current knowledge of both:
    a. Cannabis overall; and
    b. Massachusetts Chapter 55, *An Act to Ensure the Safe Access to Cannabis* law and provisions.
2. Develop the campaign based on research results. Research for this campaign consisted of two primary mechanisms:
    a. Focus groups with pre-group surveys; and
    b. Online ("pre" implementation) survey of Massachusetts residents 21≤. The campaign targets both the general population, as well as parents and youth. [See research methods and results below]; and
3. Implement the campaign to educate constituents on the varying provisions within the law and potential harmful effects of using cannabis.

The implementation of the campaign has two waves. The first wave was implemented in August 2018 and targeted parents of youth. The second wave of implementation will target a general audience and is planned for implementation in winter 2019.

Massachusetts Cannabis Public Awareness Campaigns and Cannabis-Impaired Driving

A portion of the public awareness campaign targeting the general public involves information about driving after cannabis use or consumption. This topic was also a prominent concern of parents in the focus groups. Results from pre-focus group surveys, focus groups, and the pre-implementation survey regarding perceptions and concerns of cannabis-impaired driving and changes to Massachusetts's law(s) are provided below.

i. Focus Groups

The campaign conducted eighteen 90-minute focus groups from May 7-18, 2018 in three disparate geographic locations in Massachusetts:

1. Boston, MA "Urban;"
2. Framingham, MA "Suburban;" and
3. Greenfield, MA "Rural."

At each location, six specific groups were conducted, stratified by either: age and use status OR parental status and grade of child. Overall, the 206 focus group participants represented a mix of race/ethnicity, income, and education consistent with the state census data for the respective geographic regions [See Table VII.D.2. below].

Prior to commencing the focus groups, participants completed an anonymous pre-group survey. Moderator guides were developed to lead the various groups through a series of questions.

The research objectives for the focus groups were to:

- Explore knowledge, attitudes, and practices around cannabis and the new law;
- Determine preferences as they relate to existing campaigns (*i.e. Colorado, California*);
- Establish preferences for Massachusetts' overarching campaign brand (*i.e. name, logo*);
- Identify informational needs/desires and preferred channels/vehicles to receive information about the new law; and
- For parents/guardians, explore:
    - Concerns about youth cannabis use;
    - Knowledge of impact of cannabis use on youth;
    - Intention to talk to kids, including motivators and barriers; and
    - Self-efficacy around talking to kids and resources needed to support effective communications.

Table VII.D.2. Focus groups stratified by geographic location and cohort, May 7-18, 2018.

Focus Group Cohort	Framingham (Suburban)	Boston (Urban)	Greenfield (Rural)	Total per Segment
Adults 21-39				6
"Users"	✓	✓	✓	3
"Intent to Use"	✓	✓	✓	3
Adults 40+				6
"Users"	✓	✓	✓	3
"Intent to Use"	✓	✓	✓	3
Parent Groups				6
MS Parents	✓	✓	✓	3
HS Parents	✓	✓	✓	3
Total per Region	6	6	6	18

ii. Pre-Group Survey Results Regarding Cannabis and OUI or Related Issues

- Most adult respondents reported smoking as the most common method of cannabis consumption. The second most common way to consume cannabis was through edibles. Vaping was third. Adults from the "users" groups were more likely to vape cannabis than those from the "intenders" groups.
- When asked what "other" forms of cannabis they might try now that it is legal, smoking responses decreased by 24%, vaping responses increased by 16%, and edibles responses increased by 10%.
- Fifty-eight percent (58%) of adult ("Users" and "Intent-to-Use" group) respondents who answered a question about the dangers of driving while high did not know and/or did not think that driving after consuming cannabis is as dangerous as driving after using alcohol.

Chart VII.D.1. Pre-Survey Focus Group Results: Survey Question: "*Is driving after using "marijuana" less dangerous, more dangerous, or equally dangerous as driving after using alcohol?*"

Sample: 137 adult (21≤) cannabis "Users" or "Intent-to-Use," May 2018.

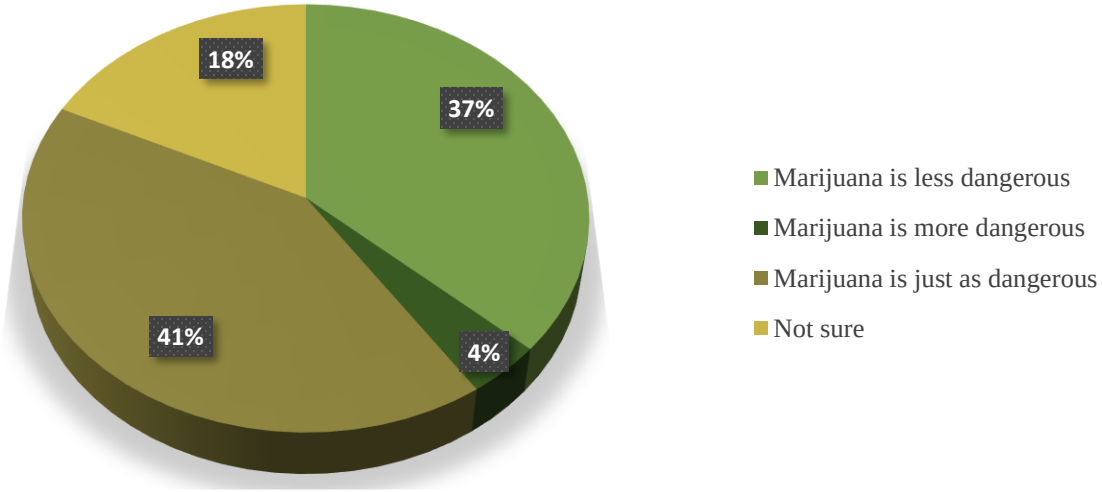
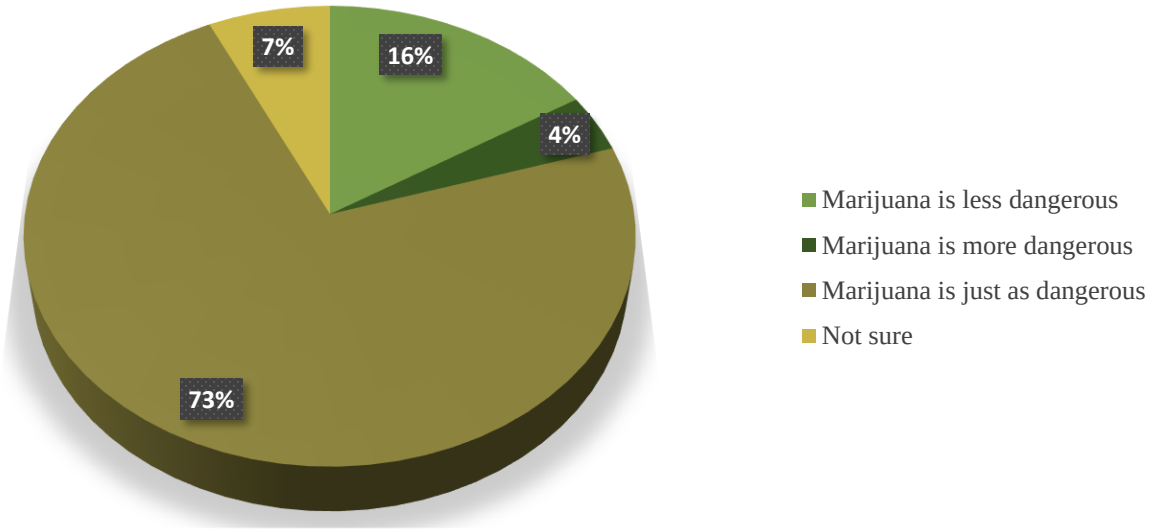


Chart VII.D.2. Pre-Survey Focus Group Results: Survey Question: "*Is driving after using "marijuana" less dangerous, more dangerous, or equally dangerous as driving after using alcohol?*"

Sample: 69 parents of middle-school or high-school children, May 2018.



iii. Focus Group Survey Results Regarding Cannabis and OUI or Related Issues

- In all groups, all but four participants had heard of the law and understood it was related to the non-medical use of cannabis. There was some confusion about whether the law was already in effect or going into effect July 1, 2018;
- There was some confusion over the legal age of use (18≤ or 21≤). The older participants (40+ group[s]) were more likely to be confused about the legal age;
- All groups talked about cannabis and driving as it relates to current OUI laws;
- In most groups, people had many follow-up questions about enforcement, particularly as it relates to the difference between using and driving versus "driving while high," which were seen by participants as two different things;
- Many had questions about some sort of definitive OUI test, like a breathalyzer test used for alcohol-impairment. Questions and concerns surrounded the burden of evidence in determining if someone is impaired while driving after cannabis use and science not yet having a definitive measure to detect the intoxicating components of cannabis (metabolites);
- Other participants had questions about cannabis use and driving, storage in one's car, and penalties (*e.g. ticket versus a criminal record*) for car-related infractions;
- Questions and concerns surrounded the severity of punishment of driving while impaired by cannabis and the legality if you're a designated driver and other people are smoking cannabis in the car, and how much cannabis is allowed (for possession) in the car and where it needs to be stored, like the open container law for alcohol;
- Regarding not crossing state lines with cannabis in possession, most participants acknowledged that this was "common sense," but they were also concerned that, given the close proximity of New England states, this might be easily and unknowingly violated.
- Parents were concerned how cannabis's legality will impact people's driving and how they should talk to their (middle-school or high-school) children about it; and
- Many parents wondered about the legal repercussions if their child was driving sober but a friend in the car had an open edible or similar.

iv. Representative online survey of Massachusetts residents 21≤

A national research firm, Survey USA, was contracted to conduct an online survey of Massachusetts residents (adults aged 21≤). Surveys were administered from May 10-29, 2018 using pre-recruited respondents. Respondents were weighted by gender, age, and race in accordance with U.S. Census targets for the state of Massachusetts. The final weighted sample size was 2,500.

Of the adults, 37% had never used cannabis, 29% had used cannabis but not within the past year, and 32% had used cannabis in the past year. One survey question directly assessed the perceived risk of OUI (alcohol vs. cannabis), results found below.

Chart VII.D.3. Results of Survey Question: "*Is driving after using cannabis less dangerous, more dangerous, or equally dangerous as driving after using alcohol?*"

Sample: 2,370 adult (21<) Massachusetts residents, May 2018.

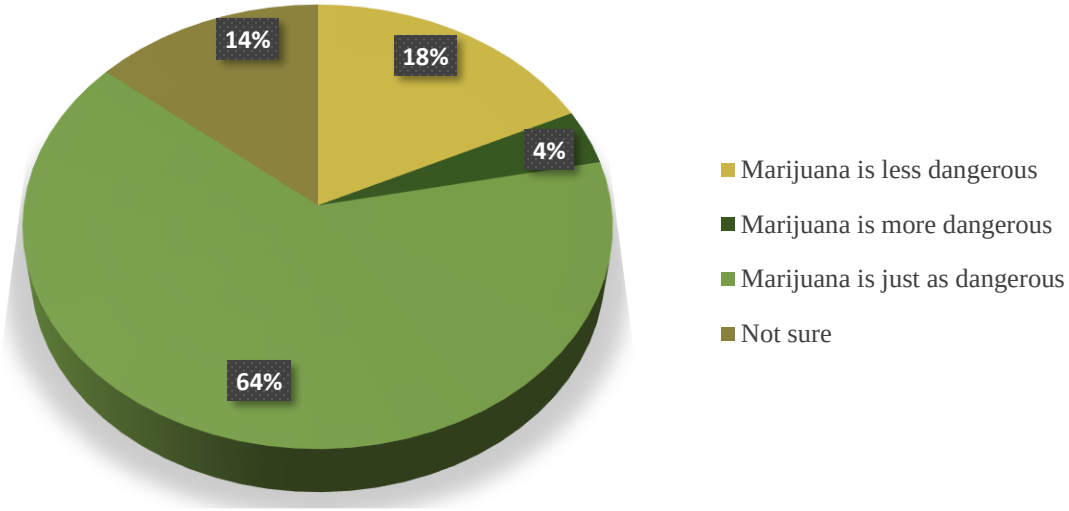


Chart VII.D.4. Perceived Risk of OUI by "User Status."

Sample: 2,370 adult (21<) Massachusetts residents, May 2018.

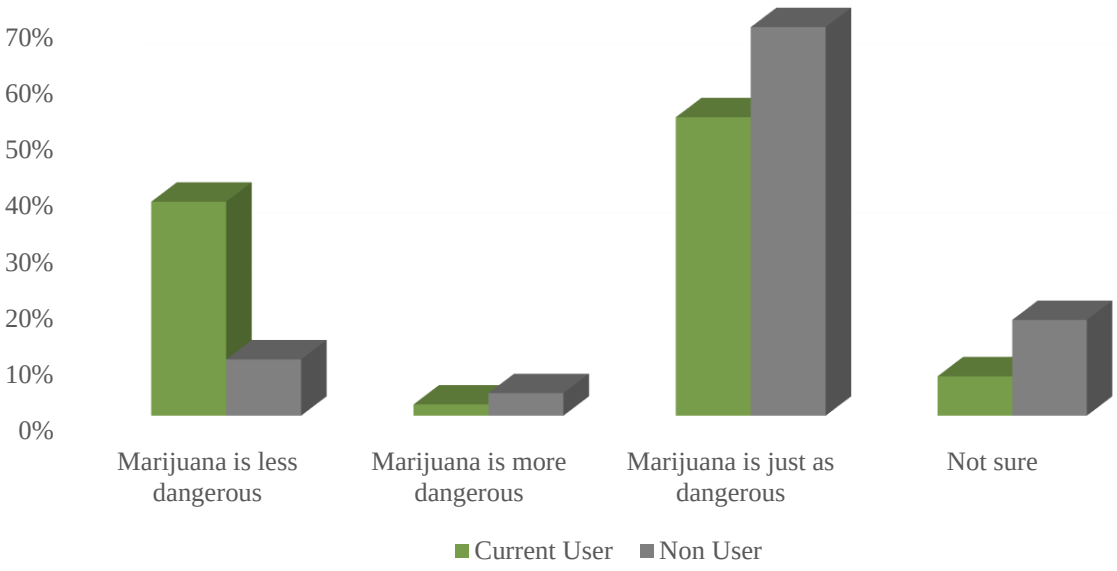
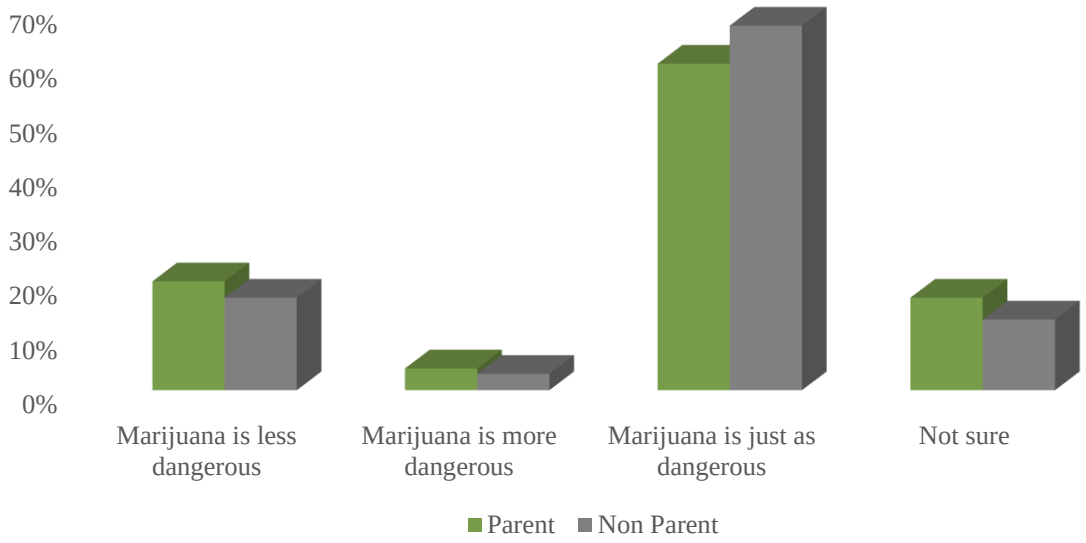
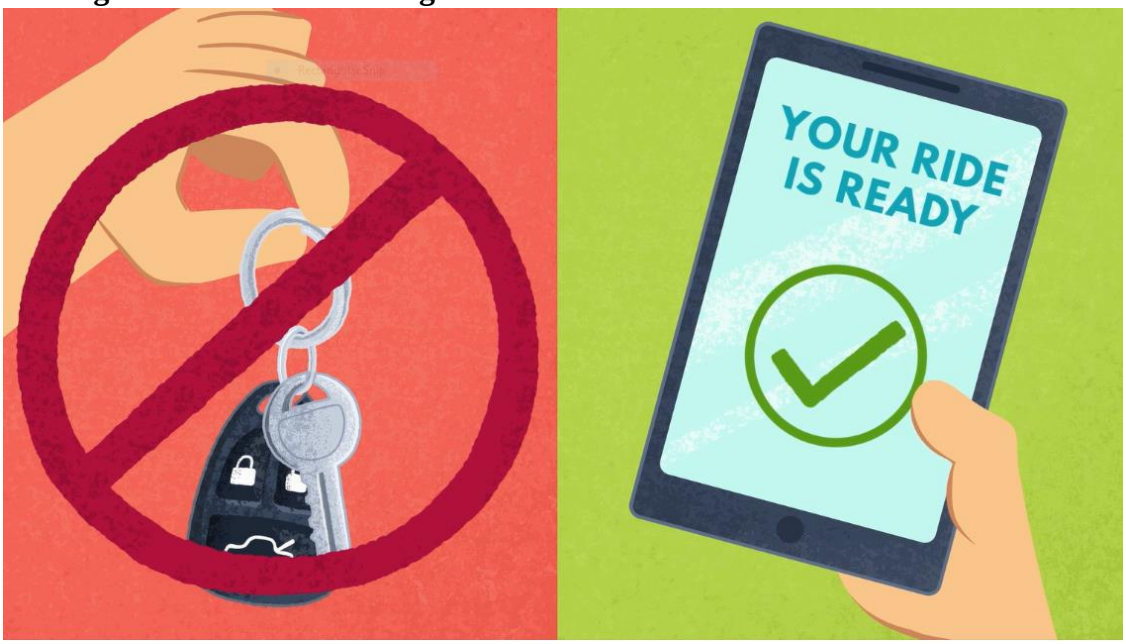


Chart VII.D.5. Perceived Risk of OUI by "Parent Status."
Sample: 2,370 adult (21≤) Massachusetts residents, May 2018.



Graphic VII.D.1: Example of Massachusetts's public awareness campaign frame relating to education on driving after cannabis use.

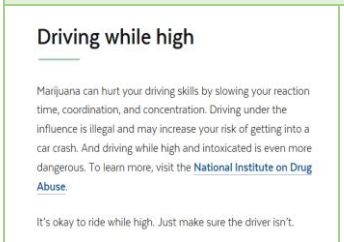


Public Awareness Campaign Effectiveness

The evaluation of public health prevention tools to prevent harmful behaviors, such as cannabis-impaired driving, is essential to assess effectiveness (*e.g. merit, worth, and significance)*.[56] In this regard, the public awareness campaign conducted a pre-implementation survey in a representative sample of Massachusetts residents to compare to a post-survey, which will be implemented in winter 2019, post-public awareness campaign implementation.

Additionally, the *More About Marijuana* campaign is monitoring the online traffic to campaign materials and sites to assess public interest and effective programming [See information about Public Awareness Campaign website traffic in Table VII.D.3. below].

Table VII.D.3. Massachusetts public awareness campaign traffic, July 1-October 25, 2018.

Website (Picture)	Website (Link)	Page Views	Unique Page Views	Average Time on Page
Public Awareness Campaign Website: General: "What's Legal"				
	https://www.mass.gov/info-details/cannabis-in-massachusetts-whats-legal	13,770	12,608	3 minutes and 46 seconds
Public Awareness Campaign Website: General: "Responsible Use of Cannabis", including: "Driving While High" tab				
	https://www.mass.gov/info-details/responsible-use-of-cannabis	964	910	1 minute and 58 seconds

VIII. Data Limitations and Future Direction

It is imperative for states to assess the trends of cannabis-impaired driving, adverse outcomes, and best practices for detecting cannabis-impairment, including available resources for local and state law enforcement agencies (LEAs) to confront this potential public safety threat. Quantitative data used in this "baseline" report specific to assessing cannabis-impaired driving included the Massachusetts State Police (MSP) Operating under the influence (OUI) data, 2007-2017 and the Massachusetts Drug Recognition Expert evaluations and trainings, 2010-2017.

Data to Assess Cannabis-Impaired Driving

(1) Massachusetts State Police Data

This report used MSP OUI data from 2007-2017 to assess retrospective OUI-Alcohol and OUI-Drug cases. As previously discussed in *VI. Baseline Data,* subsection: *Massachusetts State Police (MSP) Operating under the influence (OUI) data*, the current limitation with MSP OUI data is the category of OUI classifications: OUI-Alcohol and OUI-Drugs. The OUI-Drugs category does not further stratify out by drug category (*i.e. central nervous system [CNS] depressants, CNS stimulants, hallucinogens, dissociative anesthetics, narcotic analgesics, inhalants, and cannabis*) or specific drug(s) under these categories (*e.g. Valium, Cocaine, Ecstasy, Vicodin etc.*), thus, this report was unable to discern "cannabis" from any other drug use for OUI-Drug cases.

The non-medical adult-use of cannabis is now legal in Massachusetts. To monitor changes in cannabis-impaired driving, LEAs under the direction of The Executive Office of Public Safety and Security (EOPSS), should systematically change the mechanisms for coding OUIs to additionally include a subsection for 'Cannabis' (in addition to 'Alcohol' and 'Other Drugs'). Systematic and mandatory changes to the system that stratifies out categories of impairing drugs ("substances") is imperative for research to assess changes in cannabis-impaired driving. Additionally, if there are multiple substances of impairment in an OUI case, these systematic and mandatory data collection mechanisms should include a mandatory designation of the primary and secondary drug category of impairment (*e.g. Two substances in OUI case: Alcohol [primary], Cannabis [secondary*]). These changes in stratification would permit the monitoring of cannabis-impaired and co-use (also referred to as poly-use) substance-impaired driving trends. These analyses will be included in future reports.

(2) Municipality Data

This report includes municipality data in the form of a primary collected survey sent to all municipality LEAs in June 2018. As previously discussed, the goal of this survey was to assess the existing procedures used and resources accessible to local LEAs and the MSP to detect cannabis-impaired driving, especially regarding Drug Recognition Expert (DRE) and Advanced Roadside Impaired Driving Enforcement (ARIDE)-trained law enforcement officers (LEOs) on

staff and/or availability and use of DREs via other LEAs. It is important for the Commonwealth to understand the best practices and available resources for local and state LEAs. Collaborating with local municipality LEAs will permit the assessment of cannabis-impaired driving at the local level and inform effective collaboration with law enforcement to ensure LEAs are well-equipped to confront this potential public safety threat in their jurisdiction(s). The Research Department seeks to collaborate with interested municipality LEAs and continue to work with the MSP to assess cannabis-impaired driving cases. These analyses will be included in future reports.

(3) Law Enforcement Trainings and Drug Recognition Expert Data

This report includes data provided by the Massachusetts Drug Recognition Expert Coordinator, Sergeant Don Decker, DRE, that is mandated by and annually reported to the International Association of Chiefs of Police (IACP). This report provides a general overview on a range of data pertinent to the assessment of and mechanisms to combat cannabis-impaired driving, including the annual: (1) Number(s) of operational DRE evaluators, instructors, and law enforcement agencies with certified DREs; (2) Total number of drug evaluations and drug category of evaluations, and (3) Number(s) of law enforcement and professional trainings hosted to prepare varying law enforcement and other front-line workers to discern cannabis-impairment. This is helpful to assess the resources available for law enforcement and related professionals to detect cannabis-impairment on the roadways and potentially prosecute OUI cases. These analyses will be included in future reports.

Potential Datasets for Future Reports

(i) Fatality Analysis Reporting System (FARS)

The most severe consequences of impaired driving are death and disability. The National Highway Traffic Safety Administration's (NHTSA) Fatality Analysis Reporting System (FARS) data is an annual nationwide census monitoring fatal injuries resulting from motor vehicle traffic crashes.[57] This data includes information from all states; However, there is important variability in states testing rates, the drugs that are tested for, testing protocols and threshold values, as well as changes to processes over time.[58] FARS data contains multiple variables which may assist researchers in assessing drug involvement in fatal crashes, including: (1) Tests Status (*i.e. if someone was tested for drugs*), (2) Test Type (*i.e. type of test if one was given*), and (3) Test Result (*i.e. if and what drugs were found*).[59]

Any research using FARS must be considered in the light of its limitations. Cannabis positive drivers cannot be assumed impaired, rather detection is only evidence of past use.[60] Drug test results include both illicit and licit drugs (*i.e. prescription medications*), which may not have been misused. FARS only reports drug presence not concentration,[61] biological matrices used to test for drugs and thresholds ("cut-off") levels for determining a positive test are unknown,[59,61] drug testing is not a uniform process[62] and differing state and local policies and practices

regarding drug tests can introduce inconsistencies into the data,[59] sample differences in who are drug tested (*i.e. only deceased drivers*),[60] drivers are more likely to be drug tested if there is evidence of use,[60] drivers are less likely to be drug tested if alcohol is detected,[60] and most drivers are not drug tested.[60] Additionally, police accident report processes vary across jurisdictions, which results in reporting differences, and possible variation in the reported number of crashes involving drug-impaired driving.[59] Slater et al. 2016 suggest that testing rates may be improved through standardization and mandatory testing policies—but cautioned researchers about the limitations of using currently available data to quantify drug-impaired driving.[63]

FARS will be assessed as potential data to assess cannabis-impaired driving, death, and disability, in Massachusetts in future reports.

(ii) Youth Risk Behavior Surveillance System (YRBSS) and Behavioral Risk Factor Surveillance System (BRFSS)

The YRBSS and BRFSS are two national and state collected datasets used to assess health and risk behaviors that contribute to the leading causes of death and disability. The YRBSS is a school-based survey of both middle school and high school students. The BRFSS is a telephone survey of adults 18≤. Both the YRBSS and BRFSS surveys utilize a standardized core questionnaire (*i.e. survey questions asked to all survey participants in all states*), optional models, and state-added questions.

The standardized BRFSS questionnaire includes specific measures on tobacco and alcohol consumption behaviors and added measures on cannabis use in the 2017 questionnaire, including: past 30-day ("current") use of cannabis, past 30-day mode of cannabis use (*i.e. smoke, eat, drink, vaporize, dab, other method of consumption*) and reason for past 30-day cannabis use (*i.e. medical, non-medical, or both*). Limitations include: (1) the lack of ability to compare these consumption rates to prior years of data collection, when these measures on cannabis were not asked and (2) lack of measures to assess driving a car after cannabis use or driving in a car with a driver who had recently used cannabis.

The standardized YRBSS questionnaire also has specific measures on tobacco, alcohol, and cannabis use behaviors. Regarding cannabis use monitoring, the YRBSS has historically measured cannabis consumption behaviors, including: lifetime ("ever") and past 30-day ("current") cannabis use, frequency of use, and age of cannabis use initiation. In recent years, an additional measure to assess use of synthetic cannabis (*e.g. Spice, K2 etc*.) was added. The YRBSS also has specific measures assessing past 30-day driving after alcohol use and riding in car with someone who had been drinking, but unlike the BRFSS, in 2017, the YRBSS included a measure specific to driving after cannabis use, but does not have a measue to assess riding with someone after their recent cannabis use.

These national-level and state-level surveys are routinely used for health behavior surveillance and monitoring; However, they are not without limitations. Any self-report data include threats to validity and recall bias. Since measures are subjectively answered in surveys ("self-report"), respondents may not answer questions honestly given the nature of the question(s) or not answer accurately because of memory recall. Additionally, these surveys are cross-sectional (vs. longitudinal), thus, analyses only permit a snapshot overview of the prevalence of behaviors during specific years rather than a view of how behaviors change over time (causal) for Massachusetts youth and adult cohorts.

In order to adequately and comprehensively assess the scope of cannabis consumption and driving behaviors, data measures that capture these phenomena are needed. Under the direction of the Massachusetts Department of Public Health (DPH) for the Massachusetts-BRFSS and the Massachusetts Department of Elementary and Secondary Education (DESE) for the Massachusetts-YRBSS, Massachusetts should add survey measures to specifically capture both cannabis-impaired driving and riding behaviors in both adult and youth cohorts. If measures are added to one or both the BRFSS and YRBSS questionnaire(s), these analyses will be included in future reports.

(iii) The Department's Office of Emergency Medical Services (OEMS) Massachusetts Ambulance Trip Record Information System (MATRIS).

The Massachusetts Department of Public Health (DPH) notes that research is one of the primary purposes of the Emergency Medical Services (EMS) data collection processes. Part of these data collection mechanisms are the Massachusetts Ambulance Trip Record Information System (MATRIS), a system that DPH has found helpful for policy development and research.[64] Currently, MATRIS does not systematically collect data on cannabis-suspected impairment. If cannabis-impairment data are added to the MATRIS data collection mechanisms, these analyses will be included in future reports.

(iv) Future Direction

In future reports, the Cannabis Control Commission Research Department will:

(1) Continue to collaborate with the MSP and DRE Coordinator to assess and report MSP and DRE data;
(2) Collaborate with and report on any available municipality OUI data;
(3) Assess Massachusetts FARS data and potentially report on fatalities as reported by FARS;
(4) Assess any Massachusetts's OEMS MATRIS data; and
(5) Assess any related YRBSS and BRFSS measures as necessary and pertinent to the report on cannabis-impaired driving.

IX. Clinical Indicators

Cannabis: Acute Effects

The National Institute on Drug Abuse (NIDA) states that cannabis significantly impairs judgment, motor coordination, and reaction time[65–67] and driving after use significantly increases the crash risk, a risk that is even greater when cannabis is combined with alcohol use (referred to as either *"co-use*" or "*poly-drug use"*).[29] The effects of cannabis intoxication may vary depending on method of consumption ("mode of administration") (*i.e. vaporizing, edible etc., which may differentially affect absorption rate*), the cannabinoid composition and potency in the product consumed, and a person's: tolerance, environment, and personality.[68] Cannabis use has both acute and long-term effects. For purposes of this report, only acute effects, which potentially influence a person's ability to operate a motorized vehicle safely, are discussed.

The acute psychological effects of cannabinoids vary and include euphoria, dysphoria, sedation, and altered perception[69] to anxiety, fear, and panic.[70] Cannabis's chemical structure and THC alters normal brain communication pathways which send chemical messages throughout the nervous system and influence pleasure, memory, thinking, concentration, movement, coordination, and sensory time and perception.[71] Cannabis affects the brain areas (*i.e. cerebellum and basal ganglia*) that regulate balance, posture, coordination, and reaction time—areas that may impair one's ability to safely operate a motorized vehicle.[71] Additionally, large doses of THC may potentially cause acute psychosis, including: hallucinations, delusions and a loss of sense of personal identity.[71] While cannabis's acute intoxication that may impair one's ability to drive safely is temporary, THC may be detectable in the human body for days and weeks post-intoxication,[70] posing a law enforcement issue for testing for cannabis metabolites to infer acute impairment. It is important to note that there is research assessing chronic cannabis use and driving safety; However, this area of research is not discussed for purposes of this report. Discerning acute impairment is further complicated by varying methods of cannabis use consumption, which have increasingly diversified in recent years and can differentially affect acute intoxication.[72]

The American Psychiatric Association's Diagnostic and Statistical Manual of Mental Disorders 5th Edition (DSM-5) provides a systematic, evidence-based standard for the diagnosis of ten classes of drugs and their associated use disorders (substance use disorders [SUDs]), including cannabis use disorders (CUDs).[73] SUDs are broadly defined as patterns of symptoms which result from a substance that a person continues to consume despite experiencing problems due to its use. For cannabis use specifically, this includes: (1) Cannabis Use Disorder, (2) Cannabis Intoxication, (3) Cannabis Withdrawal, (4) Cannabis-Induced Mental Disorder, and (5) Cannabis-Induced Physical Disorder. Important for purposes of this report are the clinical indicators for cannabis intoxication [See Table IX.1. below].

Table IX.1. Cannabis Use Disorders: Cannabis Intoxication indicators, DSM-5

- Recent use of cannabis
- Clinically significant problematic behavior or psychological changes (e.g. impaired motor coordination, euphoria, anxiety, sensation of slowed time, impaired judgment, social withdrawal) that develop during, or shortly after, cannabis use.
- Two or more of the following signs or symptoms developing within two hours of cannabis use:
    - Conjunctival injection ("red eye")
    - Increased appetite
    - Dry mouth (*i.e. a condition in which the salivary glands in your mouth don't make enough saliva to keep your mouth wet*)[74]
    - Tachycardia (*i.e. a condition that makes your heart beat more than 100 times per minute*)[75]
- The signs or symptoms are not attributable to another medical condition and are not better explained by another mental disorder, including intoxication with another substance.

X. Trends in Operating Under the Influence of Cannabis

This section is not a comprehensive literature review, rather an overview of the relevant literature focusing on papers published in the last five years with U.S. prevalence data. It aims to provide a scope of the literature and highlight challenges with data collection.

National Trends

Directed by the Substance Abuse and Mental Health Service Administration (SAMHSA), The National Survey on Drug Use and Health (NSDUH) is a yearly survey conducted in all 50 states.[76] NSDUH reported that in 2017, 22.1% of adults aged 18-25 and 7.9% of adults aged 26 years-old or older were past month ("current") cannabis users, an increase from years 2002-2016.[77]

Rates of Use (Prevalence)

It is challenging to determine accurate rates of driving under the influence of cannabis. Self-report and random roadside samples are independent ways to understand the scope of the issue. However, each are subject to limitations.

Self-Report and Study Design Considerations

Self-report indicates that an individual answers questions for themselves via a survey, in-person, or other mechanism. Answers may be, but are not always, validated by alternative or additional measures. Limitations include social desirability bias, where people report in a way that is socially acceptable rather than accurate. Recall bias may also contribute to inaccurate results if participants remember incorrectly. Self-report data may also be cross sectional (*i.e. occur at one time point rather than over a period of time*) and retrospective (*i.e. occur after the fact*). For example, differences in stigma before and after legalization make it difficult to compare to pre-legalization samples to post-legalization samples as people may be more likely to admit use after cannabis is legal.

It is also difficult to look across studies due to different sample types (*e.g. young adults, all adults over 18*) and different outcomes. Convenience samples are non-representative samples that are easier and less-resource intensive for researchers to access; However, any findings may not be generalizability to larger populations of interest. Studies also define driving under the influence of cannabis differently (*e.g. did you drive within two hours of smoking cannabis,*[78] *did you more than once drive a car, motorcycle, truck, boat, or other vehicle when you were under the influence of a medicine or drug? Which medicines or drugs? etc.*).[79] Cannabis use also tends to be defined more broadly in surveys making it difficult to compare between method(s) of consumption and amount consumed.[78]

Driving/Operating Under the Influence of Cannabis

This section looks at prevalence of driving under the influence of cannabis (DUIC) in the United States (U.S.) as measured through studies using self-reported data. In Massachusetts, driving under the influence is referred to as operating under the influence (OUI). This section is limited to only DUIC research.

Using the Substance Abuse and Mental Health Services Administration's (SAMHSA) National Survey on Drug Use and Health (NSDUH) self-report data, Azofeifa et al. 2015 found DUIC was reported by 3.1% of the 16-20 year-old cohort and 3.3% of the 21-25 year-old cohort in 2014. In comparison, driving under the influence of alcohol was 6.6% for the 16-20 year-old cohort and 18.1% for the 21-25 year-old cohort in 2014.[80]

In a national epidemiological survey of adults 18 years-old and older, the National Epidemiologic Survey on Alcohol and Related Conditions (NESARC), Le Strat et al. 2015 found that 5.15% of respondents who had ever used cannabis reported DUIC.[79] Using a national survey from AmeriSpeak Panel, Ward et al. 2018 found that the general DUIC prevalence was 8.5%, with the 18-29 year-old cohort reporting DUIC at higher rates.[81]

In a nationally representative sample, the Next Generation Health Study of young adults one-year out of high school, Li et al. 2016 found that: 5.02% reported DUIC, 2.41% reported driving under the influence of cannabis and alcohol combined ("co-use" or "poly-use"), and 4.34% reported driving under the influence of alcohol.[82]

In a sample of cannabis-using college students, Whitehill et al. 2014, found that 43.9% of men and 8.7% of women reported driving after cannabis use.[83] In a survey of college students, Glascoff et al. 2013 found that over 60% of cannabis users reported DUIC and 40% reported driving after co-using cannabis and alcohol.[84] In a convenience social media sample of an 18-34 year-old cohort targeting tobacco and cannabis users, Berg et al. 2018 found that 48.4% reported driving after cannabis use once or more in the last month.[85] In an online convenience sample of Colorado and Washington cannabis users, Davis et al. 2016 found that 43.6% reported DUIC and 23.9% reported driving within an hour after cannabis use five or more times in the past month.[86] In a 2015 ConsumerStyles survey of adults over 21 years-old, Jewett et al. 2018 found that 31.6% of those who reported cannabis use reported DUIC.[87]

Riding with Someone Under the Influence of Cannabis

This section looks at prevalence of riding with a driver who is under the influence of cannabis (RUIC) in the U.S. as measured through studies using self-reported data.

In a sample of cannabis-using college students, Whitehill et al. 2014, found that 51.2% of men and 34.8% of women reported RUIC.[83] In this sample: being male, driving after cannabis use themselves, and having more friends that use cannabis were associated with greater risk.[83] Those who reported always wearing a seatbelt in the car were associated with a lesser likelihood of RUIC.[83] In an ethnically-diverse online sample, Whitehill et al. 2018 found that 36.4% of

participants and 80.1% of cannabis users reported RUIC in the last month.[88] Of cannabis users only, 48.3% reported both RUIC and DUIC.[88]

In a convenience social media sample of an 18-34 year-old cohort targeting tobacco and cannabis users, Berg et al. 2018 found that 74% of respondents reported RUIC in the last month.[85]

Random Roadside Testing

Random roadside sampling refers to stopping cars at random and testing drivers for evidence of substance use. In this section, cannabis use is specifically assessed. There are inherent limitations in the biological matrices used to find evidence of cannabis. Importantly, impairment cannot be inferred from detection of THC, thus, findings do not indicate the percentage of cannabis-impaired drivers, rather they detect the percentage of drivers who have used cannabis and may or may not have been acutely impaired. While random roadside studies aim for a true random and representative sample of drivers, this does not always occur. [See Sections: *XIII. State of Science: Detecting Impairment* and *XIV: State of Science: Detecting Cannabis Cannabinoids* for additional information].

In the 2013-2014 National Roadside Study of Alcohol and Drug Use, 12.6% of drivers were THC-positive, which was a 48% increase from the prior data collection in 2007.[89] In a random roadside oral fluid, breath, and survey study in California, Johnson et al. 2012 found that 8.5% of weekend night drivers were THC-positive with significant regional variability in 2010.[90] In a follow-up study with one regional sampling difference, Pollini et al. 2015 found no change in rates between 2010 and 2012, with 9.2% of drivers testing THC-positive.[91]

Risk Factors

Understanding factors that are associated with or predictive of DUIC are important to understand the scope of the problem and to target effective solutions.

Perceived Dangerousness of DUIC

Several studies found that when DUIC is perceived as more dangerous, people were less likely to DUIC.[78,86,92] Arterberry et al. 2013 found that college students who perceived DUIC as more dangerous were less likely to report DUIC and RUIC.[78] Aston et al. 2016 also found that frequent cannabis users who perceived DUIC as dangerous were less likely to drive after smoking or to smoke while driving.[92] In an online convenience sample of Colorado and Washington cannabis users, Davis et al. 2016 found that perceived dangerousness of DUIC was associated with lower odds of DUIC and its frequency.[86]

Other Risk Factors

Other risk factors identified as associated with DUIC include: more frequent cannabis use,[83,85,88] earlier cannabis initation,[79,83] being male,[84,88] having ridden with a cannabis-using driver,[83,88] being younger,[85] greater friend cannabis use,[85] less concern related to driving after use,[85] not perceiving friends as disapproving of DUIC,[92] having more than a high school education,[88] prior

driving after drinking behavior(s),[83] finding driving after cannabis use enjoyable,[81] believing "*it is up to me whether I drive or not after using marijuana*,"[81] general risky or dangerous driving behaviors,[93] negative emotional driving,[93] being a heavy plant user,[94] and being a plant and concentrates user.[94] Krauss et al. 2017 found that light cannabis users and edible (cannabis) users were less likely to drive after use.[94] Ward et al. 2018 found that people were less likely to DUIC if they believed people important to them would be disappointed if they did.[81] Whitehill et al. 2018 found no difference in DUIC or RUIC likelihood by race or ethnicity.[88]

In an online convenience sample of Colorado and Washington cannabis users, Davis et al. 2016 found increased knowledge of DUIC laws were associated with lower odds of "ever" and "frequent" DUIC; However, perceiving DUIC as unsafe was the greater predictor in likelihood of driving.[86] In this sample, increased knowledge of DUIC laws were not associated with a decreased openness to DUIC.[86]

In a sample of 18-25 year-olds presenting in an emergency room, Bonar et al. 2018 found that the most frequent reasons for driving under the influence of drugs were needing to get home, thinking drugs did not affect driving, having a short distance to go, and not feeling high.[95]

Alcohol Co-Use Prevalence Data

Using NSDUH self-report data, Azofeifa et al. 2015 found that the prevalence of driving under the influence of alcohol and cannabis together ("co-use" or "poly-use") was 1.4% for a 16-20 year-old cohort and 1.9% for a 21-25 year-old cohort in 2014.[80] In this dataset, Azofeifa et al. 2015 found that rates of driving under the influence of alcohol and driving under the influence of alcohol and cannabis combined declined from 2002-2014; However, driving under influence of cannabis rates stayed the same for the 16-25 year-old cohort.[80]

In a 2015 ConsumerStyles survey of adults 21≤, Jewett et al. 2018 found that of those who reported co-use of cannabis and alcohol, 10.8% reported driving under the influence of both substances combined.[87]

XI. Risks and Mechanisms

Cannabis Use and Driving Risk (Metanalyses)

Meta-analyses combine data from multiple studies and analyze the data in aggregate. They are helpful to look across study findings but are subject to the limitations within the compiled studies. Heterogeneity, including different samples and different outcomes may muddy results if there are differences between groups ("cohorts") or outcomes. Meta-analyses can also be compromised by publication bias if certain findings are more likely to be published than others. This section includes meta-analyses that examined associations between cannabis use and negative driving outcomes. Drivers who tested positive for cannabis cannot be assumed as impaired at the time of the test due to limitations of blood, urine, and oral fluid testing. In this literature, there is also concern about choosing the correct control group(s), assessing comparable outcome measures, and choosing the best statistical models.[96]

Several meta-analyses examined risks between cannabis use and negative driving outcomes.[96–100] Two meta-analyses examining cannabis use and motor vehicle crashes found that cannabis use was associated with an approximate doubled risk of crash.[97,98] However, a replication of both studies identified methodology problems,[b] which may have led to an overestimation of risk.[100] Rogeberg and Elvik et al. 2016's meta-analysis found a statistically significant increase in the odds of crash but a lower risk than earlier studies (*random-effects model [Odds Ratio (OR): 1.36 [Confidence Interval (CI): 1.15-1.61}, meta-regression (OR: 1.22 [CI: 1.1-1.36]).*[100] This finding was revised to a slightly lower but significant effect (*random effects model OR: 1.32 [95% CI = 1.09, 1.59])* after errors were identified.[101,102] Hostiuc et al. 2018's meta-analysis did not find an association between cannabis use and negative driving outcomes (in adjusted odds ratios analyses), but did find associations in subgroup analyses.[96] Hostiuc et al. 2018 also found evidence of publication bias in the literature where findings with negative driving outcomes were more likely to be published.[96]

In an innovative analysis (not a meta-analysis), Wettlaufer et al. 2017 compiled Canadian data sources to create cannabis-attributable fractions that estimated the cost(s) of cannabis in traffic crash data.[103] Researchers found cannabis was responsible for: 75 fatalities, 4,407 injuries, and significant property damage costs in Canada in 2012.[103] Youth and young adults made up a greater share of costs relative to group size.[103]

[b] This paper found Li et al.'s study (2012) pools "qualitatively different types of associations" and found Ashbridge et al. (2012) pools case-control and culpability studies which "yield incompatible estimators" (Rogeberg & Elvik, 2016).

Post Legalization Samples (Difference-in-Difference with FARS data)

Studies using difference-in-difference analyses examine a variable before-and-after an intervention. An important assumption in these studies is that the group with the intervention and group without would display parallel trends if neither received the treatment. For example, a study analyzing cannabis use in two states where one legalizes adult-use cannabis and the other does not, assumes if neither legalized the rates of use would change at the same rate between the two states. Factors that contribute to policy change, such as public perceptions in one state, may cause this assumption not to be met.

Several recent studies examined rates of negative driving outcomes before and after medical cannabis or adult-use cannabis law(s) were legalized compared to control states. However, analyzing policy impacts will take time and little can be said about long-term effects of adult-use cannabis legalization on impaired driving to date. There are also significant concerns with the use of Fatal Analysis and Reporting System (FARS) data for such analyses. [See Section *VIII. Data Limitations and Future Direction* for additional information on FARS data limitations].

Santaella-Tenorio et al. 2017 examined the association between medical cannabis legalization and state-wide traffic fatalities using FARS data.[104] Researchers found that medical laws were associated with decreases in fatal accidents, although there were heterogeneity between states.[104] Authors proposed that alcohol substitution and increased policing were potential mechanisms for these initial reductions.[104] Importantly, only associations and not causation were examined, and the time frame was short.[104] Anderson et al. 2013 also compared total traffic fatalities (FARS data) between states with medicinal cannabis and without.[105] Authors found that legalization was associated with an approximate 10% decrease in weekend traffic fatality rates.[105] Authors suggest alcohol substitution was a possible mechanism.[105]

Salomonsen-Sautel et al. 2014 examined the fatal crashes between Colorado and control states before and after medical cannabis legalization with FARS data.[106] Authors found that more drivers in Colorado tested positive for cannabinoids in blood or urine after a fatal crash compared to states that did not legalize.[106] However, a positive test does not mean drivers were impaired at the time of crash.[106]

Hansen et al. 2018 used a synthetic control method to examine whether adult-use cannabis legalization in Colorado and Washington caused additional cannabis-related, alcohol-related, and overall traffic fatalities with FARS data.[107] Authors found no difference between cannabis-related, alcohol-related, and overall fatal crashes—although authors observed a trend toward more cannabis-related fatal crashes in Colorado and Washington compared to their controls.[107] Aydelotte et al. 2017 examined total fatal crash rates before and after adult-use legalization in Washington and Colorado to non-legalized states using FARS data.[62] Authors found no difference between crash fatality rates in Colorado and Washington compared to control states in the three years after adult-use legalization.[62] Long-term effects of adult-use laws and impaired

driving are unknown and will require time ("lagged effects"), consistent monitoring, and research to ascertain.

In addition to FARS limitations, studies had short follow-up times and did not look at local variation or state differences between medical laws (*i.e. heterogeneity inherent in law design*). Studies also only measured associations. Additionally, choosing the correct control group in this type of research is a challenge, thus, it is difficult to make conclusions about the impact of laws on traffic fatalities.[62,104,106]

XII. Social Equity

AIM: This section examines social equity in the context of cannabis policy and adult-use legalization to assess impacts of impaired driving considerations and research on cohorts ("groups") disproportionately affected by prohibition.

Prohibition and Disproportionate Impact

Drug policies and politics in America have historically harmed minority communities.[108] The history of cannabis prohibition in the U.S. emerged in a social political context of temperance, government reform, and racism.[13] Prior to its prohibition, cannabis had long existed in the U.S. with pharmaceutical uses; However, during prohibition, it was politically re-branded as "marihuana," a dangerous drug linked to Mexico and poor Mexican laborers,[14,109] and marked by racist fearmongering (*i.e. the action of deliberately arousing public fear or alarm about a particular issue*)[110] that tied cannabis to non-Whites, and particularly Black men, who were portrayed as violent and immoral cannabis users.[108]

Current drug policies, which stem from the post-Prohibition War on Drugs, operate within a context where historic drug policy choices (*e.g. heavier punishment for crack than powder cocaine which was used more frequently in the Black community than in White;*[109] *minimum drug sentencing*[109]) and political tactics (*e.g. campaign moves that tied Black men to drugs and violence to appeal to Whites*[109]) have had unequal impacts on different racial/ethnic groups.

Specifically, the War on Drugs "Law and Order" (*i.e. politicization of crime*) and "Crime and Punishment" (*i.e. a culmination of fear of street crime that created a "morally and justified" reason for the heavy punitive response to drug crime*) phenomena disproportionately affected minority groups who had been increasingly subject to surveillance and harsher penalties for drug crimes.[18] Harris 2002 reports that the practice of targeting minority groups can be traced back to the War on Drugs, which promoted profiling as an effective tactic to detect drug offenders.[111] Racial profiling has come under scrutiny in conjunction with efforts to increase race/ethnicity data collection by law enforcement; this data collection remains critical.[18] [See Section *III. Brief History of Cannabis Laws* for additional information on the history and progression of cannabis laws nationally and in Massachusetts specifically].

Cannabis Citations and Arrests

Nationally, research shows persisting inequality where Blacks and Latinos are arrested for drug offenses at higher rates than Whites despite similar rates in drug use and sale.[112,113] In Massachusetts, cannabis arrests for possession and sale show disproportionately higher rates for Blacks compared to Whites.[114] An analysis of Federal Bureau of Investigation (FBI) Crime Data by the American Civil Liberties Union (ACLU) found that Blacks were 3.9 times more likely to be arrested than Whites for cannabis possession in Massachusetts in 2010.[115] From 2001 to 2010,

the racial disparity between Black and White arrests increased by 75.4%.[115] A recent update found that Black people in Massachusetts had a 3.3 times higher cannabis possession arrest rate and 7.1 times higher cannabis sales arrest rate compared to Whites in 2014.[114] While Blacks make up approximately 8% of the Massachusetts population, this group made up 24% of cannabis possession arrests and 41% of cannabis sales arrests in 2014.[115]

Driving Stops, Searches, and Arrests

In a comprehensive evaluation of state police data in twenty states from 2011-2015, Pierson et al. 2017 found that Black drivers were stopped at higher rates than Whites relative to driver population, and Hispanic drivers are stopped at similar or lower rates compared to Whites.[116] Of cars that are stopped by law enforcement, Pierson et al. 2017 found that Blacks and Hispanics were more likely to have a negative outcome (*i.e. receive ticket, searched, or arrested*) from stops.[116] In the Massachusetts data, Pierson et al. 2017 found that Black and Hispanic drivers were also more likely to have consented vehicles searches.[116]

Other researchers found that Black and Hispanic drivers were more likely to be stopped for non-speeding offences, vehicle defects, and license/registration checks and Black drivers were more likely to have force used against them.[18] Researchers found that Black drivers were more likely than Whites to be stopped in discretionary searches,[117] but groups differed in whether officers were more likely[117] or equally likely[18] to find contraband in Black stops compared to White stops.

Mechanisms

The mechanisms behind disproportionate effects on predominately Black and Latino communities identified in research include:

1. Intentional bias from police and juries;[109]
2. Implicit bias from law enforcement and juries;[109]
3. Concentrated drug enforcement and police scrunity[112] in inter-city and minority neighborhoods;[109]
4. Racial profiling;[112] and
5. Mandatory minimum sentencing.[109]

Legalization: Progress & Persisting Inequality

In 2009, Massachusetts decriminalized up to one ounce of cannabis, and from 2008 to 2009 there was an 85% decrease in cannabis possession arrests.[115] As a result, Massachusetts had the lowest cannabis possession arrest rate in the country (2010: 18 per 100,000).[115] Despite these decreases, racial disparities persisted and worsened.[115] While the total number of arrests decreased, the difference in arrest rates for Blacks (2010: 61 per 100,000) in comparison to Whites (2010: 16 per 100,000) increased.[115] Pierson et al. 2017 examined the effect of adult-use cannabis

legalization on Colorado and Washington search and misdemeanor rates.[116] In Colorado, only cannabis-related misdemeanors were included in the analysis, while in Washington all drugs misdemeanors were included since the data did not differentiate between drug type.[116] Pierson et al. 2017 found that while the absolute number of searches decreased for all racial cohorts after legalization, the relative difference rate between minorities and Whites remained. In other words, minority drivers continued to be searched at higher rates than Whites.[116]

A 2018 Colorado report, *Impacts of Marijuana Legalization in Colorado,* analyzed cannabis arrests from 2012-2017 and found that overall arrest rates decreased for all groups with Whites experiencing the greatest reduction (-56%), compared with Hispanics (-39%), and Blacks (-51%).[118] Cannabis arrest rates remain unequal.[118] In 2017, Whites had an arrest rate of 118 per 100,000, Hispanics had an arrest rate of 133 per 100,000, and Blacks had an arrest rate of 233 per 100,000.[118] Hispanics and Blacks were also more likely to have an on-view arrest (*i.e. taken into custody and arrested without a warrant based on law enforcement observations*) compared to Whites.[118] Despite overall decreases in juvenile arrest rates, Black juveniles also had a disproportionately higher arrest rate (642 per 100,000) compared to Whites (517 per 100,000) and Hispanics (369 per 100,000) in 2017.[118]

A 2018 report from The Drug Policy Alliance highlights the trend that although the total number of arrests for all racial and ethnic groups decrease following legalization, disparities in the rates of arrests persist.[113] This pattern was identified in Colorado, Washington, Alaska, and Washington D.C. samples.[113] Authors concluded that cannabis legalization can make progress in reducing arrests but law enforcement reform is also needed to decrease persisting disparities.[113]

Policy Options: Considering Unintended Consequences

In considering varying policy considerations to counter cannabis-impaired driving in Massachusetts, a discussion on social equity is warranted. A focus on structural racism in the criminal justice system offers a feasible and promising approach towards advancing and improving equity in minority groups. Inequalities may persist without a vision for equity which includes concrete solutions.[119] Varying mechanisms to prevent or counter this phenomenon may have differential impacts on different racial/ethnic cohorts. Bender et al. 2016 noted detection of use rather than impairment could disproportionally hurt minorities stopped by law enforcement at higher rates.[110] Increased use of DRE and/or ARIDE trained law enforcement may reduce subjectivity in regard to detecting cannabis-impairment, potentially helping bridge the unequal racial divide. However, DRE and ARIDE officers' judgement will always have a level of subjectivity. There is not research available on whether DRE and/or ARIDE officers have equal specificity in detecting impairment (*i.e. accuracy in judging non-drug impaired people, non-impaired)* between minorities and whites. Importantly, if retail stores are concentrated in areas where greater proportion(s) of minorit(ies) reside, law enforcement in these areas may increase arrests and prosecutions of cannabis-impaired driving, affecting these minority cohorts disproportionately in comparison to other racial/ethnic cohorts.

Accountability: Data Collection, Monitoring, and Policy Considerations

Massachusetts codified a commitment to addressing the harms of prohibition through avenues that prioritize and promote participation of disproportionately affected communities in the adult-use cannabis industry. [Please see https://mass-cannabis-control.com/equityprograms/ for more information about social equity programs].

Impaired-driving prevention education must be inclusive, multi-lingual, and reach all affected communities. Preventing cannabis-impaired driving to maximize safety is crucial in places designated as "areas of disproportionate impact" because they may see greater retail store concentrations and potentially greater rates of impaired driving. However, efforts to prevent driving after cannabis use should not result in disproportionate rates of arrests and citations for those disproportionately affected, particularly Black and Hispanic/Latino communities. Data and monitoring will be essential for accountability.

Rates of stops, arrests, citations, and prosecutions for suspected cannabis-related incidents should be comprehensively tracked and monitored by race/ethnicity in the state and all municipality law enforcement agencies. Court decisions and results of law enforcement action should also be tracked and monitored by race/ethnicity. Public awareness and educational efforts (*e.g. vendor training*) should be evaluated to validate their effectiveness in reaching varying racial/ethnic audiences. DRE and ARIDE-trained law enforcement officer rates per municipality should be examined to ensure parity between low-income and disproportionately impacted communities with municipality averages. Additionally, DRE and ARIDE-trained law enforcement officer demographics, including: race/ethnicity should be examined and compared to the overall demographic rates in the department or agency. Law enforcement officers from disproportionately affected communities and racial and ethnic minorities who are interested in DRE or ARIDE training should be prioritized.

XIII. State of Science: Detecting Impairment

Introduction

Driving is a complex task involving comprehensive psychomotor, physical, and cognitive skills. This section is comprised of a series of literature reviews. The review includes other literature reviews and findings from experimental and observational studies. The purpose of this section is to present the current state of science regarding the effects of cannabis on the varying psychomotor, physical, and cognitive skills used while driving.

The section begins by examining studies that have the greatest control over conditions, followed by studies more like real-world driving. First, we review laboratory studies on the psychomotor processes acutely affected by cannabis. Next, we examine laboratory driving simulator studies followed by research studies that measure driving in real-world scenarios. Lastly, we review roadside testing through law enforcement mechanisms and tests (*i.e. standardized field sobriety tests [SFSTs], drug recognition experts [DREs]*) to assess their ability to accurately detect cannabis impairment.

Methods

Targeted searches were conducted in August-November 2018 on PubMed and GoogleScholar and included the terms: “cannabis,” “marijuana,” “THC,” “driving,” “impairment,” “psychomotor,” “cognition,” “driving simulator,” “driving,” “standardized field sobriety test,” “horizontal gaze nystagmus,” “walk and turn,” “one leg stand,” “drug recognition officer,” and “drug evaluation and classification program.” Author reference libraries searches were also conducted.

Academic articles published from 2009 to October 2018 were collected. Highly relevant papers and reports were included through 2005. Articles that only examined chronic or long-term effects of cannabis or only examined synthetic cannabinoids were excluded. The search was limited to human participants and English language papers.

1. What is psychomotor impairment? Why is it important?

AIM: This section synthesizes and builds on previous literature reviews to examine the acute effects of cannabis use on psychomotor and cognitive skills.

Psychomotor behaviors are physical responses that originate from cognitive mental processes. For example, seeing a ball rolling into the road may heighten awareness, (*e.g. is a child following?),* divided attention allows the driver to take in other factors, (*e.g. are there cars on the other side of the road?*), the driver makes a quick decision (*e.g. reduce speed),* then physically reacts (*e.g. puts foot on brake).* Substances that impair any part of the mental or physical processes necessary to safe driving pose a risk.

This section reviews the scientific literature assessing acute effects of cannabis on cognitive and physical processes that relate to driving. Acute effects refer to the short-term impairing effects of cannabis. The period from consumption of cannabis to its (acute) impairing effects does not easily lend itself to a delineated time frame. The method of consumption (*e.g. smoking verses edibles*) affects the time period when acute effects are seen. For these purposes, acute consumption refers to the effects resulting from a single period of consumption.

This section limits itself to acute effects of cannabis since they are the most immediate risk to safe driving. However, there is also concern about the long-term or chronic effects of cannabis use on psychomotor skills, cognition, and driving; However, this area of research is outside the scope of this report, thus, not further discussed.

Methods

The search focused on the acute effects of cannabis on psychomotor skills and cognition. Literature reviews were collected from 2008-November 2018. Experimental and observation studies were collected from 2015 through November 2018, which follows and extends Broyd et al.'s 2016 systematic review that included 105 studies from 2004-2015.[120] Brain imaging studies that only focused on long-term effects were excluded, see Nader et al. 2018[121] for brain imaging review. Reviews focused on medical cannabis were also excluded due to their low numbers, see Gruber et al. 2017[122] and Neavyn et al. 2014[123] for review.

Findings

Six literature reviews were identified, one study[120] was a systematic review and five studies[124–128] were nonsystematic reviews. A range of outcomes were assessed, including: memory,[120,124–128] attention,[120,124–126] motor skills,[120,124,127] executive functioning,[120,124,125,127] inhibition,[120,125] cognition,[120,126] impulsivity,[125,126] learning,[120] reaction time,[127] processing speed,[127] and time perception.[124]

Eight experimental and observational studies were identified.[129–136] Five studies were randomized, blinded, placebo-controlled, cross-over designs.[130,132–135] One study was nonrandomized pre-post design study.[131] Two studies had brain imaging components and primary questions related to cognitive skills and psychotic symptoms and states.[129,130] Only their relevant driving-related and psychomotor findings are discussed.

Samples varied and included: frequent users,[131,133] regular users,[132,135] occasional users,[129,131,133,136] recreational users,[134] abstaining moderate users,[130] and non-cannabis users (fewer than five joints in lifetime).[130] Some researchers looked explicitly at polysubstance users included those who co-used cannabis and cocaine,[135] and cannabis and tobacco.[132] Most sample sizes were in the 20s,[129–133] with the largest sample size being 122.[135]

In these studies, methods of consumption included: smoked,[131,133] oral,[129,130,133,136] and vaporized.[133–135] THC concentrations consumed by participants ranged from 6.9%[131,133] to 12.9%.[134] Outcomes were measured at different times following consumption, including: 55 minutes,[132] one hour,[129,130,134–136] 1.5 hours,[131,133,136] three hours,[134,136] 3.5 hours,[131,133] four hours,[136] five hours,[133,134] 5.5 hours,[131] six hours,[136] eight hours,[136] and 22.5 hours[131] after consumption.

Recent studies assessed the following psychomotor outcomes: divided attention,[131,133,134,136] working memory,[131,132,136] attention,[132,135,136] motor inhibition[129,130] time perception,[133] executive functioning,[135] impulse control,[135] psychomotor functioning,[135] risk taking,[131] impulsivity,[131] verbal memory,[132] and motor impulsivity.[129]

Psychomotor and cognitive tasks to asses these constructs included: divided attention task,[131,135,136] critical tracking task,[131,135] n-back task,[131,132] go/no-go task,[129,130] the Modified Romberg Balance (MBR),[133] one leg stand,[133] walk and turn,[133] time perception through MBR 30 second estimate,[133] Tower of London,[135] stop-signal task,[135] balloon analog risk task,[131] useful field of vision (UFOV),[134] digit symbol substitution,[136] paced auditory serial additional task,[136] and prose recall.[132] [See *Appendix Table 1. Terminology* for descriptions of each of these outcome measures and tests].

Results

Motor Control

Motor control is the ability to execute coordinated body movements. Driving requires motor control and coordination for safe steering, stopping, lane positioning, and more. The critical tracking task is one measure of motor control.[137] This task has participants use a joystick to counteract movements to maintain an on-screen bar in its central location.[127] Researchers measure how frequently control is lost.[135]

Broyd et al. 2016 found evidence of critical tracking task impairment in infrequent users but not in frequent users.[120] Prashad et al. 2017 also reported mixed findings where some studies[137,138] found motor impairment and other studies[131,139,140] observed no impairment.[127] Both studies noted a dose-dependent response to the critical tracking task.[120,127]

In recent studies there are also nuanced findings. Ramaekers et al. 2016 found that cannabis impairs performance on the critical tracking task for frequent and infrequent users.[135] However, Ramaekers et al. 2016 also found an interactive effect where frequent users had less critical tracking task impairment in the cannabis condition, although authors noted that this finding is largely due to placebo performance variation.[135] Desrosiers et al. 2015 found occasional smokers showed impaired critical tracking at 1.5 hours after smoking, but frequent smokers did not show impairment compared to baseline.[131]

Motor Impulsivity and Inhibition

Motor impulsivity and inhibition refer to the ability and failure to stop a pre-supposed action or process.[137] Motor inhibition is important to driving because a driver must be able to make a quick physical reaction to end an ongoing action for any unexpected event (*e.g. stop pushing the gas petal when an animal runs into the road*).

In a literature review, Bondallaz et al. 2016 found dose-dependent impairment in motor impulsivity for both occasional and heavy users.[124] However, Prashad et al.'s 2017 review noted mixed findings where motor impulsivity was found when measured in the stop-signal task but not found when measured through the go/no go task.[127]

The stop-signal task measures motor impulsivity. In this task, participants must make rapid judgments in response to "stop" or "go" visual cues.[135] The main outcome is number of commission errors for stop conditions.[135] Accuracy and reaction time are also measured. Ramaekers et al. 2016 found that cannabis resulted in greater commission errors (*i.e. giving the wrong answer*) in the stop-signal task, indicating motor impulsivity impairment regardless of cannabis use frequency.[135]

The go/no go task measures motor impulsivity and inhibition.[129] In this task, participants had to respond quickly to visual cues. Most cues are "go" cues in which the participants press a left or right button. Fewer clues are "stop" cues in which the person is not supposed to hit anything. Accuracy and reaction time are measured.[129]

Two studies found acute effects of cannabis on motor inhibition errors in the go/no go task compared to placebo.[129,130] Colizzi et al. 2018 found this effect was greater for never users than for abstaining moderate users.[130]

Reaction Time

Reaction time refers to how long it takes a person to respond to a stimulus. An unimpaired reaction time is critical to safe driving particularly when circumstances require a rapid response (*e.g. a car veering into one's lane*). Five studies examined reaction time.[120,124,127,129,132]

Bondallaz et al.'s 2016 review found support for impaired reaction time as a result of acute cannabis consumption.[124] However, Prashad et al.'s 2017 literature review reported mixed results for reaction time impairment across studies.[127] Broyd et al. 2016 found that infrequent users showed dose-dependent impairment for reaction time.[120] Broyd et al. also reported reaction time impairment for occasional and heavy users in the stop-signal task.[120]

The "n-back task" for working memory also measures reaction time. Hindocha et al. 2017, found impairment in the 2-back and not the 1- or 0-back, which suggests an effect of cognitive load on reaction time.[132]

Bhattacharyya et al. 2015 found a shorter response latency or faster reaction time in the go/no-go task compared to placebo.[129]

Executive Functioning

Executive functioning refers to higher order cognitive processes including but not limited to: attention, decision making, risk taking, and memory, all of which are critical to safe driving.[125] Two studies report on executive functioning.[120,135]

Broyd et al. 2016 reported mixed findings for planning, reasoning, interference control, and problem solving with some studies finding impairment and others finding none.[120] Authors suggested that performance may be impacted by cannabis use history, method of consumption, dose, and cannabinoid levels in bloodstream.[120]

One test of executive functioning and planning is the Tower of London.[135] This task asks users to indicate how many steps it would take to rearrange three colored balls into a particular end-result. The number of correct answers are measured.[135]

In a large sample, Raemakers et al. 2016 found that all users showed impairment in the Tower of London task and found no evidence of tolerance for frequent users.[135]

A traffic go/no-go task was used by Anderson et al. 2010 to assess decision making. In this task, participants hit a yellow light and must stop or go through.[141] Hesitation and crossing intersection while the light was still yellow were measured.[141] Anderson et al. 2010 found that cannabis did not have an effect on decision making or hesitation, and both cannabis and placebo groups successfully crossed the intersection while the light was still yellow.[141]

Participant response to an emergency vehicle, dog crash avoidance, and intersection crash avoidance was also measured by Anderson et al. 2010 to assess attention, time perception, and decision making.[141] There were no differences between the cannabis group and placebo for any of these measures.[141]

Attention and Divided Attention

Attention is the ability to concentrate and process information. Divided attention refers to the ability to manage multiple sensory inputs, crucial to safe driving. Six studies examined at least one measure of attention.[120,124,125,131,133,135]

Broyd et al.'s 2016 literature review found support for acute cannabis impairment on focused, divided, and sustained attention.[120] Others report divided attention tasks show impairment in frequent and nonfrequent users, but samples of daily users either found no difference or improvement.[124] Another literature review examined attentional processing, divided and sustained attention together, and found mixed and conflicting results, including: improvement, no difference, and impairment following cannabis use.[125]

Two reviews found evidence of attentional impairment being dose-dependent, which means attentional impairment worsens as THC dose increases.[120,126] Additionally, three reviews note possible tolerance effects for daily users.[120,124,125] Differences in cannabis use rates between samples and different measures of attention may help explain discrepant findings in the literature.[125]

Ogourtsova et al. 2018 used the Useful Field of View (UFOV) task to measure processing speed, divided attention, and sustained attention.[134] This task is validated for crash risk.[134] There are three UFOV tasks (UFOV-1, UFOV-2, UFOV-3) which become increasingly more complex.[134] UFOV-1 is a basic task where participants identify a central object.[134] UFOV-2 is more complex and participants need to identify a central object and peripheral object. UFOV-3 is the most complex and participants need to identify a central and peripheral object but there are distractors on the screen.[134]

Ogourtsova et al. 2018 found no difference in UFOV-1 performance for the cannabis condition at one, three, and five hours after consumption.[134] In UFOV-2, cannabis consumption

individually and order of tasks individually were not related to performance; However those who were three hours post-consumption performed worse than controls when the task was unfamiliar to them.[134] In UFOV-3, cannabis consumption alone and order of tasks alone were also not related to performance, but at three and five hours after smoking, participants performed worse than controls when the task was unfamiliar to them.[134] Authors suggest this indicates that cannabis impairs complex and novel tasks.[134]

The divided attention task asks participants to perform the critical tracking task while also monitoring numbers on a screen and moving their foot off of a pedal each time a target number appears.[135] Tracking errors and correct petal hits are measured.[135]

Ramaekers et al. 2016 found that cannabis impairs both tracking errors and target responses on the divided attention task regardless of use history.[135] Similar to executive functioning, in this large sample, Ramaekers et al. found no tolerance effects for attention based on use history.[135] In a study of infrequent users, Vandrey et al. 2017 found impairment in tracking aspects and reaction time for the middle and higher oral dose, but not lower dose edible cannabis.[136]

Desrosiers et al. 2015 found a difference in baseline between occasional and frequent users where occasional users outperformed frequent users in the divided attention task.[131] Relative to baseline, both groups had more false alarm errors and slower reaction time in the cannabis-condition.[131] Occasional users performed worse than frequent users at 1.5 hours after smoking.[131] There was a non-significant trend where occasional users had fewer tracking errors although more false alarms compared to frequent users.[131]

The one leg stand and walk and turn also measure divided attention, along with other psychomotor skills. [See Section *XIII. State of Science: Detecting Impairment* subsection: *Can Standardized Field Sobriety Tests measure impairment by cannabis? Which parts of the test are more or less effective?* for findings related to these tests].

Decision Making and Risk-Taking

There are mixed and task-dependent results in regard to impairment with decision-making and risk-taking.[125,126] Crean et al. 2011 found evidence that cannabis had some effects on planning and decisions, with speed, accuracy, and latency particularly affected.[125] Broyd et al. 2016 found some evidence of impaired decision-making and risk-taking due to changed sensitivity to reward and punishment; However, this is inconsistent across studies.[120]

One test of risk-taking and impulsivity is the balloon analog risk task. This task shows a balloon on screen and each time the participant clicks, the balloon is digitally inflated a little more. Each click to inflate the balloon earns the participant one cent. Participants aim to inflate the balloon as much as possible without popping it. Participants can stop clicking and receive their money earned at any time. The number of clicks to pop the balloon is randomized. The test is validated and shown to correlated with risk-taking behaviors.[131]

Desrosiers et al. 2015 found cannabis had no effect on risk-taking behavior as measured through the balloon analog risk task.[131]

Cognition

Despite inconsistencies, Prashad et al. 2017 found support that cannabis acutely impairs cognition.[127] Authors suggest mixed results between studies may be partly due to different samples and categorization of users, small samples, other bias, and confounding variables.[127]

The digital symbol substitution task has participants copy an earlier shown pattern and measures cognitive functioning. In a sample of infrequent users, Vandrey et al. 2017 found that the overall percentage correct in the digit symbol substitution task showed impairment compared to baseline following a middle and high-dose edible, but not the low-dose edible.[136]

Time Perception

Two reviews examined the evidence for time perception impairment.[120,124] Bondallaz et al. 2016 found mixed results for time perception impairment.[124] Broyd et al. 2016 noted that there is missing objective evidence to substantiate the subjective effect of cannabis distorting time.[120]

The Modified Romberg Balance (MRB) is used to measure balance and time perception. Participants are directed to stand with feet together, head back and eyes closed, and estimate 30 seconds. Sway, eye tremors, and time estimation are observed.[133] [See Section *XIII. State of Science: Detecting Impairment* subsection: *Step 5 Divided Attention Psychophysical Tests* for more results related to this test].

Newmeyer et al. 2017 found no effect of oral, vaporized, or smoked cannabis on time perception in frequent or occasional users as measured through a 30-second estimation task at 1.5 and 3.5 hours after cannabis consumption.[133]

Impulsivity

In this context, impulsivity refers to uncontrolled and socially unacceptable behaviors.[125] This section is different from motor impulsivity which is discussed in *XIII. State of Science: Detecting Impairment* subsection*: Motor Impulsivity*. Two studies report impulsivity measures.[125,126]

In a review of the acute and long-term effects of cannabis on executive and cognitive functioning, Crean et al. 2011 reported some evidence[137,142] for increased impulsivity after an acute cannabis dose.[125] However in another review of cannabis cognition and addiction, authors reported mixed findings in regard to behavioral inhibition impairment and impulsivity.[126]

Memory

Memory includes the processes of encoding, storing, and remembering information and experiences. There are many types of memory, including: working memory, episodic memory, semantic memory, and spatial memory. Memory is critical to safe driving for a range of processes, including: navigating, remembering rules of the road, and recalling dangerous intersections or curves.

Broadly, Broyd et al. 2016 found evidence of memory impairment with the greatest evidence for verbal learning and memory.[120] Curran et al. 2016 found greatest impairment for "online tasks" such as solving a math problem rather than recalling numbers.[126] Sagar and Gruber 2018 found evidence that THC affects brain processes for memory even when performance impairment was not found.[128] Different authors also noted evidence of tolerance effects[126] on memory and CBD protective effects.[128]

Episodic Memory

Episodic memory is recollection of specific experiences and events including autobiographical events. In a review, Curran et al. 2016 found acute impairment related to episodic memory that is dose-dependent.[126]

The prose recall (subset of Riverhead Behavioral Memory Test) is one measure of episodic memory. In this task, participants hear a passage and recall it immediately and again after a delay.[132] Hindocha et al. 2017 administered two prose recall tasks and found an impairing effect of cannabis for the second story and not the first.[132] The opposite effect was found in placebo condition. This finding indicates that cannabis impairs delayed recall more than immediate recall.[132]

Working Memory

Working memory is the ability to briefly hold and process information while reasoning, comprehending, and learning.[131] Broyd et al. 2016 found mixed results in regards to working memory and suggested differences between the tasks used to measure working memory play a role.[120] Three other review studies also found evidence of acute working memory impairment after cannabis consumption.[124–126]

The spatial n-back test is one measure of spatial working memory. This test has participants identify whether a stimulus matches a stimulus presented in either the previous trial (1-back), two trial previously (2-back) or three trials previous (3-back).[131] This gives researchers the ability to examine if cannabis has greater effects on a more difficult cognitive load. Accuracy, reaction time, and errors are measured.

Desrosiers et al. 2015 found impairment in occasional and frequent users in 1-back reaction time, and 2-back accuracy and reaction time in the spatial n-back task.[131] Hindocha et al. 2017 also found cannabis impaired the 1- and 2-back but not 0-back, indicating a greater effect of cannabis for more complex cognitive loads.[132] This study also found an impairing effect of cannabis on memory manipulation.[132]

Tolerance

Tolerance refers to users showing a more muted effect to a stimulus due to repeated exposure. Understanding tolerance has many implications for increasing road safety and minimizing risks. Frequent users are more likely to drive while high.[143] If tolerance results in less psychomotor impairment, frequent users may be less dangerous drivers than infrequent users. If tolerance effects do not exist, all users may be show equal impairment on psychomotor skills critical to safe driving. Crucially, lesser impairment or not, any impaired driver jeopardizes road safety.

Four reviews suggest the possibility of tolerance effects in one or more outcomes; However, none reach clear conclusions.[120,124–126] Possible tolerance effects are noted for attention,[120,125] motor control[120,126] (critical tracking),[120] motor impulsivity,[124] divided attention,[120,124] memory,[124,126] including: spatial working memory,[120] verbal memory,[120] and time estimation.[120]

Broyd et al. 2016 specifically noted that despite some tolerance to impairment, frequent users still show psychomotor impairment levels that are potentially dangerous for driving.[120]

In contrast, a recent large study examining tolerance specifically rejects any pervasive role of tolerance.[135] Ramaekers et al. 2016 largely did not find tolerance to impairing effects of cannabis on neurocognitive functioning for frequent users.[135] Authors suggest tolerance effects may be found in other studies due to small sample sizes and failure to control for baseline THC use.[135] Authors did note the users in their sample were not as heavy cannabis users as in some other study samples, thus, tolerance effects may exist in extremely heavy daily users.[135]

Alcohol

Two reviews considered the effects of alcohol and cannabis simultaneous use (*i.e. co-use*) on cognitive and physical skills.[120,124] Specifically, studies consider whether effects are additive or interactive. An additive effect of alcohol on cannabis means the two substances produce a level of impairment equal to the combined impairment of alcohol-only impairment plus cannabis-only impairment. An interactive (*i.e. synergetic*) effect means alcohol and cannabis together produce a level of impairment that is larger than the product of their sum.

Bondallaz et al. 2016 presented mixed results between a number of studies as to whether alcohol had interactive or additive effects on impairment when co-used with cannabis.[124]
Broyd et al. 2016 identified inconsistency between studies when dealing with alcohol co-use and suggested further research is necessary to understand whether alcohol had an additive or interactive effect on impairment.[120]

Inconsistencies

Mixed findings abound. Researchers noted many possible reasons for these inconsistencies. Factors include: external factors such as change in cannabis potency over time,[127] research factors, and sample factors. Authors noted the lack of standardized amount and potency of cannabis consumed,[120,125,127,128] chronic user length of time defined differently,[120,125,127] sample bias,[120,127] differences in methods of consumption[127,128] categorization of frequent verses occasional cannabis users,[127] recency of use,[125] uncontrolled confounding variables,[120] different outcome measurements for constructs,[120] and different abstinence periods[127] as relevant factors. Sample level characteristics also play a role. These include age of use onset,[125,128] heterogenous samples,[120] different age samples,[128] all male samples,[120] polydrug confounds,[127] different use-histories,[128] participant comorbidity differences,[128] small sample sizes,[127] and variation in use patterns.[127]

1. What can driving simulator studies tell us about driving under the influence of cannabis?

AIM: This section examines and synthesizes driving simulator studies to measure the acute effects of cannabis consumption.

Driving simulators are laboratory models that researchers use to study driving behavior. Models range in appearance and sophistication. For example, some models include 360-degree screens while others use a projected image. All typically include a steering wheel and petals. The driving simulator allows for precise measurement of relevant driving skills.[67] The main strengths of simulators are their safety and consistency of conditions.[144] This allows researchers to study dangerous scenarios that cannot be tested in real driving conditions. Consistency in conditions allow for more reliable comparisons of the same driving scenarios across different participants and the same person at different times. Simulators also allow for performance measurements that may be unobtainable in a real car.[67]

Weaknesses to consider with driving simulators include external validity and predictive value.[145] External validity includes how well experimental findings match what would occur in the real world. External validity also includes whether the findings in one sample can be generalized to anyone who would fit in that sample. Predictive value is how well the simulator induces real world actions or predicts what would happen on the road.[145] In studies comparing driving simulator outcomes to real driving outcomes there is evidence of relative validity but absolute validity is less clear.[144] Relative validity means how well variables or outcome measures compare to other variables or outcomes measures (*e.g. cannabis affects weaving a certain percentage more or less than alcohol*). Absolutely validity measures whether the effect in the simulator is comparable on absolute terms to the effect in the car (*e.g. cannabis affects weaving by x% in the simulator and y% on the road*).

This section includes driving simulator studies that examined the effects of cannabis on simulated driving and studies that compared cannabis outcomes in the simulators to real world conditions. Studies that examined the acute effects of cannabis on real-world driving only are presented in the following section.

Methods

The search focused on the acute effects of cannabis as measured in driving simulators. Papers that only examined the long-term effects of cannabis and review papers were excluded. In addition, papers that only had a real-world driving condition were excluded.

Findings

Nine experimental driving simulator studies were identified.[65,66,68,134,141,144–147] Two studies compared performance of participants in the driving simulator to a real driving condition.[144,145]

The papers had a range of aims, including: alcohol and cannabis combined effects,[65,66,68,146,147] validating the simulator to real driving,[144,145] effects by THC dose,[68] day-driving verses night-driving,[146] driver age/experience (*e.g. novice verses experienced drivers*),[65,134] effects by THC blood concentration,[148] willingness to drive,[147] sex differences,[141] young drivers,[134] and timing effects.[134]

Most samples were of occasional users.[66,68,141,144,147] Occasional cannabis use (including low-moderate use) classifications varied, including: Less than one time per month,[144] at least one time per month but <10 times per month,[141] one to four times per month,[68,147] one or more in the last three months and three or fewer times per week.[66] Sample sizes varied from 10-20,[66,68,147] 20-30,[144,145] and 45-80.[65,134,146]

Cannabis was most frequently smoked,[65,68,141,144,146,147] but also consumed orally,[145] and vaporized,[66] or otherwise inhaled.[134] The dosage and percentage of THC varied across studies and conditions. THC percentages varied from 12.9% THC[134] to 1.8% THC.[146] The percentage of THC found in cannabis has been increasing, yet the cannabis used in most studies fell below the average 11.8% THC potency in 2014 (as measured in seized cannabis).[149]

The time between cannabis consumption and simulated driving also ranged and occurred between five minutes[65] to five hours after consumption.[134] The simulator condition for the oral dose took place four to five hours after consumption.[145]

Driving simulator quality also varied between studies. Simulators included highly advanced models such as the NADS-1 simulator, which features a sedan in a full-motion dome with 330 degree rotation display[66] and less advanced models including a STI-SIM fixed simulator with a 40 degree visual display.[68,147]

Many outcomes were assessed, including: weaving,[65,66,134,144–147] reaction time,[65,68,134,141,146,147] speed,[65,134,141,146,147] steadiness,[65,66,68,147] inappropriate line crossing,[66,144,146] collisions,[68,146,147] headway distance,[65,146] car following,[145] maximum lateral acceleration,[66] signal errors,[146] sustained attention,[134] stopping space,[146] divided attention,[141] and decision making.[141]

Results

Standard Deviation of Lateral Position (SDLP)

Standard Deviation of Lateral Position (SDLP) measures weaving.[145] It is calculated by taking the difference between the road center and the car center throughout the driving condition.[144] SDLP is shown to be a sensitive measure for driving impairment.[66] Six studies examined SDLP in a driving simulator.[65,66,144–147]

One validation study found that SDLP was larger in the simulator than on the real road;[144] However, the second validation study did not find a statistically significance difference between

SDLP in the simulator and on the road.[145] The study that found a difference in SDLP between simulator and road does not consider the simulator an inaccurate measure, rather, Micallef et al. 2018 proposed that the simulator is more sensitive to SDLP and able to better measure it than in the real-car.[144]

Micallef et al. 2018, found larger SDLP in the THC condition compared to placebo in the simulator and road condition.[144] Veldstra et al. 2015 found that only those with the high dose of THC had greater SDLP compared to placebo in the simulator, but this effect was small.[145] In the most advanced driving simulator study, Hartman et al. 2015 found that cannabis increased SDLP.[66] Lenné et al. 2010 and Ronen et al. 2008 both found that both high and low-dose THC increase lane position variability, but not in a dose-dependent manner.[65,68]

Hartman et al. 2015 found that SDLP is negatively affected in an additive way by the co-use of cannabis and alcohol.[66] In contrast, Lenné et al. 2010 did not find an additive or interactive effect of alcohol on SDLP.[65] Ronen et al. 2010 found no effect of THC or alcohol alone on lane position variability, but found an interaction effect when both substances are consumed.[147]

Speed

Mean speed (*i.e. average speed for the total drive*) and speed variability (*i.e. the changes in speed across the total ride*) play a key role in safe driving. Four studies examined cannabis and mean driving speed.[65,141,146,147] Two studies examined speed variability.[146,147] One study examines lane-keeping speed control.[134]

Lenné et al. 2010 found that high dose cannabis increased standard deviation of speed compared to placebo (average of 0.62 kph faster than placebo).[65] Anderson et al. 2010 found that drivers were slightly slower in the cannabis condition compared to placebo.[141] Ronen et al. 2008 also found decreased speed in the cannabis conditions which was dose-dependent.[68] Ronen et al. 2010 found a slight but an insignificant difference in mean speed between conditions.[147] There was a significant difference with the cannabis group having a slower average speed compared to the 24 hours post-consumption (non-impaired) group.[147] Speed in the cannabis and alcohol combined group did not differ from baseline, and authors suggested that the two drugs counteracted each other.[147]

Ronen et al. 2008 and 2010 found that speed variability was not affected by cannabis condition compared to placebo.[68,147]

Ogourtsova et al. 2018 found no difference in lane-keeping speed control between the cannabis condition and control at one, three, and five hours after cannabis consumption.[134]

Inappropriate Line Crossing

Inappropriate line crossings are incidences where the wheels of a car exit the lane.[144] Three studies examined inappropriate line crossing.[66,144,146]

One simulator to real driving validation study examined inappropriate line crossings.[144] In the real driving condition passing and emergency maneuvers were not included as inappropriate line crosses.[144] The study found inappropriate line crossing were more frequent in the simulator compared to real road condition.[144]

Two studies did not find a difference in inappropriate line crossing or lane departure in the cannabis condition compared to the placebo.[66,144] In contrast, Downey et al. 2013 found straddling the sold line and barrier line occurred more frequently in both high and low-THC conditions with or without alcohol.[146]

Car Following

Car following measures the drivers ability to respond to speed changes of a leading car.[145] Veldstra et al. 2015 measured driver accuracy and reaction time to maintain following distance during speed changes of the leading car during a 25-minute drive.[145]

Veldstra et al. 2015 examined car following in the simulator and on the road and found no absolute differences between conditions indicating it was a valid measure.[145] This study also found no overall differences in car following responses between the cannabis and placebo conditions.[145] In other words, the average gain on the front car were the same in cannabis and placebo conditions.[145] However, there were differences in reaction time to the front cars actions where drivers were slower in the high-THC condition in the simulator compared to placebo and slower in the low-THC condition compared to placebo in real driving.[145]

Maximum Lateral Acceleration

Maximum lateral acceleration is the rate at which a car moves toward one edge of the road. One study measured maximum lateral acceleration in sections without sharp turns.[66]

Hartman et al. 2016 found that maximum lateral acceleration was not affected by cannabis.[66]

Steering Wheel

The steering wheel angle, movement, steadiness, and reaction time can be used to measure stability and safe driving. Five studies measured at least one steering wheel outcome.[65,68,134,147,150]

Hartman et al. 2015 found no effect of cannabis on the standard deviation of steering wheel angle.[66] Anderson et al. 2010 also found no difference in mean or standard deviation of the steering wheel position during a secondary divided attention task.[141]

Ogourtsova et al. 2018 found steering reaction time was no different between the cannabis condition and control at one, three, and five hours after cannabis consumption.[134]

In contrast, Lenné et al. 2010 found steering wheel movements increased in both low and high-dose THC conditions compared to placebo for inexperienced drivers.[65] Ronen et al. 2008 found steering wheel steadiness had greater variability in the low-THC condition but not the high-THC condition.[68] Ronen et al. 2010 found that THC alone did not cause greater instability in the steering wheel, but co-use of alcohol and THC decreased participants' ability to keep the wheel steady.[147]

Headway Maintenance

Headway maintenance is the amount of space left between the front of driver's car and back of the car in front of it. Two studies assessed highway maintenance.[65,146]

Lenné et al. 2010 found that the difference in mean headway distance was always larger for experienced drivers, and dose-dependently increased from both groups placebo distance in low-THC and high-THC conditions.[65] Downey et al. 2013 found that participants in the high dose THC condition left larger headway distance between themselves and the car in front compared to the low and placebo conditions.[146] Authors suggest this findings shows that THC dosage impacts safe distance perceptions,[146] and may be attempts to compensate for impairment.[65] However, Lenné et al. 2010 cited increased speed and driving variability as evidence that compensatory actions do not resulting in better control of the vehicle.[65]

Lenné et al. 2010 found that headway variability increased for high dose THC only.[65] Both measures showed an increase when task demands were greater.[65]

Signaling Errors

Only one study assessed signaling errors.[146] This study found that regular cannabis users had more signaling errors in high-THC conditions than nonregular users; However, the impairment was subtle.[146]

Reaction Time

Reaction time is measured in different ways. Six studies included a measure of reaction time.[65,68,134,141,146,147]

Lenné et al. 2010 measured reaction time with a sign detection task.[65] This task required participants to click a button on the wheel indicating whether any signs that appear during the simulated drive were real or fake words.[65] They observed slower reaction time for the high dose of THC compared to placebo.[65] Ronen et al. 2008 and 2010 also measured reaction time in a secondary task.[68,147] High dose THC resulted in a slower reaction time than placebo sessions.[68] THC alone and in combination with alcohol slightly increased reaction time in the secondary task.[147]

Reaction time can also be measured by time to take off from red light, yellow light, or stop sign. Downey et al. 2013 found that nonregular users were faster to take off than regular users in the high dose THC condition.[146] There were no residual effects on reaction time in the 24-hour follow-up.[146] Anderson et al. 2010 did not find any impaired reaction types or response to a yellow-light task or emergency vehicle in the simulation.[141]

Ogourtsova et al. 2018 measured braking and steering reaction times. Authors found no difference in reaction time between the cannabis condition and control at one, three, and five hours after cannabis consumption.[134]

Collision

Collisions are any accidents or crashes during the driving session. Four studies examined collisions.[68,134,146,147] One study created an overall high/low crash risk variable.[134]

Downey et al. 2013 found no difference in collisions between placebo and THC conditions.[146] Likewise, Ogourtsova et al. 2018 found no difference in obstacle avoidance accuracy or obstacle avoidance crash rates between the cannabis condition and control at one, three, and five hours after cannabis consumption.[134]

In a measure of high or low crash risk, Ogourtsova et al. 2018 found cannabis doubled overall crash risk at one, three, and five hours after cannabis consumption.[134] In this study, high risk was defined as intersection crossing accuracy <100%, obstacle avoidance crash rate >0%, vigilance (sustained attention) <100%, and obstacle avoidance accuracy <100%.[134]

Ronen et al. 2008 did not have the statistical power to report on differences between collisions;[68] However, authors reported a total of 20 collisions, six of which occurred in the high-THC dose, three occurred in the low-THC dose, three participants had a total of four collisions in the alcohol condition, and four collisions occurred in the placebo conditions.[68] Ronen et al. 2010 also did not have the statistical power to find statistical differences in collisions. They reported 11 total collisions, five of which occurred in the THC and alcohol co-use condition, three occurred in the THC-only condition, two occurred in the alcohol-only condition, and none occurred in placebo conditions.[147]

Stopping Clearance Space

Stopping clearance space is the amount of space left between the driver's car and the car in front of them. One study measured stopping clearance.[146] Downey et al. 2013 found that insufficient stopping space occurred more frequently in the high-THC condition with or without alcohol.[146]

Intersection Crossing

Intersection crossing was measured as the number of missed crosses, crashes in intersection, and the time it takes to cross. One study measured intersection crossing.[134] Ogourtsova et al. 2018 found no difference in intersection crossing between the cannabis condition and control at one, three, and five hours after cannabis consumption.[134]

Sustained Attention

Sustained attention or vigilance refers to the ability to concentrate on task over a period of time. One study measured sustained attention.[134]

Ogourtsova et al. 2018 found cannabis-positive users were about twice as likely to be classified as highly vigilant compared to the placebo control condition at one-hour after consumption.[134] This was the one measure where the non-cannabis group had a higher crash risk than the cannabis-positive group.[134] Authors noted that this is consistent with other findings where cannabis-impaired drivers show compensation or overcompensation for their impairment.[134] However, cannabis-positive drivers had worse vigilance than controls at three and five hours after consumption.[134] Authors suggested this may indicate that a different type of impairment occurs later which may be characterized by greater drowsiness or distractibility.[134]

Divided Attention

Divided attention refers to the ability to manage multiple sensory inputs. One study examined divided attention.[141]

The paced auditory serial-addition test is one measure of divided attention or multitasking.[141] Anderson et al. 2010, administered this task during an uneventful section of the simulated drive.[141] Participants were asked to add new numbers to previous numbers heard.[141] Outcome measures were speed, steering position, and reaction time.[141]

Anderson et al. 2010 found that those in the placebo condition showed improvement from baseline scores which they attribute to practice effects.[141] In contrast, those in the cannabis condition did not improve and had no difference compared to their baseline scores.[141] During the task, mean speed decreased in the THC group only.[141]

Overall

The two studies that compare driving simulators to a real-driving condition conclude: the driving simulator tested was sensitive to THC, especially when using higher doses,[145] and that the simulators they tested were good qualitative predictors of real driving.[144] The quality of driving simulators vary so these findings may not generalize to all driving simulators.

Studies that examined whether cannabis causes impairment in the driving simulator concluded that: cannabis impairs driving in simulators,[66,141,144,146] higher doses of THC generally impair more than lower doses,[65,66,68] inexperienced drivers were somewhat more impaired after cannabis doses than experienced drivers,[145] cannabis impairs driving in regular and infrequent users,[146] cannabis impairs lateral control when driving,[66] cannabis may impair driving in recreational users,[68] cannabis impaired drivers did not show practice effects in simulators,[141] and there were no sex differences in THC impairment in simulators.[141]

Studies that examined alcohol and cannabis co-use concluded that alcohol and cannabis together have an additive effect on impairment[66,146] and the greatest impairment occurred in the cannabis plus alcohol condition.[147] Lenné et al. 2010 found no additive or interactive effects of alcohol, but authors indicate inadequate alcohol doses were likely the cause for this finding.[65]

Limitations

Authors noted many potential limitations in studies, including: small sample sizes that limited ability to detect significance,[144] lack of statistical power,[145] not counterbalancing conditions so driving on the road always came before simulated driving,[145] all male sample that may limit generalizability,[144] simulated session did not included unexpected events,[65] difficulty related to alcohol placebo conditions,[147] too low alcohol doses did not result in impairment,[65] frequent and infrequent users were included as one group,[145] and including occasional smokers only.[66]

There are also limitations related to driving simulators, including: less physical cues in driving simulators than real cars,[145] drivers know there is no real chance of injury in the simulator,[145] lack of experience with the simulator,[145] and some people get motion sick in simulator.[145]

Authors also noted that research studies themselves may impact motivation. For example having an instructor in the passenger seat next to driver could motivate the driver to perform better because they are aware of being watched or worse because they know the driver can take over in case of emergency.[145] Being in a research study may also impact motivation as participants know they are being observed which could motivate them to perform well.[66]

2. What can studies of real driving tell us about cannabis and impairment?

AIM: This section examines and synthesizes studies that use real-driving to measure the acute effects of cannabis consumption.

Real driving conditions are the "gold standard" to measure the impact of drugged driving impairment.[144] However, safety, logistics, and cost limit the pervasiveness of such research. Driving simulators are frequently used as they overcome some of these barriers. [*See Section XIII: State of Science: Detecting Impairment*, subsection: *Attention and Divided Attention: What can driving simulator studies tell us about driving under the influence of cannabis?*].

Methods

The search focused on the acute effects of cannabis as measured in real driving conditions. Papers that only examined the long-term effects of cannabis and review papers were excluded.

Findings

Three studies were identified.[144,145,151] All studies had an instructor in the passenger seat able to take over in case of emergency. Two studies compared the performance of participants in the driving simulator to real driving condition.[144,145] Two studies were based on the same experiment and therefore include same sample.[145,151] These two papers examined oral medicinal doses of dronabinol (10mg, 20mg).[145,151] The other study used smoked cannabis.[144] Sample sizes all were between 20-25 participants.

Studies measured the following outcomes: standard deviation of lateral positioning (SDLP),[144,145,151] car following,[145,151] and inappropriate line crossing.[144]

Results

Standard Deviation of Lateral Position (SDLP)

Standard Deviation of Lateral Position (SDLP) measures weaving.[145] It is calculated by taking the difference between the road center and the car center throughout the driving condition.[144] SDLP is shown to be a sensitive measure for driving impairment.[66]

Micallef et al. 2018 found that SDLP increased in cannabis conditions compared to placebo.[144] Veldstra et al. 2015 found that low and high-doses of THC worsened SDLP,[145] and Bosker et al. 2012 found greater impairment for occasional users compared to frequent users.[151] Additionally, Bosker et al. 2012 also found interpersonal variation in heavy users, where some but not all, showed tolerance to impairing effects.[151]

Car Following

Car following measures the drivers ability to respond to speed changes of a leading car.[145] Two studies examined car following.[145,151]

Veldstra et al. 2015 measured driver accuracy and reaction time to maintain following distance during speed changes of the leading car during a 25-minute drive.[145] This study found no main effect of car following reactions between the THC and placebo conditions; However, Veldstra et al. 2015 found that reaction time slowed at the 10 mg dose, but not in the 20mg dose condition in real driving unlike the dose-dependent relationship observed in the simulator.[145]

Bosker et al. 2012 found that time to speed adaptation did not significantly differ between placebo and either dose of THC; However, time to speed adaptation did show greater impairment in occasional users compared to frequent users.[151]

Inappropriate Line Crossing

Inappropriate line crossings are incidences where the wheels of the car exited the lane.[144] One study examined inappropriate line crossings.[144] Micallef et al. 2018 found no difference in the number of inappropriate line crossings from THC to placebo conditions.[144]

Overall

Studies that examined whether THC causes impairment in real-driving conclude that driving is impaired by THC on the road[144,151] and in a dose-dependent way.[151]

Limitations

Authors noted many potential limitations in research and study design, including: small sample size,[144] only male sample which may limit generalizability,[144] and occasional and frequent users in study sample.[145] There were also limitations related to the real-driving, including: real-world circumstances which prevented completion,[144] external variables cannot be controlled in real life unlike in the simulator,[145] and the effect of having an instructor with ability to take control in passenger seat reduces generalizability.[144,145]

3. Can Standardized Field Sobriety Tests measure impairment by cannabis? Which parts of the test are more or less effective?

AIM: This section examines and synthesizes studies that evaluate the validity or presence of acute cannabis impairment through the Standardized Field Sobriety Test (SFST) and its composite tests.

Standardized Field Sobriety Tests (SFST) are typically the first thing a law enforcement officer will do when they suspect impairment in a driver that they have pulled over. The SFST consists of three tests: Horizontal Gaze Nystagmus (HGN), Walk and Turn (WAT), and One Leg Stand (OLS). The SFST was developed by The National Highway Traffic Safety Administration in 1975 to test for alcohol-impaired driving.[152] These tests may be performed by the arresting law enforcement officer or by a Drug Recognition Expert (DRE). Additional tests may be conducted in the field, but they are not formally part of the SFST.[152] [See *Section IV: Law Enforcement Trainings* subsection: *The Standard Field Sobriety Test (SFST) Training* for a comprehensive review of the SFST mechanisms and Section *XIII: State of Science: Detecting Impairment* subsection*: Can Drug Recognition Experts measure impairment by cannabis? Which parts of the process are more or less effective?* for a review of the validity of DRE mechanisms].

The SFST was developed and validated to detect alcohol impairment. In the field, the SFST is used for any type of impairment, including suspected drugged driving. There is concern about the validity of the test to correctly detect cannabis impairment. This review examines literature reviews and studies that: validate the test in the field and the laboratory, report rates of impairment on test in the field, or conduct parts of the SFST in laboratory settings.

Findings

Overall, twelve studies were identified in this search.[133,151,153–162] Eight studies took place in a laboratory,[133,151,153–155,158,161,162] four used Drug Recognition Expert (DRE) data from the field,[153,157,159,160] and one study used a forensic database with Norwegian clinical test for impairment data.[156] Two of these studies were published reports, not peer review papers.[154,160]

Of the laboratory studies, six used smoked cannabis,[133,151,154,158,161,162] two used oral,[133,151] and one used vaporized cannabis.[133] All of the laboratory studies were blinded and placebo controlled. Of the DRE data studies, three examined cannabis-only samples,[157,159,160] and one included other drug samples.[153] All except for one study included a non-impaired control group.[157] The Norwegian clinical test for impairment sample included an alcohol-only sample for comparison.[156] Four studies evaluated the effects of co-use of THC and alcohol. [154–156,158]

Results

Overall SFST

The Standardized Field Sobriety Test (SFST) consists of three tests and two or more unsuccessful tests typically constitutes a finding of "impaired."[151] Of studies that report total SFST impairment scores, conclusions varied.[154] Three studies conclude that SFST is a moderately good predictor of THC impairment.[154,161,162] Bosker et al. 2012 concluded that SFST is mildly sensitive to cannabis impairment in heavy users although they did not find a difference between baseline and total SFST score.[155]

In a study of medicinal THC, Bosker et al. 2012 found that the SFST did not accurately differentiate between cannabis and placebo.[151] This study found no differences between placebo, low, and high-dose oral THC in the SFST, despite observing differences in the driving simulator.[151]

Stough et al. 2006 and Papafotiou et al. 2005 identified that an additional clue related to head movements and jerks would increase the sensitivity of SFST particularly for people who consumed higher levels of THC.[154,162]

Overall SFST: THC + Alcohol

Bosker et al. 2012 found that the SFST more accurately measured cannabis and alcohol combined impairment and attributed this to SFST's sensitivity to alcohol.[155] Downey et al. 2012, also found that cannabis and alcohol together produced more impairment on the SFST than cannabis alone, however, they found no consistent additive or interactive effect of alcohol.[158] Stough et al. 2006 concluded SFST is a moderately good predictor of cannabis and alcohol combined impairment.[154]

Overall SFST: Dose-Response

Stough et al. 2006 found that the SFST correctly classified 73.9% of low-THC cases 50 minutes after smoking.[154] Papafotiou et al. 2005 similarly found that 71.8% of low-THC cases are correctly classified at 55 minutes.[162] However, Stough et al. 2006 had a sensitivity of 33.3% and specificity of 88.2%, whereas Papafotiou et al. 2005 had a sensitivity 88.2% and specificity of 38.5%.[154,162]

Papafotiou et al. 2005 found that the SFST correctly classified 66.7% of participants 105-minutes after cannabis consumption for the low-THC condition, with a sensitivity of 100% and specificity of 0%.[162] Papafotiou et al. 2005 found that overall, the walk and turn test was the best predictor of driving performance.[162] In a different study, Papafotiou et al. 2005 found that in the low-THC condition: 38.5% were correctly classified as impaired at 5-minutes post-consumption, 28.2% at 55-minutes post-consumption and 25.6% at 105-minutes post-consumption.[162] Both

Papafotiou et al. 2005 studies included head movement and jerks as a cue in HGN which increased classification accuracy, as reported above.

Stough et al. 2006 found that the SFST correctly classified 69.4% of the high-THC plus alcohol group 50 minutes after smoking.[154] Papafotiou et al. 2005 similarly found that 65.8% high-THC cases were correctly classified at 55-minutes post consumption.[162] However, their findings diverge in false positives and false negatives. For THC-impaired, Stough et al. 2006 found that 38.5% (participants also had low-dose alcohol) were correctly classified where as Papafotiou et al. 2005 found that 92% were correctly classified.[154,162] For nonimpaired drivers, Stough et al. 2006 found that 87% were correctly classified (participants also had low-dose alcohol) and Papafotiou et al. 2005 found that 15.4% were correctly classified.[154,162]

In another study Papafotiou et al. 2005 found that 56.4% of the high-THC condition were correctly classified at 5-minutes, 48.7% at 55-minutes, and 38.5% at 105-minutes.[162]

Overall Single Test Impairment

Porath-Waller et al. 2014 found that only the OLS is negatively affected by cannabis.[153] Papafotiou et al. 2005 also found that OLS was the best predictor of cannabis impairment.[161] In contrast, Declues et al. 2016 found that the WAT was the most sensitive to THC impairment.[157] Hartman et al. 2016 looks specifically at the clues within each test, and identified OLS sway and two or more clues on WAT as strong indicators of cannabis impairment.[159] Newmeyer et al. 2017 found that only oral consumption and not smoked or vaporized cannabis was associated with OLS and WAT errors.[133]

Horizontal Gaze Nystagmus

Horizontal gaze nystagmus (HGN) is involuntary eye jerking as eyes look to the side.[153] Three outcomes are measured in HGN: smooth pursuit, nystagmus at maximum deviation, and nystagmus before 45 degrees.[153] Outcomes are measured in each eye for a total of six clues.[159] Impairment is classified by four or more errors.[151]

HGN Impairment (two or more clues)

Declues et al. 2016 and Bramness et al. 2010 found that 78.6% and 87.3% of THC-positive drivers respectively did not show HGN impairment.[156,157] Based on HGN signs, Porath-Waller et al. 2014 found that only 1% of cannabis cases were classified correctly.[153] Likewise, Hartman et al. 2016 found no HGN differences between cannabis cases and controls.[159] In an oral medicinal cannabis study, Bosker et al. 2012 also found that cannabis use was not significantly related to HGN impairment.[151]

Papafotiou et al. 2005 found that HGN impairment was associated with THC consumption at 55-minutes and 105-minutes after smoking although they did not observe any HGN at 5-minutes

after smoking.[162] Stough et al. 2006 found that a greater likelihood of HGN in low and high-THC conditions compared to placebo.[154] Additionally, cannabis combined with alcohol produced greater incidences of HGN in a dose-dependent manner.[154] Bosker et al. 2012 also found that alcohol and cannabis co-use were related to HGN impairment.[155]

HGN Individual Clues

Porath-Waller et al. 2014 found that none of the three HGN signs were individually predictive of cannabis use in comparison to no drug use.[153] Papafotiou et al. 2005 found that the accuracy in predicting cannabis consumption with the HGN was higher when head movement and jerks (HJM) were included as a cue.[162] Including HJM did not affect the placebo group, but it increased the low-THC group impairment classifications from 2.6% to 33.3% with HMJ and the high-THC group classifications from 5.1% to 30.8%.[162]

Walk and Turn (WAT)

Eight outcomes are measured in WAT: losing balance during test instructions, beginning test before instructions are complete, stopped walking during test, does not walk heel-to-toe, steps off line, uses arms to balance, takes incorrect number of steps, and improper turn.[159] Impairment is classified by two or more errors.[159]

WAT Impairment (two or more clues)

Researchers found between 39.7-87.8% of cannabis-cases showed two or more WAT cues compared to 2.3-23.4% of controls.

Based on the full WAT test, Porath-Waller et al. 2014 found that 39.7% of cannabis cases were classified correctly.[153] Logan et al. 2016 found that 78% of THC-positive drivers displayed two or more clues compared to 23.4% of THC-negative drivers.[160] Declues et al. 2016 found that 87.8% of THC-positive drivers had two or more errors, but these errors were not related to THC blood concentration levels.[157] Hartman et al. 2016 found 80.5% of cannabis cases had two or more clues compared to 2.3% of controls, with a sensitivity of 80.5% and a specificity of 97.7%.[159]

Stough et al. 2006 found that high and low-dose THC were associated with WAT impairment compared to placebo.[154] Newmeyer et al. 2017 found that only oral dosing, and neither smoked nor vaporized cannabis, significantly increased errors observed in the WAT compared to placebo.[133]

Bosker et al. 2012 found no difference between baseline and cannabis condition in the WAT.[155] Declues et al. 2016 found no correlation between WAT impairment and THC concentrations.[157] In contrast, Papafotiou et al. 2005 found that impairment on the WAT was related to THC in a dose-dependent way.[162]

WAT Individual Clues

Porath-Waller et al. 2014 found that none of the WAT clues were individually predictive of cannabis use compared to no drug use. It is important to note that in this study, only seven outcomes were assessed and improper turn was not included.[153] Hartman et al. 2016 found that improper turn was the most distinctive clue for cannabis with 57.3% of cannabis cases showing improper turn compared to 0% of controls.[159] In contrast, Downey et al. 2012 found that only steps of line was affected by THC condition, no other measures showed differences from placebo, including in the THC combined with alcohol conditions.[158] Stough et al. 2006 also found steps of line occurred more often in low and high-THC condition compared to placebo.[154]

Hartman et al. 2016 examined the percentage of THC-positive DRE records that recorded impairment for each cue.[159] Hartman et al. found that the use of arms to balance was present in 43.7% of cases and 2.3% of controls. Stopping occurred with 41.4% of cases and 2% of controls.[159] Not walking heel-to-toe occurred in 41.1% of cases and 3% of controls.[159]

Papafotiou et al. 2005 observed "use of arms to balance," and "no balance" at five, 55, and 105-minutes after consumption.[162]

One Leg Stand

The one leg stand (OLS) is a test used in roadside impairment detection during which a driver is given instructions to lift one leg six inches off the group with arms at their side and count out loud.[133] Four outcomes are measured in the OLS: swaying, using arms to balance, hoping to balance, putting raised foot down.[153] Impairment is classified by two or more errors.[159]

OLS Impairment (two or more clues)

Researchers found between 44-64.9% of cannabis-cases showed two or more OLS cues compared to 3-16.9% of controls.

Logan et al. 2016 found that 44% of THC-positive drivers had two or more errors on the OLS compared to 16.9% of THC-negative drivers.[160] Hartman et al. 2016 found that 55% of THC-positive drivers had two or more clues on at least one leg.[159] Stough et al. 2006 also found that people in the low and high-THC conditions were more likely to show OLS impairment than those in the placebo.[154] Declues et al. 2016 found that 64.9% of THC-positive drivers showed two or more clues on the OLS but this was not related to THC blood concentration levels.[157] Hartman et al. 2016 found 55% of THC-positive drivers had two or more clues on at least one leg compared to 3% of controls, with a sensitivity of 55% and a specificity of 97%.[159] Based on all OLS signs, Porath-Waller et al. 2014 found that 55.4% of cannabis cases were classified correctly.[153]

Three studies found that cannabis use was related to OLS impairment,[155,158,162] and one study observed this effect at five, 55, and 105-minutes after THC consumption.[162] Newmeyer et al. 2017 found that only oral dosing, but not smoking or vaporizing cannabis, significantly increased errors observed in the OLS compared to placebo.[133] Of all standardized field sobriety tests, Papafotiou et al. 2005 found that OLS was the best indicator of THC.[162]

OLS Individual Clues

Three studies specifically identified sway as predictive or showing greater impairment in THC-positive drivers/participants.[153,154,159] Two studies identified using arms to balance and hopping as predictive or showing greater impairment in THC-positive drivers/participants.[153,154] While Stough et al. 2006 found that putting a raised foot down was more likely in high and low-THC conditions, Porath-Waller et al. 2014 found that it was not predictive of cannabis.[153,154] Hartman et al. 2016 found that cases counted faster on the second leg compared to the first relative to controls.[159]

Hartman et al. 2016 also looked at the median number of clues (*i.e. the middle number in the range of clues observed*) for cannabis cases and controls. Authors found a median of one clue for cannabis-cases and a median of zero clues for non-impaired controls.[159]

OLS Dose Dependent

Three studies found evidence for THC dose dependent impairment on the OLS where higher doses were associated with greater impairment.[154,158,162]

Interestingly, Downey et al. 2012 found more OLS errors in the low-THC combined with alcohol condition compared to the high-THC combined with alcohol condition.[158]

Limitations

Authors noted many potential limitations in research and study design. There is no comparable roadside DRE data on THC-positive drivers who are not pulled over.[160] If only the most impaired drivers are detected and pulled over by law enforcement officers this may result in a more impaired sample and may not be generalizable. Another author noted that samples including heavy users may not have conclusive findings due to tolerance effects.[155] Others expressed the need for more normative data with concern that the OLS could be too sensitive.[153] Without solid normative data it is unknown how similar or different THC-positive drivers are to non-impaired drivers.

One group noted that their control group may not have been fully drug free because they were not confirmed by toxicology tests.[159] However, authors suggest this is unlikely as their control group consisted of law enforcement officers at a training. Law enforcement officers as a control may also be problematic if the officers perform differently on SFST tests due to their experience

with the tests.[159] If officers performed better than a general public this may inflate THC-positive impairment because the control group has artificially low levels of impairment. In addition to concerns about the proper control group, other researchers were limited by the lack of any control group or placebo condition.[157]

4. Can Drug Recognition Experts measure impairment by cannabis? Which parts of the process are more or less effective?

AIM: This section examines and synthesizes studies that evaluate the validity or presence of acute cannabis impairment through Drug Recognition Experts (DREs) and the composite assessment measures.

This section first examines the three frequently cited early studies that evaluated DRE validity. Next, it examines the overall effectiveness of the full DRE process in identifying cannabis-impairment from more recent studies. Next each step of the DRE process is examined independently to assess the effectiveness of each test/procedure for detecting cannabis impairment. The three tests included in the Standardized Field Sobriety Test (Horizontal Gaze Nystagmus, Walk and Turn, and One Leg Stand) are not included in this section). [See Section *XIII. State of Science: Detecting Impairment*: subsection: *Can Standardized Field Sobriety Tests measure impairment by cannabis? Which parts of the test are more or less effective?*].

Drug Recognition Experts (DREs) are law enforcement officers who have trained in a twelve-step process to detect impaired driving and classify impairment as medical, alcohol, or drug based. [See Section *IV. Law Enforcement Trainings: Drug Evaluation and Classification Program Drug Recognition Expert Training* for a comprehensive review of the DRE process].

The steps in the DRE process are briefly outlined below:

1. Breath Alcohol Test
2. Interview of the Arresting Officer
3. Preliminary Examination and First Pulse (checking for medical reason)
4. Eye Examination (HGN*, VGN, LOC)
5. Divided Attention Psychophysical Tests
    - Modified Romberg Balance
    - WAT*
    - OLS*
    - Finger to Nose
6. Vital Signs and Second Pulse (pulse rate, blood pressure, body temperature)
7. Dark Room Examinations
8. Examination for Muscle Tone
9. Check for Injection Sites and Third Pulse
10. Subject's Statements and Other Observations
11. Analysis and Opinions of the Evaluator
12. Toxicological Examination

* = not included in this section [See Section *IV. Law Enforcement Trainings: The Standard Field Sobriety Test Training*].

Initial Studies

Three early studies[163–165] examined the validity of DREs and continue to be cited in courts today.[166] Two of these studies used data from real DRE evaluations performed in the field[163,165] and one study[164] took place in the laboratory. The laboratory study administered either cannabis, a depressant, a stimulant, or placebo.[164] Studies that used in-field samples confirmed DRE opinions primarily by blood[163] and urine samples.[165]

In the "LAPD 173 Study," Compton et al. 1986 examined DRE and toxicology reports for 201 predominately men suspected of drugged driving.[163] Assessments were conducted by 25 senior DRE officers.[163] Only one person did not have a toxicology drug or alcohol finding.[163] Compton et al. 1986 found that 49% of the time, DREs correctly identified any and all drugs confirmed in toxicology.[163] DREs correctly identified at least one drug, but not all drugs indicated in toxicology 38% of the time.[163] In this sample, DREs had a sensitivity of 59.7% for cannabis and a specificity of 86.4%.[167]

In the "Arizona DRE Validation Study," Adler et al. 1994 linked Arizona DRE records to urine samples for 500 cases conducted by 37 DREs.[165] Adler et al. 1994 found that 83.5% of cases where a DRE indicated drug presence were supported in toxicology findings.[165] In a review however, Beirness et al. 2007 noted the high false-alarm rate in this sample, where 61.7% of drug-negative cases were reported as drug-impaired by DREs.[167] Cannabis-specific findings could not be calculated from reported data.[167]

In the "Johns Hopkins Study," Bigelow et al. 1985 included 80 men who were given either cannabis, a depressant, a stimulant, or placebo.[164] Four DRE officers then used a shortened DRE protocol to assess participants.[164] Bigelow et al. 1985 reports that of those classified by DRE officers as drug-impaired, DREs identified the correct drug category 91.7% of the time.[164] DREs classified a person as drug-intoxicated when they had not consumed any drug only 1.3% of the time.[164] Beirness et al. 2007 reports, that in this sample, DREs had a sensitivity of 48.8% and specificity of 92.7% for cannabis.[167]

In 2013, an analysis of study quality used a tool called QUADAS to evaluate the three foundational DRE studies above and found evidence of bias and methodological concerns.[166] Kane 2013 found bias in multiple areas and in all studies.[166] Sources of bias were found within the sample, reference tests, and impact of alcohol.[166] Kane 2013 also identified concerns in statistical methods that resulted in findings which may not generalize to a wider population.[166] DRE protocols used in these studies do not always match what occurs in the field and insufficient method descriptions preclude study reproduction by other researchers.[166] This review highlights the need for additional rigorous research related to DRE validity.[166] The next sections includes a review of more recent research on DREs.[166]

Methods

Papers published in the last ten years were prioritized (2009-November 2018), although highly relevant papers identified in references were collected through 2005. [See Beirness et al. 2007 for a review that includes DRE studies prior to 2005.[167]] Papers that included any measure of the DRE are also include in this section even if they were conducted independent of a full DRE process.

Findings

Twelve studies were identified that include any components of the DRE process.[133,154,156–160,167–171] Two studies were reports and not peer review papers.[154,160] Seven studies use DRE data from officers in the field.[157–160,168,170,171] Three studies were laboratory based.[133,154,169] One study used a forensic database with Norwegian clinical test for impairment data.[156]

Of the DRE data studies, three examined cannabis-only samples[159,160,171] and two included other drug samples.[168,170] All except for one study included a non-impaired control group.[171] Sample sizes ranged from 20[133] to 2,142.[153]

All of the laboratory studies examined smoked cannabis.[133,154,158,169] One study also examined an oral dose and vaporized cannabis.[133] One study included a cannabis and alcohol co-use measure.[154] The study with Norwegian clinical test for impairment data included a THC-only sample, THC and alcohol co-use, and alcohol-only sample.[156] One laboratory study used real DRE officers to make assessments.[169] Only one laboratory study included the full DRE process,[169] three included only one or more parts of the DRE.[133,154,158]

Studies had different aims which include: identify the best indicators of cannabis impairment in the DRE process,[159,171] compare DRE to non-DRE officer findings,[171] identify the best indicators for differentiating cannabis from other drugs,[168] and identify if signs of impairment correlate with THC in blood.[160]

Results

Full Drug Recognition Expert Process

Three studies report the accuracy or sensitivity of DREs to correctly identify cannabis-impaired drivers following the full DRE process.[168–170] These studies found that the overall accuracy of DRE officers for identifying cannabis-positive drivers is 87.3% (sensitivity: 79%; specificity: 98%),[170] 72% (when 12 datapoints from the DRE session were used; see article for specific criteria),[168] and 41.7%[167] (sensitivity: 49%; specificity: 77%).[169]

In Beirness et al. 2009's sample, 92.1% of cases had the same conclusion supported by DRE opinion and toxicology reports.[170] Very few cases had no drugs detected in toxicology, but of those that did, 80% of DRE assessments correctly found no impairment.[170] Those judged impaired by a DRE with no drugs detected were <1% of the entire sample.[170]

One study reported measures of sensitivity and specificity in a number of the composite tests in the DRE.[159] Sensitivity is the proportion of cases who are impaired being correctly classified as impaired. Specificity is the proportion of cases who are not impaired being correctly classified as not impaired.[170] These measures of sensitivity and specificity are reported in the relevant section of the DRE process below.

Step 1 Breath Alcohol Test

Not applicable for purposes of this report.

Step 2 Interview of the Arresting Officer

DREs interview the arresting officer of the suspected impaired person before a face-to-face meeting with the individual. Two studies report why the driver was pulled over[157,159] and one study reported arresting officer observations.[159]

Speed was the most frequent reason cannabis-impaired suspected drivers were pulled over and weaving was the second most common reason in both studies.[157,159] See below for all reasons for stops.

Hartman et al. 2016 reported that in 72.3% of cases, one or more moving violations were listed as reasons for the traffic stop. Moving violations included: improper speed (27.7%), weaving (19.0%), crash (9.3%), improper turn (7.7%), disobeying traffic control devices (7.0%), and failure to yield (3.3%). Other cited reasons included: equipment failure, such as headlight or taillight defects (10.3%), expired vehicle license (3.7%), criminal activity such as observable cannabis smoking or driving in prohibited areas (2.7%), and other (11.3%). In all but one of the improper speed cases, the suspect was reported driving faster than the posted limit. The one case reported driving slower than the limit also was drifting within the lane.[159]

Declues et al. 2016 reported that the following behaviors were observed by police officers for cannabis drivers: speeding (24%), unable to maintain lane position (23.2%), ran red light or stop sign (13%), unsafe lane change (8.7%), collision (8.3%, going too slow (6.7%), no headlights at night (5.6%), no turn signal (5.6%), and driving the wrong way (5.1%).[157]

Hartman et al. 2016 reported that the most frequent demeanor characteristics arresting officers indicated were: "relaxed" (34.0%), "lethargic" (21.6%), "slow" (17.5%), and "carefree" (6.2%). Other adjectives (≤3 cases) reported included: "sluggish," "laughing," "restless," "emotional," "dazed," "shaking," "rigid," "disoriented," "sleepy," "anxious," and "withdrawn."[159]

Step 3 Preliminary Examination and First Pulse

During the preliminary examination, DREs determine whether impairment may be caused by medical problems. This step includes observation of the driver's face, speech, breath, eyes, and pulse [See Section *IV. Law Enforcement Trainings: Drug Evaluation and Classification Program Drug Recognition Expert Training* for a comprehensive review of the DRE process and tests].

Speech Affected

Speech is observed during the preliminary examination by the DRE and may also be reported in the interview of the arresting officer. Two studies included a measure of speech.[156,171]

Declues et al. 2018 found that 87.6% of cannabis-positive drivers had their speech reported as affected in the DRE report.[171] Declues et al. also reported that 96.2% of cannabis-positive DRE reported tongue coating.[171]

Bramness et al. 2010 found that 4.5% of THC-only impaired drivers had snuffled, slow, or speech with latency.[156] Bramness et al. 2010 found that 1.4% of THC-only impaired drivers did not have meaningful speech content.[156]

Cannabis Odor

The smell of cannabis is first observed by the DRE in the preliminary examination. It may also be noted by the arresting officer in the interview with the arresting officer. Two studies reported cannabis odor.[159,171]

Hartman et al. 2016 reported that cannabis odor was detected by officers in 72.3% of cannabis-positive cases.[159] Declues et al. 2018 found that 82.4% of cannabis-positive DRE reports included an observation of cannabis odor.[171]

Pulse

During the 12-part DRE process, the pulse is taken three times. These three readings are averaged. The DRE student manual noted that an elevated pulse (*i.e. over 100 beats/minute*) is consistent with cannabis impairment.[172] While only the first pulse is recorded in Step 3, research related to any and all pulse measures are included in this section. Seven studies include a measure of pulse.[156,158–160,168,169,171]

Declues et al. 2018 found an elevated pulse in most THC-positive drivers (88.5%).[171] Schechtman et al. 2005 also found a faster pulse in cannabis cases compared to controls at the beginning of the session (84.8 beats/minute compared to 67.9).[169] Hartman et al. 2016 reported mean pulse was greater in cases (91 beats/minute) compared to controls (71 beats/minute).[159]

Logan et al. 2016 also found that THC-positive drivers had a greater pulse than THC-negative drivers.[160]

Declues et al. 2018 did not find a difference in pulse rate between any of the three times it was taken across the DRE process.[171] However, Schechtman et al. 2005 found that pulse changes across timepoints, although only for the cannabis group who had a drop in heart rate over the course of the session (-5.7 beats/minute).[169]

Additionally, Declues et al. 2018 found no correlation between THC blood concentrations and pulse.[171] In a comparison between drug groups, Porath-Waller et al. 2009 found that cannabis-impaired drivers had a higher mean pulse compared to narcotic analgesic users.[168]

Bramness et al. 2010 examined whether the pulse is regular and found that only 1.6% of THC-positive cases had an abnormal pulse.[156]

Step 4 Eye Examinations

Horizontal gaze nystagmus (HGN)

The DRE matrix for cannabis indicates that no horizontal gaze nystagmus (HGN) is consistent with cannabis impairment.[172] [See Section *IV. Law Enforcement Trainings: The Standard Field Sobriety Test Training* for studies that report HGN].

Vertical gaze nystagmus (VGN)

The DRE matrix for cannabis indicates that no vertical gaze nystagmus (VGN) is consistent with cannabis impairment.[172] Three studies report VGN.[157–159]

Downey et al. 2012 and Stough et al. 2006 found that VGN is not associated with THC or THC and alcohol.[154,158] Likewise, Declues et al. 2016 found that VGN is not associated with THC presence and only 3.2% of THC-positive drivers had VGN.[157] Hartman et al. 2016 also found that VGN is no different for cannabis cases compared to controls.[159]

Hippus

Hippus is "rhythmic change in the pupil size of the eyes, as they dilate and constrict when observed in darkness independent of changes in light intensity, accommodation (focusing), or other forms of sensory stimulation. It is normally only observed with specialized equipment."[172] One study reports hippus.[171]

Declues et al. 2018 found that 38% cannabis-positive DRE reports recorded an observation of hippus.[171] Declues et al. also reported findings from a 1994 NHTSA study that found 20% of THC-positive people showed hippus.[171]

Declues et al. 2018 found that 88.8% of cannabis-positive DRE reports found either hippus or rebound dilation.[171] Declues et al. also reported findings from a 1994 NHTSA study that found 91% of THC-positive people showed either hippus or rebound dilation.[171]

Lack of Convergence (LOC)

Lack of convergence (LOC) is the inability of a person's eyes to converge, or 'cross' as the person attempts to focus on a stimulus as it is pushed slowly toward the bridge of his or her nose.[172] The DRE matrix for cannabis indicates that lack of convergence is consistent with cannabis impairment.[172] Five studies report LOC.[133,157,159,160,168]

Hartman et al. 2016 found that LOC occurs more frequently in cannabis cases (78.8%) compared to controls (10.9%).[159] Declues et al. 2016 reported that 86.1% of THC-positive drivers showed LOC.[157] Logan et al. 2016 found that 55.2% of THC-positive drivers showed LOC compared to 34.9% THC-negative drivers.[160] Newmeyer et al. 2017 observed LOC at baseline and after dosing in 50% of participants, but could not make statistical comparisons.[133]

Porath-Waller et al. 2009 compared cannabis-positive drivers to other-drug positive drivers and found that LOC is more likely in cannabis-impaired drivers compared to those impaired by a CNS stimulus.[168]

In Hartman et al.'s 2016 sample, LOC has a sensitivity of 78.8% and a specificity of 89.1%.[159]

Red Eyes

The DRE participant manual noted that the reddening of the conjunctiva is consistent with cannabis impairment.[172] Six studies report on the presence of blood shot, red eyes, or red conjuctivia.[156,159,160,168,169,171]

The percent of THC-positive people who displayed red eyes ranged from 73.3% to 94%. Specifically, Schechtman et al. 2005 found that bloodshot eyes were present in 73.3% of cannabis cases compared to 44.4% of placebo.[169] Declues et al. 2018 found that 94% of

cannabis-positive DRE reports recorded the driver had red eyes.[171] Logan et al. 2016 found that 76.7% of THC-positive have blood shot eyes compared to 20.1% of THC-negative people.[160] Hartman et al. 2016 found that 77.5% of cannabis-cases had bloodshot eyes compared to 3.1% of control cases.[159]

Logan et al. 2016 found that 37.4% of THC-positive participants had red conjunctiva compared to 10.6% of THC-negative participants.[160] Porath-Waller et al. 2009 compared cannabis-positive drivers to other-drug positive drivers and found that cannabis-impaired drivers were more likely to have red conjunctiva compared to those impaired by a CNS stimulus.[168]

In Hartman et al.'s 2016 sample, bloodshot eyes had a sensitivity of 77.5% and a specificity of 96.9%.[159]

Bramness et al. 2010 found that drivers with higher THC blood concentrations were more likely to show conjunctival injection.[156]

Watery Eyes

Two studies reported on watery eyes or tear shedding.[156,160]

Logan et al. 2016 found that 40.7% of THC-positive participants had watery eyes compared to 11.5% of THC-negative participants.[160] Bramness et al. 2010 reported that 1.7% of THC-only positive drivers showed tear shedding.[156]

Droopy Eyes

Two studies report on droopy eyes.[168,171]

Declues et al. 2016 reported that 85.6% of THC-positive drivers had droopy eyelids.[171] In contrast, Declues et al. also reported that a 1994 NHTSA study found that droopy eyelids were present in 37% of cannabis-positive users.[171] Logan et al. 2016 found that 42.5% of THC-positive participants had droopy eyelids compared to 12.3% of THC-negative participants.[160]

In a comparison between drug groups, Porath-Waller et al. 2009 found that that cannabis-impaired drivers were less to have droopy eyelids compared to narcotic analgesic users.[168]

Eyelid tremors (general, not observed during Romberg task)

One study reports on eyelid tremors generally.[160] Logan et al. 2016 found that 69.4% of THC-positive participants showed eyelid tremors compared to 22.9% of those who were THC-negative.[160]

Step 5 Divided Attention Psychophysical Tests

Modified Romberg Balance

The modified Romberg balance (MRB) is used to measure balance and time perception. Participants are directed to stand with feet together, head back, and eyes closed, and estimate 30 seconds. Sway, eye tremors, and time estimation are observed.[133] Five studies include at least one measure of the MRB.[133,156,157,159,160]

Overall, Declues et al. 2016 found that THC-positive drivers did not show impairment on the MRB.[157] Bramness et al. 2010 found that 34.6% of THC-only positive drivers were judged as impaired in the Romberg test.[156]

30-Second Estimate Accuracy

During the Romberg task, drivers are asked to close their eyes and estimate 30 seconds. Estimates within five seconds of 30 are considered non-impaired. Three studies reported on the accuracy of the 30-second estimate during the MRB.[133,157,159]

Newmeyer et al. 2017 found no effect of oral, vaporized, or smoked cannabis on time perception in frequent or occasional users as measured through the 30-second estimation task at 1.5 and 3.5 hours after cannabis consumption.[133] Hartman et al. 2016 also found that cases and controls over and under estimates of 30 seconds were not different.[159]

Declues et al. 2016 found no difference between the results when MRB was conducted by a DRE or a non-DRE officer, 46% and 48.7% of cannabis-impaired cases had accurate estimates (falling within five seconds of 30 seconds).[157]

Hartman et al. 2016 found a difference in 30-second estimations between cannabis cases and controls where only 4% of cannabis cases exactly estimated 30 seconds compared to 29.9% of controls.[159] Hartman et al. 2016 and Newmeyer et al. 2017 noted wide variability in the distribution of estimates, and Hartman et al. found a more normal distribution of answers for controls.[133,159]

Eyelid Tremors in MRB

Eyelid tremors in the MRB are observed when the driver has their eyes closed. One study report on eyelid tremors in the MRB.[159]

Hartman et al. 2016 found that 86.1% of cannabis cases showed eyelid tremors during the MRB compared to 6% of controls.[159]

In Hartman et al.'s 2016 sample, eyelid tremors during the MRB had a sensitivity of 86.1% and a specificity of 94%.[159]

Sway in MRB

Sway is observed during the MRB. Three studies report sway in the MRB.[133,159,160]

Hartman et al. 2016 found that 78.5% of cannabis cases showed sway during the MRB compared to 11% of controls.[159] Logan et al. 2016 also reported cannabis-positive drivers had more sway on the Romberg balance compared to those who were not cannabis-impaired.[160] Newmeyer et al. 2017 found that smoked cannabis was associated with greater sway (87.5%) than sway in placebo (65%), and vaporized and oral cannabis doses were not associated with a greater likelihood of sway compared to placebo.[133]

In Hartman et al.'s 2016 sample, sway during the MRB had a sensitivity of 78.5% and a specificity of 89%.[159]

Finger to Nose

The finger to nose task has participants close their eyes and bring their index finger to touch their nose.[156] Four studies report results from the finger to nose task.[156,157,159,160]

Declues et al. 2016 found that finger to nose misses did not differ based on THC concentration in blood.[157] Declues et al. 2016 also found no difference in finger to nose findings when conducted by a DRE or a non-DRE.[157] Bramness et al. 2010 reported that of THC-only positive drivers, 12.4% tested positive on the finger to nose test; However, the threshold to test "positive" was not reported.[156]

No misses

Logan et al. 2016 found that 5.2% of those THC-positive had no misses compared to 49.2% of those THC-negative.[160]

1 miss

Logan et al. 2016 found that 94.8% of those THC-positive had one or more misses, compared to 50.7% of those THC-negative.[160] Declues et al. 2016 found that 95.2% of cannabis-positive drivers missed one or more attempt(s).[157]

2 or more misses

Between 88.9-94.4% of cannabis-positive cases were reported to miss two or more finger to nose attempts. Specifically, Declues et al. 2016, found that 88.9% of cannabis-positive drivers missed two or more attempts.[157] Logan et al. 2016, found that 90.3% of those THC-positive had two or

more misses compared to 40.8% of those THC negative.[160] Hartman et al. 2016 found that 94.4% of cannabis cases had two or more misses compared to 16.6% of controls.[159]

3 or more misses

Between 76-87% of cannabis-positive cases were reported to miss three or more finger to nose attempts. Specifically, Hartman et al. 2016 found that 87.1% of cannabis cases had three or more misses compared to 6.6% of controls.[159] Logan et al. 2016 found that 80.4% of those THC-positive had three or more misses compared to 31.9% of those who were THC-negative.[160] Declues et al. 2016 found that 76% of cannabis-positive drivers missed three or more attempts.[157]

Hartman et al. 2016 found that three or more misses on the finger to nose was the best predictor of cannabis.[159]

4 or more misses

Between 64.2-71.9% of cannabis-positive cases were reported to miss four or more finger to nose attempts. Specifically, Hartman et al. 2016 found that 71.9% of cannabis cases had four or more misses compared to 4.6% of controls.[159] Logan et al. found that 67.2% THC-positive people had four or more misses compared to 24.6% of those THC negative.[157] Declues et al. 2016 found that 64.2% of cannabis-positive drivers missed four or more attempts.[157]

Logan et al. 2016 found that 48.9% of those THC-positive had five or more misses compared to 19.5% of those who were THC-negative.[160] Logan et al. 2016 found that 34.8% of those THC-positive had six misses compared to 12.8% of those who were THC-negative.[160]

Step 6 Vital Signs and Second Pulse

Blood Pressure

The DRE student manual indicates that high blood pressure is consistent with cannabis impairment.[172] Three studies examined blood pressure.[159,168,171]

In a study of DRE reports for toxicology confirmed THC-positive drivers, Declues et al. 2018 found that 50% of drivers had high blood pressure, 42.4% had normal blood pressure, and 7.1% had low blood pressure.[171] Hartman et al. 2016 found a higher systolic blood pressure in cannabis cases (median: 138 [range: 82-205]) compared to controls (median: 130 [range: 90-170]).[159]

Hartman et al. 2016 found no difference in diastolic blood pressure between cannabis cases and controls.[159]

In a comparison between drug groups, Porath-Waller et al. 2009 found that cannabis-impaired drivers were more likely to have a higher systolic blood pressure compared to narcotic analgesic users.[168]

Declues et al. 2018 found no correlation between THC levels in blood and blood pressure.[171]

Temperature

The DRE student manual noted that an average temperature is consistent with cannabis impairment.[172] One study examines body temperature.[159]

Hartman et al. 2016 found no difference in body temperature between cannabis cases and controls.[159]

Step 7 Dark Room Examination

Pupil Dilation/Pupil size

The DRE matrix for cannabis indicates that dilated pupils are consistent with cannabis impairment, but noted that pupil size may be normal.[172] Six studies examined pupil size.[133,156,159,168,169,171]

Room Light

Four studies examined pupil size in room light.[133,156,159,171]

Declues et al. 2018 found that 63.6% of cannabis-positive subjects had dilated pupils in room light.[171] Hartman et al. 2016 also found cannabis cases mean pupil size was more dilated than controls in room light.[159] Conversely, Newmeyer et al. 2017 found no difference for smoked, oral, or vaporized in room light.[133]

Bramness et al. 2010 reported that 30.9% of THC-positive drivers had an abnormal pupil size in "present light."[156]

Near Total Darkness

Three studies examined pupil size in near total darkness.[133,159,171]

Declues et al. 2018 found that 13.9% of cannabis-positive subjects had dilated pupils in near total darkness.[171] Newmeyer et al. 2017 found no difference for smoked, oral, or vaporized in near total darkness.[133] Conversely, Hartman et al. 2016, found cannabis cases mean pupil size was more dilated than controls in near total darkness.[159]

Direct Light

Four studies examined pupil size in room light.[133,156,159,171]

Declues et al. 2018 found that 45.4% of cannabis-positive subjects had dilated pupils in direct light.[171]

Hartman et al. 2016 and Schechtman et al. 2005 found that pupil sizes were more dilated for cannabis cases than for controls in direct light.[159,169] In contrast, Newmeyer et al. 2017 found no difference for smoked or vaporized cannabis in room light, but did find larger pupils in the oral dose group compared to placebo.[133]

Reaction to Light

The DRE matrix for cannabis indicates that a normal reaction to light is consistent with cannabis impairment.[172] Three studies examined reaction to light.[156,168,169]

Schechtman et al. 2005 found that 45% of cannabis-impaired participants had abnormal reactions to light compared to 21% of placebo participants.[169] Specifically, this study found that cannabis slowed reaction to light.[169] In contrast, Bramness et al. 2010 found that 21.5% of THC-only positive drivers had an abnormal reaction to light.[156] Bramness et al. 2010 did find that those with greater THC concentrations in the blood had a decreased reaction to light.[156]

In a comparison between drug groups, Porath-Waller et al. 2009 found that cannabis-impaired drivers were more likely to have a faster reaction to light compared those impaired by a CNS stimulant or by narcotic analgesics.[168]

Rebound Dilation

Rebound dilation is a period of pupillary constriction followed by a period of pupillary dilation where the pupil steadily increases in size and does not return to its original constricted size."[172] Three studies examined rebound dilation.[159,160,171]

Hartman et al. 2016 found that rebound dilation occurs more frequently in cannabis cases (70.9%) than controls (0%).[159] Declues et al. 2018 found that DRE officers recorded rebound dilation in 50.8% of THC-positive drivers.[171] In their paper, Declues et al. also reported that a 1996 NHTSA study found that 71% of cannabis-positive users showed rebound dilation.[171] Logan et al. 2016 found that 57.1% of those who were THC-positive showed rebound dilation compared to 7.6% of those who were THC-negative.[160]

In Hartman et al.'s 2016 sample, rebound dilation has a sensitivity of 70.9% and a specificity of 100%.[159]

Step 8 Examination for Muscle Tone

Muscle tone

The DRE student manual noted that muscle tone is usually normal with cannabis impairment.[172] No studies were identified that report on muscle tone.

Step 9 Check for Injection Sites and Third Pulse

Officers check for injection sites on the driver by inspecting their skin. Two studies report on injection sites.[156,168]

In a comparison between drug groups, Porath-Waller et al. 2009 found that cannabis-impaired drivers are less likely to have visible injection sites compared to narcotic analgesic and CNS stimulant users.[168]

Bramness et al. 2010 found that 24.7% of THC-only positive drivers had needle marks and 10.3% had superficies thrombosis or phlebitis indicating past intravenous substance use.[156]

Step 10 Subject Statements and Other Observations

No studies were identified that report on subject statement and other observations.

Step 11 Analysis and Opinions of the Evaluator

Models

Hartman et al. 2016 found that the model with the best sensitivity and specificity is meeting two of four criteria: three or more misses of finger to nose, eyelid tremors during MRB, two or more clues on the OLS, and two or more clues on the WAT. This yielded a sensitivity of 97% and a specificity of 96.7%.[159]

Step 12 Toxicological Examination

Timing

Hartman et al. 2016 found that the median time between arrest and DRE evaluation was 47.5 minutes with a range of 2-189 minutes.[159] Declues et al. 2018 found that the average time to obtain blood was over an hour.[171]

Blood Levels/Per Se

Logan et al. 2016 found no support for per se limits.[160]

Bramness et al. 2010 found an association between blood THC levels and the following: conjunctival injection, pupils dilated, slow or no pupil reaction to light, and at least one symptom of the eye.[156]

Limitations

All studies have strengths and limitations. There are also key differences and tradeoffs between in-field studies of real DRE-trained law enforcement officers and laboratory studies. In a review, Beirness et al. 2007 found that in-field studies provided better support for DRE accuracy compared to laboratory studies, methodological differences may play a role in these different findings.[167]

Other study limitations include but are not limited to: a non-toxically confirmed "non-impaired" group who were law enforcement officers with experience in the tests,[159] those being pulled over may represent a different group from those who also consumed cannabis and were not pulled over (*i.e. selection bias)*,[156,160] observational study design,[156] only some DRE outcomes could be examined,[168,169] and full DRE process was not conducted.[133]

XIV. State of Science: Detecting Cannabis Cannabinoids

Introduction

Cannabis cannabinoids and metabolites detection is an area of public interest regarding impaired-driving. Proponents of treating cannabis like alcohol, have pined hopes on a method analogous to a blood alcohol content for alcohol. Some states and countries have set per se limits, *a numeric threshold (i.e. cut-off) for cannabis analytes,* despite a lack of empirical evidence. Researcher and former Chief of Chemistry and Drug Metabolism at the National Institute on Drug Abuse (NIDA), Dr. Marilyn Huestis remarked:

> "*There is no one blood or oral fluid concentration that can differentiate impaired and not impaired…It's not like we need to say, 'Oh, let's do some more research and give you an answer.' We already know. We've done the research.*"[173]

This section is comprised of a series of literature reviews. The review primarily includes findings from experimental and observational studies in the past decade. The purpose of this section is to present the current state of science related to detecting cannabinoids and cannabis metabolites.

The section begins with an overview of cannabinoids, the difference between detection and impairment, and key differences between cannabis and alcohol. The section is then organized by biological matrices: blood, oral fluid, urine, breath, hair, and sweat. Each biological matric section includes a series of questions that are addressed through literature reviews. Strengths, limitations, and feasibility for implementation are discussed.

Methods

Targeted searches were conducted in August-November 2018 on PubMed and GoogleScholar and included the terms: “cannabis,” “marijuana,” “THC,” “cannabinoids,” “blood,” “frequent users,” “alcohol,” “concentrate(s),” “impairment,” “oral fluid,” “sensitivity,” “specificity,” “passive exposure,” “feasibility,” “urine,” “urinary,” “breath,” “breathalyzer,” “hair,” and “sweat.” Author reference libraries searches were also conducted.

Academic articles published from 2009 to October 2018 were collected. Highly relevant papers and reports were included through 2005. Articles that only examined chronic or long-term effects of cannabis or only examined synthetic cannabinoids were excluded. The search was limited to human participants and English language papers.

1. What are cannabinoids?

Cannabinoids are active chemical agents[174] and important biological markers that refer specifically to a group of varying molecules that bind to cannabinoid receptors throughout the body. There are more than 100 known cannabinoids.[175] Cannabinoids are further categorized as: (1) endogenous endocannabinoids (*i.e. the body's own chemical compounds that activate the same receptors as delta-9-tetrahydrocannabinol*), (2) synthetic cannabinoids (*i.e. various manmade, unrelated chemical compounds functionally similar to Delta 9-Tetrahydrocannabinol e.g. "K2*"), and (3) phytocannabinoids (*i.e. cannabinoids that occur naturally in the cannabis plant*).[176]

The interaction of two phytocannabinoids in cannabis are particularly important when discussing cannabis laws: (1) Tetrahydrocannabinol (THC), the main psychoactive component of cannabis accounting for the main cognitive effects and addiction potential, and cannabidiol (CBD), a non-psychoactive, but highly physiologically relevant component.[176]

The ratio of THC:CBD in the individual cannabis plant contributes to its phenotype.[177] Cannabinoid composition has three chemical types: (1) Chemotype I, where there is a high THC concentration [THC content >0.3% and CBD <0.5%], (2) Chemotype II, where CBD is the prevalent cannabinoid with lowered THC concentrations, and (3) Chemotype III, where there is a low-THC concentration.[178] In the body, THC metabolizes primarily into 11-hydroxy-THC (11-OH-THC) and 11-nor-0-carboxy-THC (THC-COOH).[175]

THC increases brain activity in the cerebellum, frontal, and paralimbic regions of the brain. THC acts on two cannabinoid receptors in the brain: CB_1 and CB_2. The CB_1 receptor is important to note here due to its location in the brain regions involved in cognition, memory, reward, pain perception, and motor coordination. THC has both therapeutic and adverse acute, and long-term effects, including: impairment of cognitive functions, analgesia, intoxication, short-term memory loss, muscle relaxant, and anti-inflammatory effects. Less well studied are effects of CBD, which include: anti-anxiety, anti-psychotic, anti-oxidant, anti-inflammatory and immunomodulatory effects, as well as modulate the metabolism of THC and prevent glutamate excitotoxicity. Only acute effects are discussed for purposes of this report.

Biologically testing for active versus passive cannabis exposure is important for assessment of cannabis-impaired driving, but requires sensitive detection.[179] THC and other cannabinoids can be measured through different biological samples, including: blood, oral fluid, urine, breath, hair, and sweat.[175]

Table XIV.E.1. Major Cannabis Analytes

Cannabinoid/Analyte	Abbreviation	Description
delta9-Tetrahydrocannabinol	THC	THC is the major psychoactive cannabinoid, there are nine known types of THC.[180]
11-hydroxy-THC	11-OH-THC	11-OH-THC is the primary active metabolite of THC (psychoactive)[181]
11-nor-0-carboxy-THC	THC-COOH	THC-COOH is the primary inactive metabolite of THC, it occurs as a result of 11-OH-THC oxidation (non-psychoactive)[181]
Cannabidiol	CBD	CBD is the cannabinoid with the most of the studied therapeutic properties, there are seven known types of CBD.[180]
Cannabinol	CBN	CBN is a minor cannabinoid that occurs as a result of THC oxidation.[182]
Tetrahydrocannabinolic Acid	THC-A	Δ9-tetrahydrocannabinolic acid A (THC-A) is a biosynthetic precursor of THC found in cannabis plants.[183,184] It is not psychoactive until changed into THC by heating or drying.[183]
delta9-tetrahydrocannabivarin	THCV	Tetrahydrocannabivarin (THCV) is "the propyl analogue of THC."[185]
Cannabigerol	CBG	Cannabigerol (CBG) is a minor cannabinoid that is the "biosynthetic precursor of THC and CBD."[185]

2. What is the difference between detection and impairment?

Detecting any past cannabis use and identifying a person who is currently impaired are two different goals. Certain policy options conflate these aims. In this report, detection of cannabis refers to identifying any past cannabis use. Impairment refers to identifying a person who is currently under the influence of cannabis.

Biological measures of cannabinoids and cannabis metabolites are generally effective, although imperfect, for detecting whether someone has consumed cannabis. However, these tools are generally ineffective at identifying impairment, in other words whether a person was impaired at the time of the test.

3. How quickly is cannabis ingested in the body?

Smoking

Smoking cannabis has rapid effects that can be felt within minutes.[183] The lungs efficiently deliver THC to the brain, although efficiency varies between people.[186] Cannabis effects correlate with THC levels in the brain, but these levels cannot be measured in live people.[150] Effects are less aligned with cannabinoid and metabolite concentrations in blood, but blood is the best known approximate.[150] THC can be measured in blood and oral fluid rapidly after intake, but peak levels drop quickly despite its continued effects due to its fat-soluble properties.[183]

Vaporizing

Vaporizing cannabis has a similar time course and effects as smoking,[187] although effects may be slightly slower (minutes) than smoked effects.[72] The potency (or strength) of vaporized THC can be comparable to smoked cannabis or a stronger concentrate.[72] One preliminary study found plasma blood THC concentration peaks were no different between smoked and vaporized cannabis although vaporized cannabis resulted in higher THC plasma concentrations at 30 and 60 minutes,[188] while another study found that vaporized cannabis had stronger effects and higher peak concentrations.[189]

Edibles or Oral Consumption

Cannabis edibles and other oral doses have delayed effects compared to inhaled methods of consumption.[72] Absorption occurs more slowly and the amount of THC absorbed varies based on what has previously been consumed.[183,186] Consuming an edible on an empty stomach results in greater effects because the proportion of THC to other bioproducts is larger.[183]

Other methods of consumption

Less frequent methods of consumption include: tinctures, oromucosal/sublingual (mouth/under tongue) sprays, topical, intravenous, and rectal routes.[72] In a review, Russell et al. 2018 identified very little research related to these methods in a non-medical context.[72]

4. How does cannabis measurement compare to alcohol measurement (blood alcohol content (BAC)?

Alcohol is water-soluble, it remains measurable in blood during its peak effects and decreases at a steady rate. In contrast, cannabis is fat soluble. This means THC and other metabolites are stored in body tissue and are not eliminated at a steady rate.[183] Overtime, THC and metabolites are slowly and variably released back in the body at low levels.[186] Generally, impairment does not occur during this later time.[183] The re-release of cannabinoids allows for the detection of cannabis after its acute effects ("impairment") have worn off. The length of time cannabinoids can be detected varies based on factors, including: metabolism,[183] method of consumption,[190] amount of cannabis consumed,[183] and frequency and history of use.[183]

Blood

Research with smoked cannabis shows a counter-clockwise hysteresis pattern in blood (*i.e. THC concentrations rise and spike in blood then decrease, but physiological effects [including impairment] are lagged and increase while THC concentrations decrease*).[174] For smoked and vaporized cannabis, THC blood levels typically peak within minutes[125,188] of consumption whereas cannabis effects typically peak after 30 minutes and last several hours[125] following consumption, but impairing effects may be detected up to 4-8 hours.[124] Oral and edible doses of cannabis peak later and effects last longer.[133] THC effects correlate with THC levels in the brain; However, THC levels in the brain do not match THC levels in blood.[150] Brain concentration levels cannot be assessed in live people.[150] Thus far, literature shows that blood concentrations remain the best biological marker for detecting possible impairment.[150]

Blood concentration levels vary between individuals and within individuals. Factors that contribute to variation are: dose,[186] method of consumption,[186] absorption rates,[186] and metabolism.[186]

First, this section briefly examines how cannabinoids are measured in blood. Next, it examines differences in measurement and detection for: frequent compared to occasional users, different consumption methods, time of testing, alcohol co-use, and cannabis potency. Evidence for whether blood levels relate to impairment is assessed. The section concludes by examining feasibility of blood collection in Massachusetts.

1. How are cannabinoids measured in blood?

AIM: This section summarizes which types of blood are used and the difference in type of blood used (i.e. whole blood, plasma, serum).

Cannabinoids are measured in blood through varying laboratory techniques that are beyond the scope of this report, see Citti et al. 2018[191] and Desrosiers et al. 2015.[185] Cannabinoids can be measured in blood plasma, blood serum, or a whole blood sample.[191,192] Plasma is commonly used in clinical settings whereas whole blood tends to be used forensically.[187] Plasma blood samples have approximately twice the concentration levels compared to whole blood samples.[186] This ratio is an approximation. One study reports a blood to plasma ratio range of 0.31-1.1.[193] It is important to note here that blood serum is different from plasma (*i.e. it does not include clotting components of blood*); However, distinctions between blood serum and blood plasma are not always made in the literature.

Although THC is the major psychoactive cannabinoid in cannabis,[180] other cannabis metabolites including 11-Hydroxy-THC (11-OH-THC) and 11-nor-0-carboxy-THC (THC-COOH), as well as lesser studied or non-psychoactive cannabinoids including cannabidiol (CBD) and cannabinol (CBN) can also be measured.[174]

2. How does frequency of use affect blood measurements?

AIM: This section examines how cannabinoid blood concentrations differ based on the user's cannabis use frequency and history.

Cannabis use history plays a role in detection and impairment. In this report, cannabis use history refers to an individual's first initiation of use, quantity of use, length of use, frequency of use, and type of cannabis use.[125] Users, particularly heavy users, may have detectable THC in blood samples even when they are not currently impaired.[174]

In this section, ten studies were identified that examined cannabinoid blood concentration levels in relation to use history.[182,193–201] Five studies included both frequent and occasional users,[182,193,197–199] four studies included only heavy users,[194–196,200] and one study included only frequent users.[201] Six studies had participants consume cannabis on-site and measured blood at multiple time points before and after consumption.[182,193,196–199] Five of these studies had participants smoke cannabis,[182,193,196,197,199] and only one study included vaporized and oral consumption.[198] Five studies measured blood levels during a period of cannabis abstinence on-site.[194,195,199–201] In this section, only smoked cannabis data is reported due to the scarcity of other methods of consumption research.

The following cannabinoids were measured in blood: THC,[182,193–201] THC-COOH,[182,193–196,199,201] 11-OH-THC,[182,193–197,199,201] CBD,[193,198] CBN,[193,198] THC-glucuronide,[193,198] THC-COOH-glucuronide,[193] THC-A,[197] CBG,[198] THCV,[198] 11-nor-9-carboxy-THCV,[198] and THCVCOOH.[198] One study reports cannabis influence factor which is 100([THC]+[11-OH-THC])/[THC-COOH].[196] Five studies measured cannabinoids in whole blood samples,[182,194,196,198,200] and five studies measured cannabinoids in plasma or serum samples.[193,195,197,199,201] Sample sizes ranged from 1-9,[194] 10-19,[196] 20-29,[193,197,200,201] 30-39,[195,199] 40-49,[182] and over 100.[198]

Baseline/Start of study differences

This section examines variability in baseline or start of study THC concentrations. First, "on-site dosing samples" which are laboratory studies that include a baseline are reported, followed by studies of abstaining cannabis users.

"On-Site Dosing" Sample

Five studies identified higher THC concentrations at baseline for frequent smokers compared to occasional users.[182,193,197,198,202]

Three studies identified frequent smokers as having higher THC-COOH concentration compared to occasional users at the start of study.[182,193,198] Newmeyer et al. 2016 found that 11-OH-THC and THCVCOOH were higher for frequent compared to occasional users at baseline.[198] Fabritius

et al. 2013 found that THC-A was higher for frequent compared to occasional users at baseline.[182]

Two studies found that CBD and CBN were negative at baseline for both frequent and occasional users;[193,198] However, one study found higher CBN baseline levels for frequent users.[202] One study reported no THC-glucuronide[193] nor THCV[198] concentrations were found in frequent and occasional users at baseline.

"Real World" Sample

Four studies measured abstaining cannabis users and reported blood concentrations at the start of study.[194,195,200,201] Participants differed in time from last use, thus, these reports cannot be considered a "baseline," nor should they be assumed as non-impaired.

Studies found a range of THC positive concentrations at the start of the study. Karschner et al. 2009 found that 56% (14:25) of chronic users were THC-positive on day one with 28.6% (4:25) of THC positive participants having whole blood THC concentrations above one ng/ml on day one.[194] Bergamaschi et al. 2013 found that on admission, 59.1% of chronic users had THC whole blood concentrations greater than or equal to one ng/ml.[195] Odell et al. 2015 found a maximum THC level of 15 ng/ml in whole blood at study start and minimum THC level of one ng/ml at study start.[200] Karschner et al. 2016 detected THC in 96.4% of chronic users at start of study with 82.1% having concentrations that exceeded two ng/ml in plasma.[201]

For analytes other than THC at start of studies: Bergamaschi et al. 2013 found that 73.3% of chronic users were 11-OH-THC positive, with 40% under or equal to one ng/mL in whole blood.[195] Karschner et al. 2016 found that 89.3% had detectable 11-OH-THC in plasma, with 42.9% less than or equal to two ng/ml.[201]

Bergamaschi et al. 2009 found that 96.7% of chronic users were positive for THC-COOH.[195] Likewise, Karschner et al. 2016 found that 100% of the sample were positive for THC-COOH.[201]

Length of measurement

This section examines how long after consumption cannabis analytes can be measured in blood. Frequent and occasional users are examined separately. Five ng/ml, two ng/ml, one ng/ml, and zero ng/ml are highlighted because these are proposed and current per se laws for THC detection in blood. Having a per se limit assumes that most users would fall above the limit when impaired and below the limit when not impaired.

THC

THC blood concentrations persist longer than the expected window of impairment which is debated, but is typically estimated to last one to three hours after consumption,[70] or six to eight hours after edible consumption.[136]

"On-Site Dosing" Sample

Studies that provide cannabis on-site then measure blood concentrations at multiple time points find different lengths of detection for frequent compared to occasional users.[182,193,196–199]

Detection

Newmeyer et al. 2016 found that all frequent users had detectable THC seven hours after consumption.[198] Skopp et al. 2008 found that 50% (8:16) of heavy users had detectable THC after 24-to-48-hours of abstinence (1.2-6.4 ng/ml in blood serum), whereas 40% (6:15) of moderate users had detectable THC after 24-to-48 hours of abstinence (1.0-2.6 ng/ml), and only 17% (1:6) of light users had detectable THC after 24-to-48-hours of abstinence.[199] Skopp et al. 2008 found that THC was detected as long as 120 hours of abstinence for one heavy user.[199]

1 ng/ml

Newmeyer et al. 2016 found that frequent smokers had equal to or over one ng/ml of THC in whole blood for over 72-hours of abstinence.[198] In contrast, Newmeyer et al. found occasional smokers fell below this limit 3.5-5-hours after smoking.[198] Toennes et al. 2008 found only one occasional smoker had a THC level over one ng/ml in blood serum at 8-hours after cannabis consumption (smoking).[197]

5 ng/ml

Newmeyer et al. 2016 found that some frequent smokers had equal to or over five ng/ml of THC in a whole blood sample 12-26 hours after use.[198] Desrosiers et al. 2014 found frequent users were equal to or over five ng/ml in whole blood from 1.1 to over 30-hours after use.[193]

On the other hand, occasional smokers were likely to fall under this limit quickly. Newmeyer et al. 2016 found that no occasional smoker was over a five ng/ml whole blood limit 1.5-hours after smoking.[198] Similarly, Desrosiers et al. 2014 found that all occasional smokers fell under this limit in whole blood by two hours, but some occasional smokers were never above the limit at the first collection timepoint.[193]

In the Desrosiers et al. 2014 sample, the median time that whole blood THC exceeded five ng/ml was 3.5-hours after cannabis consumption for frequent users and the maximum time (hours) it was detected was longer than 30 hours.[193] Specifically, 16.7% of frequent users remained over a five ng/ml limit after 30-hours of abstinence.[193] For occasional users, the median time THC

exceeded five ng/ml in whole blood was one hour and the maximum was 2.1-hours.[193] Two occasional users never had blood levels exceed five ng/ml.[193] Authors suggest that some occasional users would not be detected by a five ng/ml limit, yet frequent users may be wrongly implicated by a five ng/ml limit.[193]

"Real World" Sample

Similar to laboratory dosing research, research on cannabis-abstaining users found different detection windows for frequent cannabis users compared to occasional users.[194,195,199,200]

Detection

Odell et al. 2015 detected THC in some chronic users after one week of abstinence.[200] In fact, six cases returned to their baseline after dosing that was higher than the peak THC levels for some occasional users.[200] Karschner et al. 2016 and Bergamaschi et al. 2009 also detected THC up to a month of abstaining in chronic heavy users.[195,201]

1 ng/ml

Karschner et al. 2009 found that 12% (3:25) of heavy users remained equal to or greater than one ng/ml and 24% (6:25) had THC concentrations equal or above 0.25 ng/ml in whole blood at one week of abstinence.[194]

2 ng/ml

Bergamaschi et al. 2009 found that 4.8% (1:21) of heavy users had ≥two ng/ml THC or ≥five ng/ml THC-COOH at 9 days of abstinence. This study found that 6.3% (1:16) of heavy users remained above this limit after 18 days of cannabis abstinence.[195]

Karschner et al. 2016 found that after one week of abstinence 29.2% of chronic users had THC levels over two ng/ml.[201]

5 ng/ml

Odell et al. 2015 found that 43% (9:21) of chronic users were above five ng/ml of THC on second day of abstaining. The longest an abstaining participant was over five ng/ml was the final collection time of 129 hours.[200] In contrast, Bergamashci et al. 2009 found that no chronic users exceeded five ng/ml after one day of abstinence.[195]

Other cannabinoids

11-OH-THC

Karschner et al. 2016 found that 11-OH-THC was only detected when THC was detected, but 11-OH-THC detection rates fell faster than THC detection times.[201] Karschner et al. 2016 found that 11-OH-THC was detected at or above one ng/ml in blood plasma up to three days of abstaining.[201] Desrosiers et al. 2014 found that 11-OH-THC cannabinoid concentrations were higher for frequent smokers at most time points up to 30 hours after smoking.[193] Skopp et al. 2008 found that THC plus 11-OH-THC did not indicate recent use for heavy users.[199] Toennes et al. 2008 reported that the elimination of 11-OH-THC was slower for frequent users compared to occasional users.[197]

THC-COOH

Bergamashci et al. 2009 found that on admission, 96.7% of chronic users were positive for THC-COOH and all who were positive on admission remained positive after one day.[195] Karschner et al. 2016 also found that all chronic users were THC-COOH-positive on admission and were positive up to 10 days of abstinence, with one person remaining positive over 33 days.[201] Likewise, Desrosiers et al. 2014 found that THC-COOH concentrations were higher for frequent smokers at all times up to 30 hours after consumption.[193] Karschner et al. 2009 detected THC-COOH in all chronic users throughout a week of abstinence.[194] For some chronic heavy users, Bergamashci et al. 2009 found that THC-COOH could be detected up to a month of sustained abstinence.[195]

Skopp et al. 2008 noted interpersonal variability in levels of THC-COOH and THC-COOH glucuronide.[199]

THC interpersonal variability

A “per se” limit assumes that people show generally predicable measurements of cannabinoids in their system or that there is low interpersonal variability. However, current research assessed in the previous section showed interpersonal differences in the length of detection time of THC, thus, we can safely conclude that the current research does not support this assumption. This section includes researchers who specifically comment on interpersonal variation.

In a sample of chronic users, Karschner et al. 2009 found that whole blood THC concentrations were extremely variable.[194] THC was never detected in some participants while it was detected throughout a week of abstinence in others.[194] Karschner et al. 2009 and 2016 also found negative THC samples interspersed with positive THC samples.[194,201]

Similarly, Toennes et al. 2008 found large interpersonal variability in THC in frequent and occasional groups.[197] Authors noted that a number of frequent smokers had THC levels when sober that resemble concentration(s) found in occasional users after acute cannabis consumption.[197]

3. How do different methods of consumption affect blood measurements? (*e.g. smoked, oral, vaporized*)

AIM: This section examines differences in blood measurement based on method of cannabis consumption.

Two studies were identified that compared more than one consumption method and reported blood levels.[189,198] Both studies were double-blind, placebo-controlled, and case-crossover, meaning each participant was in all research conditions.[189,198] One study included 11 frequent and nine occasional users,[198] the other included 17 infrequent users.[189] Newmeyer al. 2016 had participants remain on the unit for at least 54 hours after consumption,[198] and Spindle et al. 2018 followed up for eight hours after dosing.[189]

Newmeyer et al. 2016 measured THC, THC-glucuronide, 11-OH-THC, THC-COOH, THCVCOOH, THC-COOH-glucuronide, CBD, CBN, CBG, THCV in whole blood.[198] Spindle et al. 2018 measured THC in whole blood.[189] Blood was collected at varying timepoints, including: baseline,[189,198] through eight hours,[189] or through 54 or 72 hours after consumption.[198]

Newmeyer et al. 2016 found few differences between vaporized and smoked cannabis conditions.[198] In contrast, Spindle et al. 2018 found that those in the vaporized condition had greater psychomotor, cognitive, and subjective effects than those in the smoking condition.[189] In this infrequent user sample, Spindle et al. 2018 also found that those in the vaporized condition had larger peak THC concentrations than those in the smoking condition in whole blood.[189]

Newmeyer et al. 2016 found differences between inhaled methods of consumption and oral doses.[198] CBG and CBN were found in the blood after smoking or vaporizing but not after oral dosing.[198] In addition, maximum THC, THC-COOH, and THC-COOH glucuronide concentrations in the blood were higher after smoking and vaporizing compared to oral dosing for both occasional and frequent users.[198] The 11-OH-THC maximum concentrations were higher and occurred later after oral dosing for occasional users only.[198]

Newmeyer et al. 2016 also found differences between frequent and nonfrequent users.[198] In this sample, frequent smokers were THC-positive for 100% of smoked cannabis conditions, 90.9% of vaporized conditions, and 100% of the oral doses at the last collection time.[198] In contrast, occasional smokers were not THC-positive after smoked or vaporized cannabis conditions, and 11.1% were positive following oral doses at the last collection time.[198]

Newmeyer et al. 2016 concluded no one criterion studied to date is capable of identifying cannabis use within a single timeframe for smokers of all frequencies and after all methods of consumption.[198] Authors suggest that any results should be interpreted with multiple, complementary criteria—presence of minor cannabinoids, THC concentrations, and analyte ratios—in conjunction with any impairment observations.[198]

4. How does the timing of blood tests affect results? What actually happens in the field?

AIM: This section examines how the timing and delay of blood tests effect results. It looks specifically at blood collection times in the field. THC is the primary focus since it is both the most well-researched thus far and the focus of proposed policy options.

THC presence can be quickly detected in blood particularly when it is smoked and vaporized (one minute after consumption); However, it decreases 80-90% 30-minutes after consumption.[66,89] Blood collection must occur as quickly as possible to the time of stop for a more accurate reading of blood concentration levels during the time of suspected cannabis-impaired driving. For example, a laboratory sample of smoked cannabis with and without alcohol in occasional users found if blood collection was delayed from 1.4-4.8 hours after consumption, median THC concentrations would show over 90% decreases from the individual's maximum THC level.[150] These authors recommend blood collection occur at the start of any impairment evaluation rather than at the end of the process, as is current status quo.[150]

Blood collection time in field

Blood collection times in the field occur later than what can be collected in laboratory settings. Seven studies that report collection times in the field were identified.[66,150,157,159,160,203,204] Two studies cited other researchers for time from police stop to blood draw,[66,150] three studies collected and analyzed new data from police stop to blood draw,[157,203,204] and three studies collected and analyzed drug recognition expert (DRE) data.[157,159,160]

Two studies report that blood collection typically occurs 1.5 to four hours (90 to 240 minutes) after an incident.[66,150] In Washington state, Banta-Green et al. 2016 linked toxicology lab data to law enforcement dispatch data and found that the median time to draw blood was 165 minutes.[203] Banta-Green et al. 2016 also found that on average, there were shorter delays for THC-positive drivers, suggesting delays underestimate drivers who exceed a per se limit at the time of suspected cannabis-impaired driving.[203]

In a Colorado and Washington sample that linked dispatch data to time of first blood draw, Wood et al. 2015 found that the average time to draw blood was 2.32 hours (139 minutes) with a range of 0.83 to eight hours.[204] In a California sample including DRE and non-DRE evaluations, Declues et al. 2016 found that the average time from first contact to blood collection was 193 minutes for DRE evaluations and 152 minutes for non-DRE evaluations.[157]

Two studies reported time from arrest to blood draw in DRE-only samples, it is unknown how long before the time of arrest the driver was pulled over.[159,160] In a DRE-only sample from nine states, Hartman et al. 2016 found that the median collection time from arrest to blood collection was 61 minutes, with a range of 0-225 minutes.[159] In another DRE sample of nine states, Logan

et al. 2016 found an average of 74 minutes and a median of 61 minutes, with the longest delay being three hours and 45 minutes.[160]

5. Can you estimate time of consumption from a blood sample?

AIM: This section examines whether it is possible and reliable to detect the time of consumption from blood samples.

This section examines studies that try to extrapolate time of cannabis use from blood samples. It includes non-model estimations, including from THC presence and presence of shorter-lasting cannabinoids, and models identified in the literature.

Estimation from THC levels

In a review article, Quijano-Mateos et al. 2017 emphasized the challenge of estimating time from blood samples due to the differences in concentrations between frequent and occasional users.[205]

One study was identified that examined time of cannabis consumption in relation to THC concentration.[150] Hartman et al. 2016 randomized participants into cannabis, alcohol, and combined conditions then measured THC in blood and plasma samples at different time points during a simulated drive.[150] Authors found interpersonal variability in both oral and blood measurements.[150] Hartman et al. 2016 concluded that without reliable information about time of last cannabis consumption, history of use, method of consumption, and individual metabolism, it is impossible to determine precisely how much or how rapidly concentrations decreased before the time of data collection.[150]

Short-term cannabinoids

This section examines cannabinoids that are detected for a shorter period of time than THC after cannabis consumption. Two studies were identified that estimate time from consumption based on alternative cannabis analytes.[193,198]

Two studies found cannabidiol (CBD),[193,198] cannabinol (CBN),[193,198] and one study found THC-glucuronide indicated more recent use.[193] Specifically, Desrosiers et al. 2014 found these analytes were not different between user groups and found that CBD, CBN, and THC-glucuronide were detected only between four to five hours.[193] Importantly, the lack of detection did not exclude recent use.[193,198]

Model I, Model II, and Combined[206]

There are several models that attempt to estimate the last time of cannabis use from THC concentrations in the blood.[186] Model I uses THC plasma concentrations, Model II is a THC-COOH/THC ratio,[190] and a third model combines the two.[186] See Huestis et al. 2005 for full models.[206] While these models show predictive ability in samples of occasional users, they are not reliable in samples of heavy chronic users. Two studies were identified that use Model I, Model II, and the combined models.[206,207]

Huestis et al. 2005 identified two models and a combined model to estimate time since consumption from a plasma blood sample.[206] In this study of non-daily users, blood samples were taken before and after up to 235 minutes after the start of smoking cannabis.[206] Some of the sample smoked a second THC cigarette at another time point.[206] THC blood plasma concentrations between were 0.5-2 ng/ml.[206] In their sample, the best model was the combined model which had a 99.1% accuracy rate with no underestimates.[206]

Karschner et al. 2012 replicated these models with a sample of daily users.[207] In the combined model, Karschner et al. 2012 found that predictive accuracy was very low, only at 10% a half-hour after dosing.[207] Accuracy was high one-to-five hours after a single dose (98.8% accurate), but worsened during the period of abstinence.[207] Models underestimated the time of last use for 80% or more cases at 22.5 hours after the last dose.[207] Karschner et al. 2012 concluded that these models are not appropriately predictive for chronic heavy users.[207]

Hartman et al. 2016 identified the following factors as challenges to time estimations from blood samples: between person variability, within person variability, metabolism differences, cannabis use history, and the lack of zero-order pharmacokinetics.[150] In the roadside context, cannabis use history, and inter-personal, and intra-personal variables will likely be unknown.

6. How does alcohol affect THC levels in blood?

AIM: This section examines whether THC and other cannabinoid levels in the blood are affected by alcohol co-use.

In this report, alcohol co-use refers to the use of both alcohol and cannabis on the same occasion. Subbaraman and Kerr 2015 used the 2005 and 2010 National Alcohol Survey data, which is a general population sample, and found that the co-use of cannabis and alcohol was nearly twice as high as the number of people who use both substances at different times.[208] Subbaraman and Kerr 2015 also found that co-users were twice as likely to drive while impaired by alcohol compared to those who use both substances but not on the same occassion.[208] There are many gaps in this research area including a lack of longitudinal studies related to substance co-use.[209]

Four studies were identified that examined alcohol and cannabis co-use.[139,150,158,210] Two studies included both frequent and occasional cannabis users,[158,210] one study included only chronic heavy users,[139] and one study included only occasional users.[159] Three studies had participants smoke cannabis[139,158,210] and one study had participants vaporize cannabis.[150] All studies measured THC in the blood, one study also measured THC-COOH and 11-OH-THC.[139] All studies measured blood alcohol content in the blood or breath.[139,150,158,210]

Three studies found larger THC peak concentrations for the THC and alcohol combined condition.[150,158,210] In contrast, in a sample of heavy chronic users, Ramaekers et al. 2011 found no difference in THC peaks between groups.[139] Ramaekers et al. 2011 also found no difference in 11-OH-THC and THC-COOH concentrations between conditions.[139]

Hartman et al. 2016 found that despite differences in peak THC concentrations, the percent decreases in THC and alcohol concentrations did not differ based on condition.[159]

7. How do high potency cannabis concentrates affect blood concentrations?

AIM: This section examines whether high potency cannabis concentrates impact THC detection in the blood.

Cannabis potency (*i.e. strength as measured through percent of THC*) has trended upward[183,211] and concentrates (*e.g. dabs, shatter*) contain extremely high doses of THC. Knowledge about more potent cannabis flower and concentrates is a gap in the literature.[175] Sagar et al. 2018 found that the use of concentrates in the U.S. is growing, but identified a lack of data regarding prevalence, use patterns, and other important variables.[211] This may be due to the newness of concentrates and their lack of availability to researchers. There were historically no concentrates available for research from the National Institute on Drug Abuse (NIDA).[c] No human experimental studies were identified that use cannabis concentrates.

Only one relevant study was identified that examined effects of concentrates on a mechanical lung.[212] This study analyzed concentrate samples submitted by medical cannabis patients for potency and found that maximum THC levels were between 23.7-75.9% with an a median maximum concentrate level of 69.3% THC.[212] Some concentrates exceed these THC levels.[211] In comparison, the average potency of seized cannabis was 11.8% in 2014.[149]

Using an artificial lung, Raber et al. 2015 measured the amount of THC that was converted to vapor in order to estimate THC exposure from one dab (40 mg concentrate).[212] Authors found appropriately 50% of available THC was recovered in the mechanical lung.[212] They noted that this does not indicate the amount actually absorbed in the body, as it is affected by a number of other factors.[212] Authors also observe great interpersonal variability in the effects patients report from dabbing.[212]

[c] https://www.drugabuse.gov/researchers/research-resources/nida-drug-supply-program-dsp/marijuana-plant-material-available-nida-drug-supply-program

8. Do cannabinoids in the blood correlate to impairment measures?

AIM: This section examines whether cannabinoids in the blood are associated with psychomotor or cognitive impairment.

In review, Armentano 2013 identified the wide range of proposed THC per se limits in the literature from one ng/ml limits to over 10 ng/ml suggestions.[174] These authors emphasize the lack of consensus in current literature.[174] This section uses the experimental articles identified in the Detecting Impairment section along with other relevant studies to determine: 1) whether impairment levels correlate to THC or other cannabinoids concentrations in the blood, and 2) whether impairment levels support a per se limit for THC. Six studies were identified.[133,136,157,159–161] [See Section *XIII. State of Science: Detecting Impairment*: subsections: *Can Standardized Field Sobriety Tests measure impairment by cannabis? Which parts of the test are effective?* and *Can Drug Recognition Experts measure impairment by cannabis? Which parts of the process are more or less effective?*].

Four studies examined whether THC blood concentrations were associated with measures of impairment as measured through a standardized field sobriety test (SFST),[133,157,160] drug recognition expert (DRE) documentation,[160] and driving simulators.[161] One study reported whether concentrations were related to the divided attention task, digit symbol substitution, and paced auditory serial addition task.[136] One study reported whether 11-OH-THC concentrations were associated with measures of impairment using the SFST.[133]

In SFSTs, Declues et al. 2016 and Logan et al. 2016 found no correlation between THC blood concentrations and impairment.[157,160] Newmeyer et al. 2017 found no association between THC or 11-OH-THC levels and impairment for frequent users; However, this study did find an association between THC and 11-OH-THC levels for infrequent users and impairment.[133]
In a driving simulator study, Papafotiou et al. 2005 found that THC in blood was not an accurate predictor of impairment.[161]

In a study of DRE reports, Logan et al. 2016 found that impairment in four of 15 DRE indicators (*i.e. diastolic blood pressure, finger to nose misses, cannabis odor, and lack of convergence*) were associated with THC blood concentration.[160] However, authors noted blood THC concentrations only explained 3% of variance within these indicators.[160] None of the other indicators were associated with THC in blood.[160]

In three cognitive and psychomotor tasks, Vandrey et al. 2017 found no correlation between THC as measured in whole blood.[136]

Impairment and Per Se Limits

Two studies report whether impairment is related to a per se limit of THC in the blood.[159,160] Both studies measured impairment through toxicology confirmed DRE reports and neither found support for per se limits based on blood concentrations.[159,160]

9. Is blood collection feasible in Massachusetts?

AIM: This section discusses the implications of blood collection in Massachusetts.

Blood collection requires significant capital and resources that extend beyond toxicology laboratory related costs. Law enforcement officer training would be required. There are logistical concerns about facilities for collection.[213] Blood collection is an invasive process[213] and requires a warrant. In Massachusetts, warrants take on average ten hours to obtain[34] which would result in a much lower THC concentration than its concentration at the time of driving particularly for occasional users. Therefore, a per se limit may miss impaired drivers whose THC blood levels are lower than the limit at the time of testing.

Blood collection and per se limits are also a social justice issue. Chronic users, potentially including medicinal users, and others using a legal substance may be wrongly convicted with THC per se limits. Some frequent users show non-zero THC concentrations at an unimpaired baseline level.[143] Massachusetts's commitment to addressing the harms of prohibition may be counterproductive if minorities and other disproportionately impacted groups continue to be wrongly or disproportionately convicted of operating a motorized vehicle under influence of cannabis.

Blood collection for the purpose of detection rather than impairment may be helpful. This could prevent wrong convictions by disproving past use, although testing is not perfect. THC and other metabolites in blood do not indicate impairment: However, blood testing may be helpful to support to a law enforcement officer's assessment of cannabis impairment.

State by state and international data

Per se limits are numeric thresholds ("cut-offs") for a drug or drug metabolite concentration in the body.[214] Zero tolerance laws are per se limits of zero which means any amount of the drug or metabolite in the body is illegal.[214]

Internationally, Wong et al. 2014 categorizes cannabis driving laws as impairment based, per se, or two-tiered.[215] Impairment laws require evidence that a drug negatively affected driving (*e.g. Greece, Ireland).*[215] Per se laws vary in limits, type of blood sample, and type of cannabinoids detected but result in punishment if a driver is over the threshold limit (*e.g. Switzerland 1.5ng/ml in whole blood with 30% error margin,*[124] *Slovenia 0.3 ng/ml in blood serum and 5 ng/ml THC-COOH in blood serum*).[215] Two-tier laws combine impairment and per se laws. Two-tiered laws punish drivers for exceeding per se limits, but the punishment is harsher if driving impairment is also documented (*e.g. Belgium, Denmark*).[215]

Table XIV.E.2. Cannabis-Impaired Driving Laws by State

State	Laws	Legal Limit	Research
Colorado	Permissible inference	5 ng/ml	Wood et al. 2015
Montana	Per se	5 ng/ml	
Washington	Per se	5 ng/ml	Banta-Green et al. 2016, Wood et al. 2015
Nevada	Per se	2 ng/ml	
Ohio	Per se	2 ng/ml	
Pennsylvania	Per se	1 ng/ml	
Arizona	Zero tolerance	0 ng/ml	
Delaware	Zero tolerance	0 ng/ml	
Georgia	Zero tolerance	0 ng/ml	
Illinois	Zero tolerance	0 ng/ml	
Indiana	Zero tolerance	0 ng/ml	
Iowa	Zero tolerance	0 ng/ml	
Michigan	Zero tolerance	0 ng/ml	
Oklahoma	Zero tolerance	0 ng/ml	Veitenheimer et al. 2017
Rhode Island	Zero tolerance	0 ng/ml	
South Dakota	Zero tolerance	0 ng/ml	
Utah	Zero tolerance	0 ng/ml	
Wisconsin	Zero tolerance	0 ng/ml	Edwards et al. 2017

Data from: https://www.ghsa.org/state-laws/issues/drug%20impaired%20driving as of 10/4/18

See Wong et al. 2014 for international law table

Oral fluid

Cannabis detection in oral fluid is similar to blood in that is affected by many factors, including: method of consumption, time from use, and collection method. THC is the most commonly measured cannabis analyte in oral fluid, but other cannabinoids and metabolites can also be measured. Unlike blood, oral fluid tests are affected by oral mucosa. This refers to the physical chemicals that transfer from cannabis and its smoke as a result of touching the mouth. While sensitive techniques allow detection of cannabis analytes in oral fluid following multiple method(s) of consumption, the largest THC spikes occur when cannabis is smoked, inhaled, or sprayed.[216] As a result, very high THC levels are often observed immediately after consumption followed by rapid declines.[185,216] In contrast, consuming enclosed THC capsules may leave little to no oral mucosal contamination.[216] Lee et al. 2014 categorizes THC elimination in oral fluid as having two phases: first, a rapid decrease of within one to two hours, then a slower decrease which varies by use-frequency.[216] Of note, eating or drinking may impact this time-course, and there is large person-to-person variability.

This section begins with brief oral fluid definitions and the measurement processes. Next, it examines how well oral fluid correlates with blood measurements. Differences in measurement and detection for: frequent compared to occasional users, different consumption methods, time of last use, passively exposed individuals, and alcohol co-use are assessed. A review of cannabinoids and metabolites identified in oral fluid follows along with the evidence for whether oral fluid can detect impairment. The section concludes by examining the feasibility of oral fluid collection and use in Massachusetts.

1. What is oral fluid?

Oral fluid includes saliva, mucus, and food particles in the mouth.[217] Oral mucosa refers to the membrane lining the mouth.

2. How are cannabinoids measured in oral fluid?

An oral fluid test typically consists of a mouth swap where liquid is absorbed on the swab and then analyzed in a lab or in the collection device. Collection devices may give an initial result at the time of screening and save a sample for confirmation.[218] Oral fluid can also be collected through passive drool and expectoration (*i.e. spitting)* but devices are generally preferred.[185,216] Unlike blood collection, oral fluid testing can be conducted in the field and performed quickly. However, there are general limitations of oral fluid and cannabis specific issues. There is also variability between oral fluid devices. Devices collect different amounts of fluid and have different sensitivities for detecting cannabis.[218] Different countries and organizations recommend a variety of screening and confirmation thresholds in oral fluid (*e.g. Belgian confirmation threshold 25 ng/ml,*[219] *Victoria, Australia confirmation threshold 2 ng/ml,*[219]*proposed Substance Abuse and Mental Health Services Administration [SAMHSA] confirmation threshold 2 ng/ml,*[219] *and DRUID threshold 27 ng/ml*).[220]

3. Does cannabinoid detection in oral fluid match detection in blood?

AIM: This section examines whether oral fluid cannabinoid detection matches blood cannabinoid detection.

There are many issues with blood detection (see section above); However, it is the best-established measure to approximate cannabinoid concentrations in the brain which correlate with impairment. Therefore, it is important to examine whether oral fluid tracks blood concentration levels. However, as with blood samples, only past cannabis use and not impairment can be detected in oral fluid. A unique aspect of oral fluid is oral mucosa contamination, which contributes to wide variability within and between individuals. Oral mucosa contamination refers to direct contact between the mouth and cannabis when it is consumed and can result in large THC peaks during and immediately after consumption in oral fluid.[218] In review, Lee et al. 2014 identified contamination as leading to higher THC detection levels but decreasing the extent to which oral fluid correlates with blood concentrations.[216] However, not all methods of cannabis consumption will result in contamination.

This section only includes studies that took a blood and an oral fluid sample. Further, this section is limited to THC and THC-COOH.

Thirteen studies were identified.[182,187,218,221–230] One study is a review[218] and another includes a review and experimental data,[225] all others are experimental studies. Cannabis was consumed through: smoking,[182,222,223,227] vaporizing,[187,230] oral/edible consumption,[225,227,228] or unknown method of consumption (real sample).[221,224,226,229] Nine studies administered cannabis in the lab [182,187,222,223,225,227–230] and three studies measured levels in roadside samples of real-drivers.[224,226,229] Five studies compared oral fluid to whole blood samples,[182,221,224–226] three studies compared to blood plasma samples,[227–229] three studies compared to blood serum samples,[222,223,230] and one study compared oral fluid to both whole blood and plasma samples.[187] The following cannabinoids were measured in blood: THC,[182,187,221–230] THC-COOH,[182,187,223,225,227,228,230] 11-OH-THC,[182,187,223,225,227,228,230] THCV,[225] CBD,[225] and CBG.[225]

THC

Prediction

Five studies addressed whether THC concentrations in oral fluid can predict plasma or whole blood levels.[187,222,226,227,229] All studies concluded oral fluid should not be used to predict THC concentrations in blood.

In an oral and spray administered cannabis study, Lee et at. 2013 concluded oral fluid should not predict plasma THC concentrations for any method of cannabis consumption.[227] Likewise, Hartman et al. 2016 also found that whole blood and oral fluid could not predict the others' concentration level due to high variability.[187] Jin et al. 2018 determined oral fluid should not be used to predict whole blood concentrates because 29% of blood variation was not accounted for by oral fluid tests.[226] Likewise, Toennes et al. 2010 concluded despite similar time courses variability prevents oral fluid from estimating blood serum concentrations.[222] Lastly, Wille et al.

2013 found that the ratio range of oral fluid to blood plasma was too large (1-142) for prediction.[229]

Correlation

Six studies examined whether THC levels in oral fluid were correlated with plasma or whole blood.[187,198,221,223,226,228] Four studies found that THC concentrations in oral fluid were not correlated blood concentrations,[187,198,221,228] and two studies found that THC concentrations in oral fluid were correlated with blood concentrations.[223,226]

In a study with vaporized cannabis, Hartman et al. 2016 found that THC concentrations in oral fluid were not correlated with whole blood and blood plasma concentrations 0.8-8.3 hours after cannabis consumption.[187] In a study with a cannabis edible, Newmeyer et al. 2016 found that THC concentrations in oral fluid and whole blood were not correlated.[198] In another study with oral cannabis, Milman et al. 2011 found that the logarithms of THC in blood plasma and oral fluid were not correlated.[228] In a real-world sample, Langel et al. 2014 also did not find a correlation between THC concentrations in oral fluid and in whole blood.[221]

Ramaekers et al. 2006 found a consistent ratio between blood serum and oral fluid concentrations after smoked cannabis.[223] In a roadside sample, Jin et al. 2018 found a strong correlation between log-transformed THC concentrations in oral fluid and in whole blood however authors noted that oral fluid concentrations accounted for only 29% of variation in the blood.[226]

Sensitivity and Specificity

Two studies examined the sensitivity (true positives) and specificity (true negatives) of oral fluid THC concentrations in predicting whole blood concentrations.[224,226]

Edwards et al. 2017 found that THC detection in oral fluid to whole blood had a sensitivity of 88.37%, a specificity of 86.89%, a positive predictive value of 82.61%, a negative predictive value of 91.34%, and an overall accuracy of 87.5%.[224] Jin et al. 2018 found that THC oral fluid testing to whole blood had a sensitivity of 79.4% and a specificity of 98.3%.[226] Jin et al. 2018 identified between group differences that impacted the sensitivity of oral fluid.[226] In Jin et al.'s 2018 sample, the oral fluid test was the most sensitive for those with positive blood alcohol concentrations and less sensitive for drivers over 55 years-old and for those with cannabis use in the past day.[226]

Maximum concentrations

Two studies examined the difference between maximum THC concentrations as measured in oral fluid and whole blood.[182,225]

In a study with smoked cannabis, Fabritius et al. 2013 found no difference between THC maximum concentrations in whole blood and oral fluid.[182] However, in a study using edible

brownies, Newmeyer et al. 2017 found that peak THC concentrations in oral fluid occurred at 0.33 hours after consumption whereas whole blood THC maximum occurred between one to five hours later.[225]

Median concentrations

One study examined the difference between median THC concentrations as measured in oral fluid and whole blood.[182] In a study with smoked cannabis, Fabritius et al. 2013 found no difference between THC median concentrations in whole blood and oral fluid.[182]

Half-Life

One study examined whether there was a difference in THC half-life between oral fluid and whole blood.[182] In a study with smoked cannabis, Fabritius et al. 2013 found no difference between THC half-life in whole blood and oral fluid.[182]

Variability

Six studies commented on variability of THC concentrations in oral fluid and blood.[187,221,222,225,227,229] All studies concluded that variability prevents prediction of THC concentrations from one substance to the other.

THC-COOH

THC-COOH is an important cannabis analyte to measure because it is not found in cannabis plants or smoke, rather it is a metabolite made in the body.[182] Therefore THC-COOH should not be found if the person was only exposed to second hand smoke. In oral fluid, THC-COOH will not "contaminate" the mouth like THC, in other words, oral fluid tests will not pick up high spikes due to cannabis contact with the mouth.[182] Unlike THC which is detected rapidly and often at very high rates immediately following smoking, THC-COOH takes longer to be detected because it is a metabolized product.[182] However, THC-COOH differences exist between frequent and occasional users where frequent users have, on average, higher THC-COOH levels at baseline.[227] THC-COOH is also challenging to measure because it is found at very low concentrations in oral fluid.[185]

Prediction

Two studies addressed whether THC-COOH concentrations in oral fluid can predict plasma or whole blood levels.[227,228]

Lee et al. 2013 found that THC-COOH in oral fluid is predictive of THC-COOH blood plasma concentrations. However, authors note that this is an inactive metabolite, therefore, its presence does not indicate impairment.[227] Milman et al. 2011 found that a high oral fluid to blood plasma THC ratio and a high oral fluid THC to THC-COOH ratio was predictive of recent cannabis smoking.[228]

Correlation

Two studies addressed whether THC-COOH concentrations correlate with plasma or whole blood levels. [227,228]

Milman et al. 2011 found that the logarithms of THC-COOH in blood plasma and oral fluid were correlated. Specifically, blood plasma had an approximately 1000 times higher concentration levels.[228] Similarly, Lee et al. 2014 found that THC-COOH had smaller oral fluid to plasma blood ratios ranges, which suggests a stronger association between oral fluid and plasma concentrations.[227]

Variability

Three studies examined variability of THC-COOH. Milman et al. 2011, Hartman et al. 2016 and Newmeyer et al. 2017 noted high variability in THC-COOH levels between participants.[187,227,228]

4. How does frequency of use affect THC in oral fluid?

AIM: This section examines how THC oral fluid concentrations differ based on the user's cannabis use frequency and history. This section only includes studies that have two or more groups of users (e.g. frequent and occasional).

Six studies were identified.[182,222,225,231–233] Cannabis was consumed through: smoking,[182,222,225,231–233] vaporizing,[225,233] and oral/edible consumption. [225,233] The following cannabinoids were measured in oral fluid: THC,[182,222,225,231–233] 11-OH-THC,[182,222,225,231–233] THC-COOH,[182,225,231–233] CBD,[225,231–233] CBN,[182,225,231,232] CBG,[225,233] THCV,[225,233] and THC-A.[182]

Please see individual studies for critical nuance related to samples, cannabis characteristics, limits of quantification, research methods, and results. The mixed findings and between-person differences presented below are valuable to understand because state-wide implementation of roadside oral fluid testing would impact people for whom sample characteristics (*e.g. cannabis use history, potency consumed, time since last use, etc.)* are unknown. Any oral fluid testing methods and devices must acknowledge and work for the range of people law enforcement officers interact with during a road stop.

Baseline/Start of Study Detection

Five studies reported baseline THC concentrations for frequent and occasional users. All studies found that frequent users were more likely to be THC-positive or had higher THC concentration levels in oral fluid at baseline compared to occasional users on average.[182,225,231–233]

Fabritius et al. 2013 found that frequent users had higher THC concentrations at baseline compared to occasional users.[182] Newmeyer et al. 2017 detected THC in (55.6%) of frequent smokers and no occasional smokers at baseline.[225] Desrosiers et al. 2014 found that all occasional users were negative at baseline for THC while frequent users ranged from 85.7-100% THC-positive.[232] Anizan et al. 2013 found that at admission, all occasional users were negative, whereas almost all frequent users were positive.[231] Similarly, Swortwood et al. 2017 found that frequent users were more likely to be THC positive and exceed a two ng/ml at baseline compared to occasional users.[233]

Peak THC

Five studies reported maximum THC concentrations for frequent and occasional users.[182,222,225,231,233] Two studies found no difference in peak concentrations,[222,233] two studies found frequent users had larger THC maximums than occasional users,[182,225] and one study found no difference in maximum medians between groups.[231]

Half-life

Two studies reported THC half-life (*i.e. length of time it takes for one half of THC content to be eliminated*).[182,222]

Toennes et al. 2010 found that THC had the same half-life in oral fluid for occasional and chronic users after smoking cannabis for zero through eight hours.[222] Fabritius et al. 2013 found that occasional users had a THC half-life of 0.8 hours and heavy users had a half-life of one hour after smoking cannabis.[182] However, it was not reported whether this difference was significant.[182]

Length of Detection

Five studies were identified that collected oral fluid samples up to eight hours or longer after cannabis consumption.[222,225,231–233] Oral fluid detection time frames ranged and extended from eight hours,[222] 30 hours,[231,232] 48 hours,[225] to 54 hours for occasional users and 72 hours for frequent users after initiation or end of cannabis use.[233]

Desrosiers et al. 2014 found that frequent users trended toward longer detection windows but did not find significant differences.[232] Authors suggest that if the study time frame was longer and real final THC detection times were captured rather than coded as >30 hours, significant differences may have been observed.[232]

Toennes et al. 2010 detected THC in all samples at eight hours for frequent and infrequent users.[222] Anizan et al. 2013 found that all occasional and frequent users were THC-positive up to 13.5 hours after smoking.[231] Frequent users had a median last detection time of >30 hours and occasional users had a median of 27 hours, but there were no significant differences in rates of detection over 30 hours.[231]

Swortwood et al. 2017 found that at 72 hours, 54.5% (6:11) of frequent users and 11.1% (1:9) of occasional users were THC-positive after smoking cannabis.[233] 27.3% (3:11) of frequent and 11.1% (1:9) of occasional users were THC-positive after vaporizing cannabis at 72 hours, and 18.2% (2:11) of frequent and no occasional users were THC positive after consuming oral cannabis.[233] Newmeyer et al. 2017 found that all frequent users were positive and no occasional users were positive for THC at two days, the final collection time following oral consumption.[225] Occasional smokers had an average last THC detection time of 17 hours.[225]

5. How long can THC be detected in frequent users?

AIM: This section examines the last detection time for cannabis analytes in urine after cannabis use in frequent users.

Six studies that measured THC in frequent users were identified.[228,234–238] Three studies included real samples of abstaining frequent users,[235–237] one of which was a sample of recently incarcerated people in prison.[235] Three studies were laboratory studies where cannabis was consumed on-site and measured for a period after.[228,234,238] Two of these studies used smoked cannabis[234,238] and one used oral cannabis.[228] Two studies used expectorated fluid (spit) rather than commercial collection devices.[228,238] Sample sizes were between 10-19[228,234,238] and 20-29.[235–237] The limit of quantification (or the smallest amount detectable) for THC ranged from 0.25 ng/ml,[238] 0.3 ng/ml,[236] 0.5 ng/ml,[228,234,237] and 0.9 ng/ml.[235] Time of oral fluid collection ranged from to 22 hours,[234,238] 9 days,[228,235] 10 days,[236] and 30 days.[237]

Length of Detection

Andås et al. 2014 found that the lengths of detection ranged from zero to eight days after admission to the detoxification unit.[236] Lee et al. 2011 found that the majority of chronic users were THC-negative in oral fluid at two days, but 17.9% remained THC-positive at two days. One participant had a THC-positive sample at day 28.[237] Milman et al. 2012 found that at the final collection point of 22 hours, four of nine remained THC-positive, ranging from 0.4-10.3 ng/ml.[238] Lee et al. 2012 found that all were THC-positive six hours after dosing, and four participants remained positive 22 hours after dosing, ranging from 0.5-5.5 ng/ml at 22 hours.[234]

In contrast, Øiestad et al. 2018 found that THC was only detected in oral fluid on the day of admission, except in one instance when it was found on day two, but new consumption was suspected.[235]

Milman et al. 2011 saw variable decreases in the amount of THC detected in oral fluid throughout the duration of study.[228] Although participants consumed multiple oral doses of THC, researchers saw a general decrease in THC cannabinoid concentrations over time—with the majority of participants below two ng/ml after cannabis consumption, suggesting oral consumption was not driving THC detection.[228]

Interspersed Samples

All three studies on abstaining users found that THC-positive oral fluid samples were interspersed with negative samples.[235–237]

6. How do different methods of consumption affect oral fluid measurement (*i.e. smoked, oral, vaporized*)?

AIM: This section examines how methods of consumption affect oral fluid measurement. It focuses on the difference in oral mucosa contamination and how this affects measurement. Only studies that compare two or more methods of consumption within subject are assessed.

Two studies were identified that compared more than one consumption method and reported oral fluid concentrations.[227,233] Both occurred on a secure research unit.[227,233] Swortwood et al. 2017 included 11 frequent and 9 occasional users (same sample as reported in blood section[198]).[233] Lee et al. 2013 included 11 chronic users.[227]

Swortwood et al. 2017 measured THC, 11-OH-THC, THC-COOH, THCV, CBD, and CBG in oral fluid from baseline, 0.17 hours after cannabis consumption through 54 or 72 hours after smoking, vaporizing, or eating an edible.[233] Lee et al. 2013 examined THC, 11-OH-THC, THC-COOH in oral fluid and blood plasma following oral and smoked cannabis doses over 51 days.[227] While both studies had an orally consumed condition, Lee et al. 2013's oral dose was in capsule form and did not leave traces in the mouth, whereas Swortwood et al. 2017 used an edible brownie which did contaminate the oral mucosa.

Swortwood et al. 2017 found no differences in THC, 11-OH-THC, THCV, CBD, and CBG maximums between smoked, vaporized, or an edible.[233] Swortwood et al. 2017 found that THC, 11-OH-THC, THCV, CBD, and CBG all peaked at or before 0.17 hours, the first collection time.[233] Lee et al. 2013 found higher THC concentration in oral fluid following smoked compared to the oral capsule which did not contaminate the oral mucosa.[227]

Swortwood et al. 2017 found that CBD and CBG were detected in all users after all methods of consumption.[233] THCV was detected in all frequent smokers.[233] Two of nine occasional smokers were not THCV-positive after vaporizing, but all others were positive in all methods of consumption.[233]

Swortwood et al. 2017 found some use history by consumption method interactions.[233] Frequent users had a later peak of THC-COOH after an edible compared to smoked and vaporized methods.[233] Lee et al. 2013 found that chronic users had similar THC-COOH concentrations following smoking and a non-contaminating oral dose and suggested this finding was because THC-COOH does not contaminate oral mucosa.[227]

Swortwood et al. 2017 found that most frequent users were 11-OH-THC positive after smoked 91% (10:11), and less likely to be positive after vaporized 18% (2:11) and oral 36% (4:11) doses.[233] No chronic users were 11-OH-THC-positive following oral capsule doses in Lee et al. 2013's study.[227] Swortwood et al. 2017 found that 33% (3:9) of occasional users were 11-OH-THC-positive after smoked, 0% (0:9) after vaporized, and 67% (6:9) after edible dosing.[233]

Swortwood et al. 2017 found that at frequent smokers' final collection, blood was THC-positive for 55% (6:11) smoked cannabis conditions, 27% (3:11) of vaporized conditions, and 18% (2:11) of oral doses.[233] At the final collection time for occasional smokers, oral fluid was THC positive for 0% of smoked cannabis conditions, 11% (1:9) of vaporized conditions, and 11% (1:9) of the oral doses.[233]

Swortwood et al. 2017 found that frequent smokers' final collection time, oral fluid was THC-COOH-positive for 73% (8:11) smoked cannabis conditions, 64% (7:11) of vaporized conditions, and 91% (10:11) of edible doses.[233] At the final collection time for occasional smokers, oral fluid was THC positive for 0% of smoked cannabis conditions, 11% (1:9) of vaporized conditions, and 22% (2:9) of the edible doses.[233]

Overall, Swortwood et al. 2017 found few differences between smoked and vaporized conditions.[233] THC concentrations were larger in smoked and vaporized conditions compared to the edible condition.[233] Lee et al. 2013 found large differences in THC and 11-OH-THC levels between a non-contaminating oral dose and smoking, and similar concentrations of THC-COOH, which indicates that oral mucosa plays a large role in oral fluid measurement.[227]

7. Can you estimate time of consumption from oral fluid tests?

AIM: This section examines whether the time of last cannabis consumption can be estimated from oral fluid tests.

No studies were identified that propose a model to extrapolate time of last cannabis use from oral fluid sample.

8. How does second-hand cannabis smoke affect oral fluid tests?

AIM: This section examines whether passive exposure to second-hand smoke results in detection of cannabinoids in an oral fluid test.

Three studies were identified that examined whether second-hand smoke or passive exposure was detected in oral fluid tests.[239–241] Passive exposure refers to cannabis smoke contact by non-smoking participants. Studies measured: THC,[239–241] THC-COOH,[240,241] CBN,[240] and CBD.[240]

All studies found that THC can be detected in passive, non-smoking participants. Two studies emphasized using THC-COOH as a confirmatory marker because it was not found in cannabis smoke.[240,241]

Niedbala et al. 2005 conducted two studies with participants exposed to smoke in a confined space.[239] In these studies, eight men were in an enclosed passenger van, four participants actively smoked, and four did not smoke but were passively exposed to cannabis smoke.[239]

The major difference between the two studies was the location that the oral fluid test occurred.[239] In the first study, the oral fluid test was conducted inside the enclosed space with cannabis smoke and the second study was conducted in an open space.[239] In study one, Niedbala et al. 2005 found that all passive (non-smoking) participants were THC-positive immediately after smoking stopped.[239] Three of four participants had peak THC levels immediately after smoking, and one participant had peak THC levels at 15 minutes after smoking stopped.[239] Peak THC levels were between 4.5-7.5 ng/ml, which is approximately 100 times lower than active smoker concentrations.[239] After 45 minutes, all passive smokers were negative for THC.[239] One participant later tested positive two and a half hours after smoking ceased, but authors attribute this to a contamination error.[239]

In study two, Niedbala et al. 2005 collected all oral fluid samples outside of the enclosed space and found that no samples exceeded a two ng/ml threshold.[239] Peak THC concentrations ranged from 0-1.2 ng/ml.[239] Niedbala et al. 2005 suggested that elevated THC rates in study one were due to smoke contamination of the oral fluid collection device.[239] Authors suggest that second-hand smoke will not falsely elevate THC detection levels when oral fluid is collected in a non-contaminated environment.[239]

Moore et al. 2011 examined ten non-cannabis smokers exposed to cannabis smoke in two Dutch coffee-shops.[240] They collected oral fluid samples before exposure, at 20 minutes, 40 minutes, one hour, two hours, and three hours of exposure, and at several time points through 22 hours.[240] Samples were collected outside of the coffee shop in a non-smoke contaminated environment.[240] No cannabinoids were detected in any participants before entering coffee shops.[240] In the crowded cannabis cafe, Moore et al. 2011 detected THC in all participants from 20 minutes through three hours of exposure.[240] Peak THC concentrations ranged from 1.3 – 17 ng/ml.[240] At three hours all participants in high and low-trafficked shops had detectable levels of THC.[240] CBN was detected in some participants with peak levels occurring at two or three hours of exposure ranging from zero to two ng/ml.[240] THC-COOH was never detected.[240] CBD was also never detected, although authors suggest this may be due to the high-THC, low-CBD cannabis

strains frequently consumed in Dutch shops.[240] Moore et al. 2011 concluded that THC-COOH should be used to avoid falsely identifying passively exposed, non-smokers.[240]

Cone et al. 2015 exposed six non-smokers to extreme second-hand smoke with two conditions in which non-smokers were in an non-ventilated or ventilated chamber with active cannabis smokers for one hour.[241] Oral fluid samples were collected at baseline and at time points up to 34 hours after exposure ended.[241] THC maximums occurred at the first collection time.[241] For the nonventilated conditions, peak THC concentrations were between 4.9-308 ng/ml and last detection times were 1.5-26 hours.[241] Peak THC concentrations in the ventilated condition were between 1.7-75 ng/ml and final detection times were between 0.25-3 hours. THC-COOH was never detected.[241]

9. How does alcohol affect oral fluid tests?

AIM: This section examines whether alcohol and cannabis co-use affects oral fluid measurements compared to blood concentrations and general efficacy.

Three studies were identified that examined alcohol and cannabis combined ("co-use" or "poly-drug use") effect(s) on oral fluid measurement.[187,220,242] Two studies compared alcohol's effect on THC to blood ratios.[187,242] One study examined whether the sensitivity and specificity of oral fluid testing is impacted by alcohol co-use.[220]

Blood ratios

Hartman et al. 2016 found that there were no effects of alcohol on THC measurement ratios for both whole blood and blood plasma.[187] Similarly, Toennes et al. 2013 found no effect of alcohol on THC measurement in oral fluid compared to blood serum.[242] However, large variability and ratio ranges do not allow for the prediction of THC concentrations from one matrix to the other.[187]

Sensitivity and specificity

Fierro et al. 2014 found that oral fluid had a sensitivity of 76.3% (range: 68.8-83.8) in the THC-only group and of 76.5% (range: 53.4-99.6) in the THC and alcohol co-use group.[220]

10. What are the minor cannabinoids and metabolites detected in oral fluid?

AIM: This section examines cannabis analytes other than THC that are detected in oral fluid, and the length of their detection time windows.

This section provides an overview of trends and findings between studies related to non-THC cannabis analytes in oral fluid. Minor cannabinoid detection is important because some researchers suggest that testing for cannabinoids in addition to THC can improve impairment detection.[185]

Eight studies were identified.[148,182,225,227,231,233,237,238] Four studies compared frequent and occasional users.[182,225,231,233] Cannabis was consumed through: smoking,[148,182,227,231,233,237,238] vaporizing,[148,233] and oral doses.[225,233] One study analyzed expectorated oral fluid.[238]

Please see individual studies for critical nuance related to samples, cannabis characteristics, limits of quantification, research methods, and results. The mixed findings and between person differences presented below are valuable to understand because state-wide implementation of roadside oral fluid testing would impact people for whom sample characteristics (*e.g. cannabis use history, potency consumed, time since last use, etc*.) are unknown. Any oral fluid testing methods and devices must acknowledge and work for the range of people officers interact with during a road stop.

CBD

In review, Lee et al. 2014 identified cannabinol (CBD) as a minor cannabinoid with a shorter detection window in oral fluid.[216] Seven studies include a baseline, maximum level, or last detection time measure of CBD measured in a laboratory.[148,182,225,231,233,237,238]

Baseline

Different sample types, different limits of quantification, and unknown time from last consumption resulted in a range of CBD positive or negative findings at study admission or baseline.

Newmeyer et al. 2017 found that no frequent or occasional users were positive for CBD at baseline.[225] Similarly, Milman et al. 2012 found that all baseline samples were negative for CBD.[238]

Anizan et al. 2013 found that all occasional users were CBD-negative at baseline, and 43% of frequent users were CBD-positive at baseline.[231] On admission, Hartman et al. 2015 found that 5% of participants were CBD-positive the night before dosing and 0.6% were positive the morning of dosing.[148] In a sample of abstaining users, Lee et al. 2011 found that 18% (5:28) were CBD-positive at admission.[237]

Maximum concentration

For studies that administered cannabis in the lab, CBD maximums frequently occur at the first collection time as a result of oral mucosa contamination.

Anizan et al. 2013 found that CBD maximums occurred at a half-hour for both frequent and occasional users in all but two cases.[231] Milman et al. 2012 found that CBD maximums occurred at the first collection time 15 minutes after smoking then rapidly decreased.[238] Swortwood et al. 2017 found that CBD average maximums occurred at 0.17 hours after consumption and there were no differences in peaks between smoked, vaporized, or oral doses.[233]

Last Detection Time

CBD final detection times varied based on the threshold used, sample type, and consumption method. The longest detection time was found in chronic cannabis users at 22 hours of abstaining.[238]

In Lee et al.'s 2011 sample of chronic users, CBD was only detected at admission and no other days after abstaining began.[237] Anizan et al. 2013 found that CBD last detection times occurred at a median of four hours for frequent and two and a half hours for occasional users.[231] Newmeyer et al. 2017 found that at 0.2 ng/ml threshold, CBD was detected up to five hours for frequent and up to 3.5 hours for occasional users following an edible consumption.[225] Milman et al. 2012 found that after 22 hours of abstaining, one specimen was still positive for CBD.[238]

Swortwood et al. 2017 found that the average last detection time for smoked cannabis was 8.1 hours, vaporized was 7.4 hours, and oral was 2.2 hours.[233] No participants remained CBD-positive after 20 hours.[233]

Hartman et al. 2015 found that the last detection time occurred at 8.3 hours following high-dose THC without alcohol with a median of 2.3 ng/ml, and a slighter later median of 3.3 ng/ml when THC was consumed with alcohol; However, there was interpersonal variability.[148]

CBN

In review, Lee et al. 2014 identified cannabinol (CBN) as a minor cannabinoid with a shorter detection window in oral fluid.[216] Five studies included a baseline, maximum level, or last detection time measure of CBN as measured in a laboratory.[148,182,231,237,238]

Baseline

Different sample types, different limits of quantification, and unknown time from last consumption resulted in a range of CBN positive or negative findings at study admission or baseline.

On admission, Hartman et al. 2015 found that 16% of participants were CBN-positive the night before dosing and 2% of samples were positive the morning of dosing.[148] Milman et al. 2012 found that all baseline samples were CBN-negative.[238]

Anizan et al. 2013 found that all occasional users were CBN-negative at baseline, and 64% of frequent users were CBN-positive at baseline.[231] Similarly, Fabritius et al. 2013 found that frequent users had higher CBN concentrations at baseline compared to occasional users.[182] In a sample of abstaining users, Lee et al. 2011 found that 50% (14:28) were CBN-positive at admission.[237]

Maximum concentrations

For studies that administered cannabis in the lab, CBN maximums frequently occurred at the first collection time as a result of oral mucosa contamination.

All four studies identified found that average CBN maximums occurred at the first collection time point.[148,182,231,238] Fabritius et al. 2013 also found that maximum concentrations were higher for occasional users than for heavy users.[182]

Last Detection Time

CBN final detection times varied based on the threshold examined, sample type, and consumption method. The longest detection time was at 28 hours of abstaining.[231]

Fabritius et al. 2013 detected CBN through the 3.5 hours of observation in all but one participant.[182] Milman et al. 2012 found that after 22 hours of abstaining, no samples remained CBN-positive.[238] When using a threshold level of one ng/ml, no samples were CBN-positive after six hours.[238] Anizan et al. 2013 found that CBN last detection times had a median of eight hours (range: 2-28 hours) for frequent users and six hours (range: 2-13.5 hours) for occasional users.[231] In Lee et al.'s 2011 sample of chronic users, CBN was only detected at admission and no other days after abstaining began.[237]

Hartman et al. 2015 found that CBN had longer final detection times when alcohol was also consumed.[148]

CBG

Cannabigerol (CBG) is a minor cannabinoid that is the biosynthetic precursor of THC and CBD.[185] Desrosiers et al. 2014 identified a gap in research analyzing CBG in oral fluid.[185] Two studies were identified that include a baseline or post-consumption measures of CBG as measured in the laboratory.[225,233]

Baseline

The one study reporting CBG baseline found that no frequent or occasional users were CBG-positive.[225]

Maximum concentrations

For studies that administered cannabis in the lab, CBG maximums frequently occurred at the first collection time as a result of oral mucosa contamination.

Swortwood et al. 2017 found that average CBG maximums occurred 0.17 hours after smoking and vaporizing, and average CBG maximums occurred 0.41-0.47 hours after edible consumption.[233] Newmeyer et al. 2017 also found that CBG peaks occurred at the first collection time, 0.33 hours, after edible consumption.[225]

Swortwood et al. 2017 found that CBG maximums averaged 87.4-244 ng/ml after smoked and vaporized doses and 11.9-17 ng/ml after oral doses.[233] All participants were CBG-positive at some point following consumption.[233] Newmeyer et al. 2017 found that frequent users CBG maximums averaged 31.2 ng/ml and occasional users average maximums were 21.2 ng/ml following an edible.[225]

Last Detection

CBG final detection times varied based on the threshold used, sample type, and consumption method. The longest detection time was at 32 hours of abstaining.[233]

Swortwood et al. 2017 found that frequent smokers were no longer CBG-positive at 26 hours, and occasional users were no longer CBG-positive at 32 hours.[233] Newmeyer et al. 2017 found that at the 0.2 ng/ml threshold, CBG was detected up to 14 hours for occasional users and up to for five hours for frequent users after consuming an edible.[225]

THC-COOH

THC-COOH is the inactive metabolite of THC.[185] THC-COOH is not found in cannabis smoke which means THC-COOH detection does not occur for those only passively exposed to smoke.[185] Six studies include a baseline, or post-consumption measures of THC-COOH as measured in the laboratory.[148,182,225,233,237,238]

Baseline

The two studies reporting baseline between frequent and occasional users found that frequent users were more likely to be positive than nonfrequent (“occasional”) users.[225,231]

Newmeyer et al. 2017 found that 55.6% of frequent and 16.7% of occasional users were THC-COOH-positive at baseline in oral fluid.[225] Anizan et al. 2013 found that at admission, no occasional users were THC-COOH-positive and 93% (13:14) of frequent users were THC-COOH-positive.[231] Milman et al. 2012 found that all (9:9) participants were THC-COOH-positive at baseline.[238]

Maximum

Five studies report a wide range of maximum THC-COOH concentrations.[182,225,231,233,238] This variability aligns with earlier findings.[233]

Fabritius et al. 2013 found that peak THC-COOH concentrations in oral fluid for heavy users were between 0.3 and 2.4 ng/ml.[182] The median time that THC-COOH peaks occurred were 0.6 hours after smoking, but participant peak times ranged from 0.3-2 hours.[182] In contrast, THC-COOH was never detected in occasional users.[182] Anizan et al. 2013 found that frequent users had THC-COOH median maximums at one hour and occasional users had a median maximums at five hours.[231] Frequent smokers had a median maximum of 126 ng/ml, and occasional users had a median maximum of 17.6 ng/ml.[231] Milman et al. 2012 found that after smoking, the median maximum concentrations occurred at one hour with a range between 24.5 to 314 ng/ml.[238]

Newmeyer et al. 2017 found that the average THC-COOH maximums occurred an average of 12 hours after edible consumption for frequent users, and 10 hours after consumption for occasional users with maximums ranging 123-1009 ng/ml (frequent) and 27.9-1281 ng/ml (occasional) following an edible consumption.[225]

Swortwood et al. 2017 found that the average THC-COOH maximums occurred 14.2 hours after smoking, 8.4 hours after vaporizing, and 25.7 hours after an edible for frequent users.[233] Authors also found that just three occasional users were THC-COOH-positive after all methods, but all occasional users were positive after the edible consumption.[233]

Last Detection Time

Final detection times ranged between studies and many studies did not identify the last time of detection because participants remained positive at the final collection point. Four studies noted large variability between or within groups.[148,225,233,238] The longest detection time identified were users who remained positive at 96 hours of abstaining with a threshold of 7.5 ng/ml.[237]

Lee et al. 2011 found that 64.3% of chronic users remained THC-COOH-positive after 96 hours of abstinence.[237] Milman et al. 2012 found that 22 hours after consumption, five of six participants remained THC-COOH-positive.[238] Anizan et al. 2013 found that 85% of frequent users remained THC-COOH-positive at 30 hours.[231] In contrast, only 15% of occasional user samples were ever positive.[231] Newmeyer et al. 2017 found that at 48 hours, all frequent users and 42.9% of occasional users remained THC-COOH-positive.[225] With a 15 ng/ml threshold, Hartman et al. 2015 found that the last THC-COOH detection typically occurred at or before 8.3 hours.[148]

Swortwood et al. 2017 found that at the final collection time (72 hours), 8:11 frequent users and no occasional users remained positive following smoked cannabis consumption, 7:11 frequent and 1:9 occasional users following vaporized cannabis consumption, and 10:11 frequent and 2:9 occasional users were positive following edible dose consumption at 72 hours.[233]

Hartman et al. 2015 found that alcohol did not impact THC-COOH concentrations.[148]

THC-A

Δ9-tetrahydrocannabinolic acid A (THC-A) is a biosynthetic precursor of THC and does not have independent psychoactive properties.[184] One study included a baseline or post-consumption measure of THC-A as measured in the laboratory.[182]

Fabritius et al. 2013 found that frequent users had higher THC-A concentrations at baseline compared to occasional users.[182] Occasional users' median peak time was 0.3 hours and frequent users' median peak time was 0.4 hours.[182] Occasional users had a median maximum of 130 ng/ml and heavy users had a maximum of 59 ng/ml.[182]

THCV

Tetrahydrocannabivarin (THCV) is the propyl analogue of THC.[185] Desrosiers et al. 2014 identified a gap in research analyzing THCV in oral fluid.[185] Two studies included a baseline or post-consumption measures of THCV as measured in the laboratory.[225,233]

Baseline

Newmeyer et al. 2017 found no frequent or occasional users were THCV-positive at baseline.[225]

Maximum

Swortwood et al. 2017 found that the average THCV maximums occurred 0.17-0.29 hours after smoking and vaporizing cannabis, and average THCV maximums occurred 0.47-0.53 hours after an edible consumption.[233] Newmeyer et al. 2017 found that all THCV maximums occurred at the first collection time (0.33 hours) following an edible consumption in both frequent and occasional users.[225]

Swortwood et al. 2017 found that mean maximum concentrations were 17.5-40.2 ng/ml after smoked and vaporized doses and 11.9-17 ng/ml after edible doses.[233] Newmeyer et al. 2017 found that frequent users had an average maximum concentration of 7.4 ng/ml and occasional users had a maximum concentration of 5.4 ng/ml following an edible consumption.[225]

Last Detection Time

Newmeyer et al. 2017 found that at the 0.2 ng/ml threshold, THCV was detected up to 3.5 hours for frequent and occasional users after an edible consumption.[225]

Swortwood et al. 2017 found that frequent smokers were no longer THCV-positive at or before 12 hours, with detection times occurring later in smoked and vaporized conditions compared to edible consumption.[233] In this sample, Swortwood et al. 2017 found that some occasional users

were never THCV-positive after vaporizing, but all were THCV-positive at some point following smoking and edible methods of consumption.[233]

11-OH-THC

11-hydroxy-THC (11-OH-THC) is highly psychoactive and the main active metabolite of THC. It does not naturally exist in the cannabis plant, but instead, is produced by the body after THC consumption. Five studies included a baseline or post-consumption measures of 11-OH-THC as measured in the laboratory.[182,225,227,233,238]

Baseline

Newmeyer et al. 2017 found that no participants were 11-OH-THC-positive at baseline.[225]

Maximum

Fabritius et al. 2013 found that median 11-OH-THC maximums were 6.5 ng/ml for heavy users and 2.6 ng/ml for occasional users.[182] Newmeyer et al. 2017 found that frequent users had a mean concentration of 11-OH-THC of 0.4 ng/ml and frequent users had a mean concentration of 0.6 ng/ml.[225] Milman et al. 2012 found that very few samples, 2.9%, were ever 11-OH-THC-positive during the 24-hour observation period following smoked cannabis at a 0.25 ng/ml threshold.[238] Lee et al. 2013 also found that only 5.9% of samples ever contained 11-OH-THC at a half hour after smoking and no samples contained 11-OH-THC following oral dosing at a threshold of one ng/ml.[227]

Fabritius et al. 2013 found that 11-OH-THC maximums occurred for frequent users at 0.28 hours and for occasional users at 0.32 hours.[182] Newmeyer et al. 2017 found that mean maximums occurred at 0.4 hours and 0.6 hours for frequent and occasional users respectively.[225]

Last Detection Time

Newmeyer et al. 2017 found that the last detection time for 11-OH-THC was at or before 3.5 hours for all users.[225] Swortwood et al. 2017 found that 11-OH-THC was infrequently detected after smoked, vaporized, or edible consumption— and never detected after 1.5 hours.[233] Lee et al. 2013 never detected 11-OH-THC more than half hour after smoking or following oral dosing with a capsule that did not contaminate the oral mucosa.[227]

Fabritius et al. 2013 reported a half-life of 1.7 hours for heavy users and 1.6 hours for 11-OH-THC in occasional users.[182]

11. Is oral fluid testing being used in the field internationally and in the U.S.?

AIM: Studies, reports, statues, and review articles were collected to identify whether oral fluid is being used or piloted internationally and in the United States.

International

In a comprehensive review article, Watson et al. 2016 examined international approaches to driving under the influence of cannabis, including laws and variation from 1995-2016.[243]

A series of European-led projects to study drugged driving, including: ROSITA (1999-2000), ROSITA-2 (2003-2005), and DRUID (2006-2011) examined oral fluid devices. The DRUID project tested eight oral fluid devices and none met their sensitivity and specificity thresholds.[243] Sensitivity for cannabis ranged from 11-59% and specificity ranged from 90-100%.[244] Watson et al. 2016 also cite recent studies[245,246] that found variation within device accuracy.[243]

Australia began random roadside oral fluid testing for THC in 2004.[215,244] Australia has a zero-tolerance policy, where any amount of THC in the body is illegal.[247] Currently, all states in Australia allow random testing of drivers, and THC detection triggers a confirmatory sample which can be used in court.[248] Tasmania is unique in that it requires the confirming evidence to be a blood sample, all other states allow the confirming test to be another oral fluid sample.[248]

In 2010, Spain allowed oral fluid testing as matrix for roadside detection with a mandatory confirmation sample, if positive.[249,250]

In June 2018, Canada approved roadside oral fluid testing for law enforcement officers. Only the Dräger DrugTest 5000 device is currently approved for use.[248]

Watson et al. 2016 reported that nine European countries permit roadside oral fluid detection.[243] However, laws vary between behavior impairment requirements, zero tolerance and other per se limits, and two-tiered approaches that combined per se and impairment requirements.[243] Asbridge et al. 2015 report that the type of oral fluid devices used differ between countries, including: Dräger DrugTest 5000, Alere DDS2, DrugWipe 5S, and RapidSTAT.[245]

Watson et al. 2016 ultimately conclude that it was too early to determine the ability of legal and other initiatives to prevent and deter driving under the influence of cannabis.[243] Authors emphasize the need for controlled, multi-method research to examine the efficacy of different legal approaches to drug-impaired driving prevention.[243]

United States

Four studies,[224,251–253] three reports,[254–256] and one statue[257] that describe or analyze oral fluid pilot programs in the United States (U.S.) were identified. Two studies used only DREs to administer oral fluid tests. [251,257] Seven studies had samples of suspected of drugged drivers[251–253,257] and two studies were random roadside stops.[253,255] Two studies included disclosures that authors are employed by the oral fluid device used in the study.[252,253] A key theme across studies was the value of oral fluid devices for presumptive but not absolute information (*i.e. oral fluid findings provide evidence, but are not independently conclusive).*

In a recent Massachusetts pilot study, the Abbott DDS2 (formerly Alere DDS2) and the Dräger DrugTest 5000 were used by Massachusetts State Police and others during roadside stops, sobriety checkpoints, and in substance use treatment facilities.[256] Each participant was only sampled on one device which makes direct comparison between devices difficult.[256] Devices also had different threshold levels for THC. On-site findings were compared to confirmatory oral fluid samples analyzed in the lab.[256] The overall accuracy of both devices for all drugs were very similar (92.6% and 92.5%).[256] For cannabis, the Abbott DDS2 (formerly Alere DDS2) had a sensitivity of 100% and specificity of 96.5% in the 49 THC-positive people tested.[256] The Dräger DrugTest 5000 had a sensitivity of 66.7% and specificity of 100% in the 21 THC-positive people tested.[256] Logan et al. 2018 noted that oral fluid devices should be considered presumptive and not absolute because false positives and negatives can occur.[256] Authors suggested that oral fluid testing with a confirmatory sample may be a helpful additional tool for investigating drug-impaired driving in Massachusetts.[256]

In Wisconsin, law enforcement piloted the Alere DDS2 device in suspected operating while intoxicated arrests.[224] Edwards et al. 2017 compared on-site oral fluid tests to blood results and DRE evaluations when available.[224] Authors found that nine of 14 DRE cannabis conclusions matched oral fluid device results, and oral and blood detection of THC generally occurred together.[224] Authors concluded that oral fluid is helpful as a "presumptive screening" device, but suggest that it is unlikely to replace blood as the preferred sample in Wisconsin.[224]

In Kansas, law enforcement officers used Alere DDS2 and Quantisal to pilot roadside oral fluid collection prior to DRE evaluations in suspected drugged drivers.[252] Authors confirmed the field results with laboratory analyses of blood and another oral fluid sample.[252] Overall, there were 18 THC-positive findings with oral fluid roadside testing.[252] Three were not confirmed by an oral fluid confirmatory screen in the laboratory.[252] There were no false negatives.[252] Four of the total 528 Alere DDS2 tests produced invalid results.[252] Rohrig et al. 2018 concluded that the Alere DDS2 performed well in the field as a presumptive screening device.[252]

In Vermont, the Alere DDS2 and Dräger DrugTest 5000 were used with a sample of participants under court-order for an intervention or suspected in an impaired driving case.[258] Logan et al. 2015 compared oral fluid samples to urine samples, in-field oral fluid tests, and blood tests.[258] Unfortunately, the sample size was small and even smaller for cannabis-only findings.[258] Authors concluded that the totality of factors must be considered along with laboratory confirmatory screenings to ensure validity of data for law enforcement and prosecution purposes.[258]

In Oklahoma, Tulsa law enforcement agency DREs used Alere DDS2 to obtain oral fluid samples from drivers suspected of driving under the influence of drugs.[251] Samples were also taken with the Quantisal collection device. In this very small sample size, there were no differences between onsite readings and laboratory confirmed samples. This paper does not report officer feedback related to use in the field.[251]

In California, a multi-site pilot study randomly stopped drivers and requested an oral fluid test using the Alere DDS2 device and Quantisal collection device.[253] In a selection of 50 drivers, all provided both samples. 76% results from Alere DDS2 were obtained, the other results could not be obtained due to device error.[253] Of samples that could be analyzed, five were THC-positive and all on-site findings matched laboratory samples.[253]

In a multi-state roadside survey of nighttime drivers, Lacey et al. 2007 reports on oral fluid, breath, and blood findings.[255] Participants were compensated to provide samples. Researchers used the Quantisal device and collected approximately 600 oral fluid samples. Cannabis was the most frequently detected drug.[255] Authors concluded that it was feasible to collect oral fluid in roadside surveys as 67% of drivers consented to give an oral fluid sample.[255]

In Michigan, a one-year pilot program of oral fluid testing by DREs began in November 2017. No findings were identified to date.[d] A report is due to the legislature 90 days following program completion.[257]

[d] For more information, see article: https://www.petoskeynews.com/gaylord/featured-ght/top-gallery/msp-wraps-up-roadside-drug-testing-pilot-program/article_d057be6e-7702-56b9-99e7-e1cf75da72f9.html

12. Is oral fluid testing feasibility in the field?

AIM: This section examines the feasibility of roadside oral fluid testing by law enforcement and device functionality.

Two studies were identified that examined the feasibility of oral fluid testing in the field.[259,260] This section is limited to studies and reports that include law enforcement feedback or driver feedback about oral fluid testing.

Law Enforcement Officer Feedback

In a Canadian pilot study that examined two collection devices, Secure DrugRead and Alere DDS2, for roadside use, Keeping et al. 2017 found that the overall law enforcement feedback for oral fluid testing was positive.[259] 91% of officers found oral fluid devices "easy" or "very easy" to use.[259] DRE officers were the most likely to find devices easy to use.[259] In another Canadian pilot study of three devices, Beirness et al. 2017 found that officers preferred collection devices with short collection times (*i.e. Secure DrugWipe)*, and short analysis times (*i.e. Alere DDS2*).[260] Officers strongly preferred oral fluid collection to urine samples.[260]

Device Functionality

In a Canadian pilot study that examined two collection devices, Secure DrugRead and Alere DDS2, for roadside use, Keeping et al. 2017 found that 94% of swabs were analyzed correctly on the first try.[259] 13% of samples had a device-related malfunction.[259] However, most malfunctions were printing issues, which can be resolved; 7% were unrelated to printing issues.[259] Keeping et al. 2017 found that temperature-related issues occurred in 1.2% of samples.[259] Time of day or darkness did not result in more malfunctions. For most, device durability was not an issue.[259]

Keeping et al. 2017 found that the average length of oral fluid testing procedures with Secure DrugRead or Alere DDS2 were approximately nine minutes.[259]

13. Do oral fluid test results correlate to impairment measures?

AIM: This section examines whether cannabinoids in oral fluid are associated with psychomotor or cognitive impairment.

This section examines experimental articles identified in the Detecting Impairment section, and additional relevant studies to determine whether impairment levels correlate with THC in oral fluid. Three studies were identified that examined whether impairment was associated with THC levels in oral fluid.[136,220,223]

In a study with smoked cannabis, Ramaekers et al. 2006 found a weak correlation between impairment and THC concentration in oral fluid.[223] Using an oral cannabis dose, Vandrey et al. 2017 found that subjective drug effects and impairment were not correlated with THC concentrations in oral fluid.[136]

Fierro et al. 2014 examined Spanish roadside data to compare law enforcement rated signs of impairment with THC as measured in oral fluid. When a threshold of 27 ng/ml of THC in oral fluid (as proposed by DRUID) was used, Fierro et al. 2014 found an association with behavioral, facial expressions, and speech signs of impairment.[220] Detecting THC over three ng/ml in oral fluid was associated with eye signs of impairment.[220] Overall, as the THC concentration in oral fluid increased, the number of impairment signs also increased.[220] While authors found an association between signs of impairment and THC concentration in oral fluid, oral fluid testing independently had low sensitivity and specificity when used in a random roadside context.[220]

14. What are the benefits and limitations of oral fluid collection in Massachusetts?

AIM: This section discusses the benefits and limitations of oral fluid collection.

Oral fluid collection has many benefits. For one, a special facility to collect samples is not needed[216] nor is a same gender collector.[216,218] In oral fluid samples, multiple collections are easy[216] and roadside collection may expedite results.[218,224] There is less biohazard or infection risk than blood and collection it is less invasive than blood or urine.[216,218] Oral fluid may be a better indicator of recent use[218] and may be less expensive than blood, although it may be more expensive than urine.[219] Most law enforcement officers prefer oral fluid to urine collection[260] and officers may not need a warrant to collect the sample.[261] Importantly, any feasible roadside testing could act as a deterrent to driving under the influence of cannabis.[243]

However, oral fluid testing also has significant limitations, most importantly being that oral fluid tests do not detect impairment.[220] Devices used for collecting oral fluid may not collect enough for confirmatory tests or polydrug tests.[224] Collection device type affects THC absorption rates.[229] There are challenges in detection after some oral doses[218] and concentrations are lower than in urine.[218] Dry mouth, a common acute effect of cannabis consumption, can prevent adequate sample collection.[218] THC reduces saliva production, thus, there is a need for more sensitive tests.[218] Additionally, there are concerns about: saliva contamination,[218] differences between devices,[218] and detecting passive exposure rather than use.[219]

Although some rigorous research had been conducted, more is needed to fill in knowledge gaps. Researchers have identified the following gaps requiring additional examination: linking oral fluid to crash risk,[219] linking oral fluid to impairment,[219] oral fluid concentrations following vape pens use,[233] effect(s) of potent concentrates in oral fluid[233] such as dabs, and waxes, and THC oils,[233] passive smoke and contamination,[219] THC washout in mouth,[219] multiple sampling agreement,[219] normalizing concentrations,[219] detection time frames between populations,[219] and detecting multiple drugs in oral fluid.[219]

Beirness et al. 2017 suggested that oral fluid devices would not replace DREs and screening may serve to identify more drivers under the influence of drugs, thereby enhancing the need for officers trained as DREs.[260]

15. Are oral fluid tests sensitive and specific? Which tests are most accurate?

AIM: This table presents sensitivity and specificity findings for oral fluid devices. Methods, samples, types and potency of cannabis consumed vary between studies. All are presented here, please see studies for specifics.

Table XIV.E.3. Sensitivity, Specificity, Positive Predictive Value (PPV), Negative Predictive Value (NPV) of Oral Fluid Collection Devices for THC (OF= confirmatory sample was oral fluid; B= confirmatory sample was blood)

Device	Sensitivity	Specificity	PPV	NPV	Additional Research
Dräger DrugTest 5000	94.4%(OF),[242] 92.3%(OF),[262] 90.9%(OF),[258] 87%(B),[263] 80.8%(OF),[264] 76.5%(OF),[220] 76.3%(OF),[220] 66.7%(OF),[256] 58.3%(OF)[265]	15.4%(OF),[242] 96.7%(OF),[262] 100%(OF),[258] 47%(B),[263] 95.5%(OF),[264] 93.2%(OF),[220] 80%(OF),[220] 100%(OF),[256] 98.5%(OF)[265]	80.0%(OF),[262] 100%(OF),[258] 92.6%(B),[263] 98%(OF),[264] 100%(OF),[256] 93.3%(OF)[265]	98.9%(OF),[262] 96%(OF),[258] 32.7%(B),[263] 64.2%(OF),[264] 85.1%(OF),[256] 93.3%(OF)[265]	See Newmeyer et al. 2017 for varying thresholds;[225] See Desrosiers et al. 2012 for varying thresholds;[266] See Wille et al. 2010 for varying thresholds;[267] See Bosker et al. 2012 for sensitivity by time from consumption.[155]
Alere DDS2 (Note: Alere is now Abbott)	100%(OF),[256] 100%[e](OF),[252] 88.4%(B),[224] 75%(OF),[251] 60%(OF)[258]	96.3%(OF),[256] 95.7%[f](OF),[252] 86.9%(B),[224] 100%(OF),[251] 100%(OF)[258]	96.1%(OF),[256] 83.3%[g](OF)[252] 82.6%(B),[224] 75%(OF),[251] 60%(OF)[258]	100%(OF),[256] 100%[h](OF)[252] 91.3%(B),[224] 100%(OF),[251] 100%(OF)[258]	See Newmeyer et al. 2017 for varying thresholds.[225]
(Mavand) RapidSTAT	91%(B),[263] 85%(B),[268] 72%(OF),[262] 71%(B),[267] 43.3%(OF)[264]	9%(B),[263] 87%(B),[268] 97%(OF),[262] 55%(B),[267] 88.3%(OF)[264]	92.6%(B),[263] 57%(B),[268] 78%(OF),[262] 91.2%(OF)[264]	25%(B)[263] 97%(B),[268] 96%(OF),[262] 36.0(OF)[264]	See Pehrsson et al. 2011 for varying thresholds;[269] See Wille et al. 2010 for varying thresholds.[267]
Securetec Drugwipe 5+	89.1%(tongue)(OF),[242] 87.8%(cheek)(OF),[242] 71%(B),[263] 46.6%(OF)[262]	93.8%(tongue & cheek)(OF),[242] 29%(B),[263] 98.9%(OF)[262]	70.6%(B),[263] 84.4%(OF)[262]	28.6%(B),[263] 93.4%(OF)[262]	See Pehrsson et al. 2011 for varying thresholds.[269]
Securetec Drugwipe 5	71%(B),[267] 52.2%(B)[270]	50%(B),[267] 91.2%(B)[270]	52.2%(B)[270]	91.2%(B)[270]	See Bosker et al. 2012 for varying time from consumption;[155] See Wille et al. 2010 for varying cut-offs.[267]
Drugwipe 5S					See Wille et al. 2015 for varying thresholds, time from

[e] Calculated from provided data (Table 3).[252]
[f] Calculated from provided data (Table 3).[252]
[g] Calculated from provided data (Table 3).[252]
[h] Calculated from provided data (Table 3).[252]

					consumption, and comparison matrix.[230]
Concateno DDS	37.8%(OF)[262]	100%(OF)[262]	100%(OF)[262]	94.1%(OF)[262]	
Cozart DDS	87%(OF),[271] 28.2%(OF)[264]	86%(OF),[271] 100%(OF)[264]	100%(OF),[264]	33.4%(OF),[264]	
Innovacon OrAlert	23.1%(OF)[264]	100%(OF)[264]	100%(OF)[264]	31.9%(OF)[264]	
Affinition DrugWipe	43.5%(OF)[265]	100%(OF)[265]	66.7%(OF)[265]	82.7%(OF)[265]	
Oral-Eze					See Desrosiers et al. 2014 for varying thresholds[232]

*Notes: Please see: (1) Scherer et al. 2017 for a meta-analysis of drug device sensitivity and specificity.[272] (see chart pg. 82); (2) Beirness et al. 2017 for range of sensitivity and specificities of three devices together; (3) Bosker et al. 2012 for false negatives, and sensitivity by time after smoking for Dräger Drug Test 5000, and Securetec Drugwipe;[155] and (4) Blencowe et al. 2011 for BIOSENS Dynamic, Cozart DDS 806, DrugWipe 5^{+}, Dräger DrugTest® 5000, OraLab 6, OrAlert, Oratect III, and RapidSTAT analyses.[273]

Some studies examined device sensitivity and specificity at varying threshold levels, for varying user groups, and at varying timepoints following cannabis consumption. These numbers are not included in the above chart.[225,230,232,242,267,269] Results are mixed and varied. Please see articles for full results.

Urine

Workplace and court-ordered drug testing frequently use urine as their main testing matrix. In Massachusetts, urine is the most frequently used matrix by DRE officers to test for drugs.[34] Urine testing is less invasive than blood testing and has a longer detection window than oral fluid testing. THC-COOH is the most commonly tested for cannabis analyte in urine samples.[274] THC-COOH is the primary metabolite of THC and it is inactive.[274] THC-COOH can often be detected in urine a half hour after cannabis use[124] but may be longer,[275] and for some, can be detected over a month after use.[125,190]

Urine testing and THC-COOH presence does not indicate impairment nor does it indicate time since last use.[124,274] THC-COOH detects past cannabis use although it is an imperfect matrix. Many factors impact cannabinoid concentrations and detection windows in urine including: cannabis use history,[190] body fat,[190] and urine dilution,[190] timing of test,[190] and sensitivity of urine testing method.[190] In addition, false positives can occur, thus, samples should be confirmed by a second testing mechanism.[190]

First, this section examines the length of time cannabinoids and metabolites can be measured in urine and whether time of last use can be predicted. Next, it examines differences in measurement and detection for frequent compared to occasional users, and for those passive exposed. Evidence for whether urine measurements relate to impairment is assessed. The section concludes by citing how urine testing is used in Massachusetts and elsewhere.

1. How long can cannabinoids be detected in urine following consumption?

AIM: This section examines the last detection time for cannabis analytes in urine after cannabis use. Only laboratory studies with monitored follow-up time are included.

Urine has a long detection time particularly for chronic and heavy users.[186] Seven studies were identified that measure urine for a period of time after cannabis use.[200,236,275–279] Of note, researchers use different laboratory methods to analyze cannabinoids, thus, comparison between studies is imperfect. See Leghissa et al. 2017[180] and Desrosiers et al. 2015[185] for more information regarding methods of quantifying cannabinoids.

THC-COOH

Six studies were identified that measure THC-COOH in urine and report a last detection time.[200,275–279] The longest detection time reported was through 24.7 days of abstinence.[277] In a review, Huestis et al. 2007 noted an extreme case where THC-COOH was detected in urine after 67 days of abstinence.[186]

Schlienz et al. 2018 found that the range of last detection times following oral consumption of cannabis were 24-146 hours (0.75 ng/ml quantification).[275] Length of detection time increased with THC dose.[275]

After smoking, Brenneisen et al. 2010 found that THC-COOH last detection time ranged from 48-120 hours in infrequent users (0.1 ng/ml).[276] In another smoking study design, Desrosiers et al. 2014 found that the last THC-COOH time was over 30 hours (last sample collected) at thresholds from one to five ng/ml.[278]

In a monitored abstinence sample of chronic users, Lowe et al. 2009 found that THC-COOH final detection time lasted through 24.7 days (2.5 ng/ml quantification).[277] Odell et al. 2015 found that THC-COOH was detected in heavy users through 157 hours from last use and some participants had THC-COOH levels over 1000 ng/ml at this time.[200] Goodwin et al. 2008 found a range from zero to 30 days for last detected THC-COOH levels in abstaining heavy users (2.5 ng/mL quantification).[279]

THC-COOH Glucuronide

11-Nor-9-carboxy-THC glucuronide (THC-COOH glucuronide) is a major urinary metabolite of THC. Desrosiers et al. 2014 found THC-COOH detection exceeded 30 hours at a five ng/ml threshold.[278]

THC

Three studies were identified that examined THC in urine and report a last detection time.[276–278]

In a monitored abstinence sample of chronic users, Lowe et al. 2009 found that THC last detection time ranged from 3.3-24.7 days (2.5 ng/ml limit of quantification [LOQ]).[277] After smoking, Brenneisen et al. 2010 found that THC last detection time ranged from two through eight hours in infrequent users (0.1 ng/ml).[276]

Desrosiers et al. 2014 examined free THC after smoking in frequent or occasional users and never detected any in urine.[278]

THC-Glucuronide

Desrosiers et al. 2014 found that THC-glucuronide last detection time ranged from 1.3-23.2 hours at their LOQ and 1.3-7.1 hours with a one ng/ml threshold in occasional users.[278] For frequent users, THC-glucuronide was detected for over 30 hours at a two ng/ml threshold.[278] Authors conclude, "THC-glucuronide presence can be used as an inclusionary, but not exclusionary, marker of recent use, if there is clear evidence of occasional consumption."[278]

11-OH-THC

Three studies were identified that examined 11-OH-THC in urine and report a last detection time.[276–278]

In a monitored abstinence sample of chronic users, Lowe et al. 2009 found that 11-OH-THC last detection exceeded 24.7 days (2.5ng/ml quantification).[277] After smoking, Brenneisen et al. 2010 found 11-OH-THC last detection time for infrequent users ranged from 12-72 hours, with one outlier still positive at 96 hours (LOQ 0.1 ng/ml).[276]

Desrosiers et al. 2014 never detected 11-OH-THC in urine for frequent and occasional users following smoking although authors noted it may be in glucuronide or sulfate conjugates which were not measured.[278]

CBD

One study was identified that examined CBD in urine.[278] Desrosiers et al. 2014 never detected CBD in frequent or occasional users urine although authors noted it may be in glucuronide or sulfate conjugates which were not measured.[278]

CBN

One study was identified that examined CBN in urine.[278] Desrosiers et al. 2014 never detected CBN in frequent or occasional users urine although authors noted it may be in glucuronide or sulfate conjugates which were not measured.[278]

2. Can you estimate time of use from urine tests? Are there models to detect time of last use?

AIM: This section examines whether the time of last cannabis use can be estimated from urine tests.

Long detection windows in urine means cannabis metabolite detection outlasts the time of acute impairment. Urinary THC-COOH cannot be used to predict last time of cannabis use.[276] There are models that aim to detect whether new use has occurred since an earlier urine sample that is applicable for courts, treatment, and other areas.[280,281] However, few models exist to identify recent cannabis use during an expected impairment window.

Desrosiers et al. 2014 propose a model based on percent differences in THC-glucuronide between two urine samples for frequent users (see below).[278] Consecutive urine samples were collected between 0.3 and 8.3 hours apart and this did not affect model results. Authors find a sensitivity of 82.9% and specificity of 93.4% for this model.[278]

> "*By collecting consecutive samples and setting new use criteria of absolute % difference between the 2 consecutive samples of ≥50% and a creatinine-normalized concentration of ≥2 µg/g in the first of the consecutive samples, we were able to identify recent cannabis smoking within 6 [hours] of the first urine collection with high efficiency. This model had lower efficiency in occasional smokers because there were fewer consecutive positive THC glucuronide samples*."[278]

3. How does frequency of use affect urine measurement?

AIM: This section examines how cannabinoid urine concentrations differ based on the cannabis use frequency and history. Only studies that include at least two use-history groups (e.g. frequent, infrequent) are included.

Cannabis use history plays a role in detection and impairment. In this report, cannabis use history refers to an individual's: onset age, length and frequency of use, and type of cannabis product used.

One study was identified that examined cannabinoid blood concentration levels in relation to use history.[278] Desrosiers et al. 2014 had ten occasional and fourteen frequent users smoke one cannabis cigarette in the laboratory and took multiple samples before and after dosing up to 30 hours after smoking.[278]

Desrosiers et al. 2014 found that frequent users were more likely to be THC-COOH-positive in all urine tests after smoking.[278] Frequent users also had higher maximum concentrations of THC-COOH, THC-glucuronide, and THC-COOH glucuronide, although there was wide variability between frequent users. Differences between last detection times could not be calculated because participants remained positive at the final collection time point (30 hours).[278]

4. How does second-hand smoke affect urine tests?

AIM: This section examines whether passive exposure to second-hand smoke will result in detection of cannabinoids in urine.

Four studies were identified that examined whether second-hand smoke affects cannabis metabolite, THC-COOH, detection in urine.[239,282–284] Passive exposure refers to cannabis smoke contact by non-smoking participants. Overall, studies found that ventilation minimizes urinary detection and most passively exposed people will fall below metabolite cutoffs, except in extreme cases.

Röhrich et al. 2010 studied non-smoking participants that were exposed to cannabis smoke for three hours in a busy (cannabis) coffee shop in the Netherlands.[283] THC-COOH was measured in urine.[283] Urine sampling occurred at 3.5 hours after start of exposure, and at six, 14, 36, 60, and 84 hours.[283] The average maximum THC-COOH detected in urine was 16 ng/ml and it occurred between six through 14 hours after start of exposure.[283] Röhrich et al. 2010 noted that at a 25 ng/ml threshold for THC-COOH in urine testing, no passively exposed participants would have been wrongly detected.[283]

Cone et al. 2015 exposed six participants to extreme second-hand smoke with two conditions in which non-smokers were in an nonventilated or ventilated chamber with active cannabis smokers for one hour.[282] Urine samples were collected at baseline, 15 minutes, one through four hours, and time points up to 34 hours.[282] THC-COOH was detected from 30 minutes through 34 hours for some participants.[282] Maximum THC-COOH concentration levels were 1.3-57.5 ng/ml.[282] Authors concluded that positive urine results can occur for passively exposed non-users, although this result will likely only occur in extreme conditions and in the hours directly following exposure.[282]

Niedbala et al. 2005 conducted two studies where participants were exposed to passive smoke in confined space.[239] In these studies eight men were in an enclosed passenger van, four participants actively smoked and four did not smoke, but were passively exposed to cannabis smoke.[239] Urine and oral fluid samples were collected for up to 72 hours in study one and up to eight hours in study two. In both studies, Niedbala et al. 2005 found a range of peak urine THC-COOH concentrations from 2.9 – 14.7 ng/ml. The average maximum in study one was 11.2 ng/ml and the average in study two was 8.42 ng/ml. In study one, THC-COOH was still detected at 72 hours in passively exposed participants.[239] Authors noted that all participants were under a 50 ng/ml urinary threshold, suggesting that passive smokers do inhale a small dose of THC but may fall under threshold levels.[239]

Herrmann et al. 2015 exposed six participants to cannabis smoke in a ventilated or unventilated chamber.[284] Authors found that one of six participants were THC-COOH positive in urine at 50 ng/ml threshold and four of six were positive at a 20 ng/ml threshold in the nonventilated chamber. In contrast, no participants were THC-COOH positive in the ventilated chamber.[284]

5. Can you estimate impairment from urine tests?

AIM: This section examines whether cannabis metabolites in urine are associated with psychomotor or cognitive impairment.

Impairment cannot be inferred from urinary cannabinoid tests.[276] In a review, Musshoff et al. 2006 reported that urinary THC-COOH has a long detection window and therefore cannot be used as an indicator of psychomotor impairment.[190]

6. Is urine testing being used in Massachusetts, United States, Internationally?

AIM: This section discusses how urine testing is being used in current law and practice.

Urine testing is currently used by Massachusetts law enforcement. Sergeant Don Decker reported that urine is the main biological matrix used by DREs in Massachusetts for toxicology testing.[34] While urine can be a presumptive test, it does not measure impairment. Despite this, Wong et al. 2014 reports that Nevada, Ohio, and Pennsylvania have per se limits for THC and or THC-COOH in urine.[215] Per se limits in urine have not been adopted in any European countries to date.[215]

Of note, Schlienz et al. 2017 identified gaps in the research related to THC-COOH urinary concentrations for frequent users, older adults, people with compromised drug metabolism, alternative consumption methods, impact of body mass, impact on menstrual cycle, and hormones.[275]

Breath

Measuring cannabis biomarkers in breath is an exciting methodology; However, it poses technical challenges. Breath detection is less invasive,[285] portable,[286] may better correlate better with time of impairment,[286] painless,[285] confirmatory samples are easy to take,[285] dry mouth issues with oral fluid do not occur,[287] and it may be tolerated well by users.[288] However, detection methods must be highly specific to detect small particles in breath and require sensitive analytical techniques.[289] As of November, 2018 no products that measure cannabis analytes in breath are on the market.

First, this section briefly examines how cannabinoids and cannabis metabolites measured in breath correlate with other biologic matrices. Results related to differences in measurement and detection for: frequent compared to occasional users, different consumption methods, time of last use, and passively exposed individuals are assessed. Results for whether breath levels relate to impairment and whether breath measurement can identify time of last use follows. Lastly, it examines the state of cannabis breathalyzers.

1. Does breath measurement correlate with other biological matrices?

AIM: This section examines whether breath cannabinoid measurements match oral fluid, urine, and blood measurements.

Five studies were identified that compare breath samples to another biological specimen(s).[287,288,290–292] Two studies compared breath to oral fluid,[287,290] four studies compared breath to a urine sample,[288,290–292] and two studies compared breath to a plasma blood sample.[288,291] One study had participants smoke cannabis then collected samples for six hours,[287] three studies collected one sample from patients with substance use disorders,[288,290,291] and one study collected samples in a prison.[292] The following cannabinoids were measured in breath: THC,[287,288,290–292] 11-OH-THC,[287] and THC-COOH.[287] Sample sizes ranged from four,[287] 45,[288] 47,[291] 51,[290] and 247.[292] ExaBreath DrugTrap[287] and SensAbues AB[288,290–292] were used to collected breath samples.

Oral Fluid

Detection

Kintz et al. 2017 found that THC was detected at all time points for up to six hours in oral fluid and breath (LOQ: 5 pg/filter) after smoking cannabis.[287]

Arvidsson et al. 2018 found that of participants who self-reported cannabis use in the last week, 72% of those had THC confirmed in oral fluid (LOD 0.3 ng/ml), and 28% of those self-reporting use had THC detected in the breath (LOQ of 66 pg/filter).[290]

Kintz et al. 2017 never detected 11-OH-THC or THC-COOH in the breath (at a LOQ of 5 pg/filter) or in oral fluid (at LOQ 0.5 ng/ml) up to six hours after smoking cannabis.[287]

Correlation

Kintz et al. 2017 found no correlation between THC in breath and oral fluid.[287]

Urine

Detection

Arvidsson et al. 2018 found that of the 35% of participants who self-reported cannabis use in the last week, 78% had detectable THC-COOH in urine (LOD confirmation of 10 ng/ml) and 28% of those self-reporting use had THC detected in the breath (LOQ of 66 pg/filter).[290]

In Beck et al.'s 2013 sample, 20 participants tested positive in one biological matrix or reported cannabis use, and of these 20, all were THCA-positive in urine and eight were THC-positive in breath (LOQ 3pg/filter).[291]

Skoglund et al. 2015 found that of the 35 samples that were THC-COOH-positive in urine, 11 were THC-positive in breath.[288] All 11 who were positive in the breath test were also positive in urine.[288]

Beck et al. 2014 found that THCA in urine and THC in breath samples were both negative in 212 samples, both positive in 22 samples, and urine was positive and breath was negative for THC in four cases.[292]

Sensitivity/specificity

Skoglund et al. 2015 found that seven of ten participants with THC-positive breath samples reported last intake in the past one to two days. For this measure of recent use (1-2 days), breath testing had a 91% specificity and urine had a 55% specificity.[288] Sensitivity for breath testing was 58% and for urine was 100%.[288]

Plasma

Detection

Both Beck et al. 2013 and Skoglund et al. 2015 found that all positive THC breath tests were confirmed by THC in plasma.[288,291]

Beck et al. 2013 found that 20 participants tested positive in one matrix of reported cannabis use. Out of these 20 participants, nine were THC-positive in plasma and eight were THC-positive in breath (LOQ 3 pg/filter).[291] Skoglund et al. 2015 found that 14 plasma samples were THC-positive and of these, 11 of were also positive in breath (LOQ 3.7 pg/filter).[288]

Sensitivity/Specificity

Skoglund et al. 2015 found that for recent use (within 1-2 days) breath testing had a 91% specificity and plasma had a 86% specificity.[288] Sensitivity for breath testing was 58% and for plasma was 73%.[288]

2. How does frequency of use affect breath measurement?

AIM: This section examines how THC breath concentrations differ based on the user's cannabis use frequency and history.

Three studies were identified that examined cannabinoid breath measurement in relation to use history.[293–295] Two studies included chronic and occasional users,[293,294]one study included a chronic user group and a non-using control.[295] Sample sizes were 13,[293] 18,[295] and 24.[294] All participants smoked cannabis before breath measurement, but one study[295] had participants smoke on their own, thus, the exact time from participants' smoking were unknown. The following cannabinoids were measured in breath: THC,[293–295] THC-COOH,[293,294] CBN,[294] and THC-A.[295] The limit of detection varied between studies: THC: 50 pg/pad,[294] six pg/filter,[293] and 3.75 pg,[295] THC-COOH: 100 pg/pad[294] and three pg/filter,[293] CBN: 50 pg/pad,[294] and THCA: 7.5 pg.[295] Two studies[293,294] used the SensAbues breath collection device, and one study[295] used Empore C_{18} disk.

Baseline/Admission

Two studies measured baseline or admission data.[293,294] Himes et al. 2013 found that two chronic users and no occasional users were THC-positive at admission (over 50 pg/pad).[294] In contrast, Coucke et al. 2016 found that all participants, except one occasional user had detectable THC in breath at baseline.[293] Coucke et al. 2016 found that THC in breath at baseline was higher in chronic users compared to occasional users.[293]

Maximum

THC

Coucke et al. 2016 found that the THC maximums ranged from 5644-80695 pg/filer and noted high variability between participants.[293] Of those with THC levels over 50 ng/ml, Himes et al. 2013 found that maximums ranged from 50.2-409 pg/pad with an outlier at 1170 pg/pad, which authors indicate may be a device malfunction or the result of contamination.[294] Beck et al. 2011 detected THC in all users at approximately one to two hours after smoking, and THC levels ranged from 18.0 and 77.3 pg/min.[295]

THC-COOH

Both Himes et al. 2013 and Coucke et al. 2016 never detected THC-COOH in breath samples.[293,294]

CBN

Himes et al. 2013 only detected CBN in one breath sample at a half hour after smoking.[294]

Length of Detection

Coucke et al. 2016 found that THC in breath could be detected through the three hours measured in chronic and occasional users.[293] At a higher threshold, Himes et al. 2013 found different detection lengths between occasional and chronic users.[294] One occasional user was never THC-positive and all were no longer THC-positive at one hour after smoking.[294] Three chronic users were last positive at a half hour, three were last positive at one hour, six were last positive at two hours, and one was last positive at four hours.[294] Beck et al. 2011 found that one participant was still THC-positive in breath at approximately 12 hours after last reported smoking time.[295]

3. How do different methods of consumption affect breath measurements?

No studies were identified that examined cannabinoid breath measurement based on method of consumption.

4. How does second hand smoke affect breath results?

No studies were identified that examined how second hand or passive exposure to cannabis smoke affects breath testing.

5. Do cannabinoids in breath correlate with impairment?

No studies were identified that examined whether breath measurements correlates with psychomotor impairment, roadside, or clinical tests of impairment.

6. Can you estimate time of consumption from a breath sample?

No studies were identified that tried to retroactively extrapolate time of last cannabis use from breath samples. No models were identified that attempted to calculate time of last use.

7. Does a cannabis breathalyzer exist? Would a breathalyzer be feasible in Massachusetts?

AIM: This section examines the state of a cannabis breathalyzer along with strengths, limitations, and gaps.

A cannabis breathalyzer similar to an alcohol breathalyzer is not on the market yet, but development efforts are ongoing.[286]

Strengths of breath detection include: less invasive and less intrusive than other matrices,[215] faster process,[287] can be conducted roadside,[287] do not need same gender collector,[287] "adulteration of breath" is extremely difficult,[287] no issues with dry mouth,[287] tolerated well by participants,[287] defensible in legal process,[287] easier to collect systematically,[287] and law enforcement have already incorporated alcohol breath testing into routines.[287]

Limitations include: amount of particles collected differ which makes concentration determination difficult,[290] occasional users may be missed soon after smoking,[294] there is a small research basis, and no device on the market yet.

Research gaps include: the window of detection in heavy users during abstinence,[294] effects of second hand or passive cannabis exsposure,[287,294] breath testing results during period of abstinence,[293] the extent to which breath testing is associated with other biologic samples,[287,293] whether breath testing correlates to impairment,[215] standardization/normalization data,[296] and breath may not detect full length of impairment.[286]

8. Which groups are working on breath detection devices?

Two groups were identified as working to create and market a device that measures cannabinoids in the breath and could be used by law enforcement officers on the roadside. One device would measure cannabinoids and alcohol in the breath. The time frame for these products entering the market, their validity, and reliability are unknown.

Organization	Type	Company website
Cannabix Technologies	Breathalyzer	http://www.cannabixtechnologies.com/
Hound Labs	Breathalyzer (alcohol and cannabis)	https://houndlabs.com/

Hair

Hair is another biological matrix used to detect cannabis use.[190] However, hair cannot be used to detect acute impairment and has low sensitivity.[190] For these reasons and for purposes of this report, only a brief overview is provided rather than a comprehensive literature review.

The major strength of hair detection is its long window of detection.[297] Cannabinoids can be detected in hair through several months depending on hair length and other factors.[180] However, hair sample accuracy may be compromised by second-hand smoke,[186] and has high false negative rates.[190]

Cannabinoids are incorporated into hair through multiple pathways.[186,190] Cannabinoids, including: THC, THCA-A, and THC-COOH can be measured in the hair;[298] However, they are found in low levels requiring sensitive analytic techniques.[190] THC is usually found at higher concentrations in hair than THC-COOH.[190] The advantage of detecting THC-COOH is that it is not found in smoke so it should not give a false-positive for passive exposure;[186,190] However, one study[298] found evidence of THC-COOH in the hair of non-consuming individuals likely transferred through sweat or sebum (*i.e. oil released by hair*) of consuming individuals.

Hair analyses have applications for work drug testing and court cases, but they are currently not a feasibility matrix for detecting driving related impairment.

Sweat

Cannabinoids and cannabis metabolites can also be detected in sweat. However, devices to collect sweat do not capture acute use, rather they are typically worn over a week (*e.g. PharmChek sweat patches*[299]).[186] Therefore, at this time, sweat is not a feasible matrix for use by roadside law enforcement officers to determine recent use. For these reasons and purposes of this report, only a brief overview is provided rather than a comprehensive literature review.

The major strength of sweat collection is that it can monitor drug use over a period of observation time.[299] Sweat patches are also less invasive than other matrices,[300] and cannot be "adulterated" like urine.[300] However, cannabinoid concentrations found in sweat are low so it requires sensitive methods of detection.[299] Other concerns surrounding sweat collection is that degradation over time may underestimate drug concentration,[299] there is wide variation in sweat production between people,[301] environmental exposure,[300] intentional patch removal,[300] and only a preliminary research base exists.[186]

THC is primarily detected in sweat rather than THC-COOH or 11-OH-THC.[186] CBD and CBN can also be detected in sweat.[300] Method of consumption likely affects the validity of sweat to detect use. Huestis et al. 2008 found that oral doses of THC did not result in THC detection through sweat patches.[299] Sweat testing can also identify non-acute usage. Huestis et al. 2008 found ten of eleven heavy users had THC over one ng/ml in sweat after one week of abstinence.[299] At two weeks, eight of eleven participants were negative.[299] One participant remained THC-positive over a one ng/ml threshold at four weeks of abstinence.[299]

Sweat analyses have applications for treatment, courts, and research among other purposes, but they are currently not a feasibility matrix for detecting driving related impairment.

XV. Research Gaps

After a comprehensive review of the state of science regarding psychomotor effects, detecting impairment, and detecting cannabis metabolites, the Cannabis Control Commission's Research Department, with consultation and collaboration with varying researchers, highlight the following gaps in our collective knowledge, gaps needed to guide evidence-based policy decisions.

Study design

Psychomotor, impairment, cannabinoid detection, and risk and mechanisms studies should include diverse populations, cannabis potency that reflects products sold medicinally and in licensed retail stores, high-concentrate cannabis, and varying method(s) of consumption.

- Sample/Cohort(s) of interest:
  - Real-driver, general population cohorts with sufficiently large sample sizes;
  - Medicinal and chronic users;
  - Samples with control groups and research that validates correct controls;
  - Cannabis and alcohol co-use impaired users, other poly-drug users (*e.g. cannabis and CNS stimulants etc.*);
  - Infrequent or new cannabis users; and
  - New or inexperienced drivers.

- Type of cannabis:
  - Cannabis with potencies that mirror retail or medicinal concentrations;
  - Concentrates (*e.g. butane hash oil products*); and
  - Differences between cannabis with different CBD:THC ratios and other cannabinoid ratio profiles.

- Method ("mode") of consumption:
  - Edibles;
  - Highly potent consumption methods (*e.g. "dabbing"*); and
  - Studies that compare more than one method of consumption.

- Reporting:
  - Researchers should collect, report, and adjust for sample characteristics, including but not limited to:
    - Cannabis-use history; and
    - Collection device and/or analytic techniques, thresholds for all measured cannabinoids.
  - Researchers should include confirmatory sample for biological matrices (*e.g. oral fluid, breath tests*) or report why confirmatory samples were not collected.

Psychomotor

Future research examining the acute psychomotor and cognitive effects of cannabis on driving-related tasks in the laboratory, driving simulator, and real-conditions should validate and expand tasks and outcomes related to key driving skills.

- Research on unexpected events while driving;
- Research on effects of drowsiness while driving under influence of cannabis;
- Divided attention tasks while driving;
- Research on longer driving periods;
- Potential tolerance effects in frequent or chronic users; and
- Simulator and real-driving task validation.

Detecting Impairment

Future research related to detecting impairment should examine and expand knowledge related to law enforcement roadside processes, the sensitivity and specificity of ARIDE/DRE evaluations in diverse populations, and current effectiveness and capacity for law enforcement to deal with drug-impaired driving.

- Validating 1-3 questions that law enforcement can ask roadside to assist in detecting cannabis-impairment;
- Validating non-impaired performance in SFST and DRE assessments in a range of people (*e.g. people with disabilities, older adults);*
- Validating SFST ability to assess cannabis-impairment in law enforcement samples, that includes validity of each composite test;
- Qualitative and quantitative research with law enforcement related to efficacy and problems in detecting cannabis-impairment;
- Best practice for law enforcement detecting impairment stops;
- More research evaluating sensitivity and specificity of the full DRE process in field and in laboratory setting; and
- Research related to DRE demographics across municipalities in Massachusetts.

Detecting Cannabinoids

Future research related to detecting cannabinoids should examine and expand knowledge related to varying methods of consumption, accuracy of testing within various populations or cohorts, and feasibility of testing in the field by law enforcement.

- Biological detection differences by method(s) of consumption;
- Studies with oral fluid or blood testing should use at least two tests to confirm accuracy or explain why a confirmatory test was not conducted;
- Breath testing sensitivity and specificity for cannabis and other drugs (including effects of second-hand smoked [passive exposure], differences between individuals, and correlation with impairment); and
- Feasibility studies conducted in-field.

Trends and Risk Factors

Future research related to cannabis-impaired prevalence, trends, and risk factors should consider sampling techniques to reduce bias, continue to assess prevalence and risk factors across populations, examine differences between methods of cannabis consumption, and monitor any racial/ethnic disparities to increase equity. There also remains a need for more precise crash risk research and monitoring.

- All-crash samples or random driver samples;
- Prevalence and characteristics of driving after alcohol and cannabis co-use;
- Youth use and driving patterns;
- Cannabis-impaired driving prevalence and openness, factors increasing and decreasing likelihood in different populations/cohorts (including a representative sample of the Massachusetts population);
- Examining whether there are differences in driving prevalence and willingness to drive between varying methods of consumption (*e.g. following smoking versus a high dose concentrate, edible vs. smoking/vaporizing etc.*);
- Examining effectiveness of laws and public awareness campaigns to prevent driving under the influence of cannabis;
- Research that includes arrest and court data, especially tracking racial/ethnic disparities; and
- Crash risk based on laboratory findings, FARS data, and potentially additional data resources.

XVI. Policy Considerations for the Commonwealth

Based on a comprehsive review of the scope of the issue of cannabis-impaired driving, the Cannabis Control Commission's Research Department, in consultation and collaboration with varying Massachusetts law enforcement agencies and our internal departments, make the following considerations to the Commonwealth regarding confronting cannabis-impaired driving in Massachusetts.

Legislation Considerations

- **Consideration 1:** Concerning Masachusetts General Law, C. 90, section *24*:
  - Consider replacing term: "drugs," with more inclusive terminology (*i.e. "any substance or substance(s) in combination used to impairment.");*
  - Consider changing implied consent as any refusal of any reasonable test recommended and conducted by law enforcement to detect potential substance impairment (*e.g. DRE evaluation, supplemented with a chemical test, such as urine test usually used in Massachusetts etc*.);
  - Consider changing driver ramifications for refusal of "any test of impairment by law enforcement" to be equivalent to the current ramifications for breathalyzer test refusal (*i.e. result in immediate license suspension with duration dependent on the age of driver and number of prior offenses*);
    [See Section *III. Brief History of Cannabis Laws, subsection: State-Level: Legal Background: Massachusetts: Implied Consent Laws G. L. c. 90, § 24* for additional information].
  - Consider differential penalties for drivers found impaired by multiple substances (*e.g. alcohol and cannabis co-use impairment etc.*);
    [See Sections *X. Trends in Operating Under the Influence of Cannabis,* subsection: *Alcohol Co-Use Prevalence Data* and Section *XIII. State of Science: Detecting Impairment*, subsection*: Blood: How does alcohol affect THC levels in blood*].
  - Consider substance use screening for problematic cannabis use for first-time cannabis-impaired driving offenders and recommending treatment for repeat offenders.
    [See Section *IX. Clinical Indicators]*

- **Consideration 2:** Consistent with St. 2017, c. 55: *An Act to Ensure Safe Access to Marijuana*, Massachusetts could extend a form of the current special commission on operating under the influence and impaired driving, which would be specific to cannabis. This commission could convene regularly or as needed to assess implementation and fidelity of implementation of the prior commission's recommendations and empirically-based tools to detect cannabis-impaired driving (*i.e. Drug Recognition Experts*). Additionally, this commission could continue to assess: Rates of cannabis-impaired driving cases at the local and state levels and adverse consequences (crashes, death, and disability); Scientific types of testing, medical types of testing, and data as new studies

emerge (post-November 2018); Technological advances in varying testing devices as new studies emerge; Civil liberties and social equity; Admissibility of evidence of impaired driving in court proceedings; Burden on law enforcement and mechanisms to collaborate with municipality law enforcement agencies; Training of law enforcement and front-line personnel (*e.g. Emergency Medical Services [EMS], Emergency Department [ED] personnel*), and criminal justice personnel (*e.g. Prosecutors, toxicologists etc*.); Testing mechanisms, including: validity, feasibility of roadside testing, intrusiveness, cost analysis etc.; Rate(s) of success in preventing and confronting cannabis-impaired operators; and any additional aspect of cannabis-impaired driving that the commission deems necessary or significant.

- **Consideration 3:** Other states have implemented "per se" laws that range from zero tolerance to permitting a five ng/ml THC level threshold in the blood. Given the current state of science, we guide against considering any "per se" law. Science does not support any "per se" threshold to infer impairment, and conversely, this provision could potentially harm medicinal or chronic users who may meet THC thresholds but are not acutely impaired to drive. Instead, the Commonwealth could focus on detecting impairment, which should include a biological sample as one piece of evidence to support other validated mechanisms of detecting impairment, such as the Drug Recognition Expert assessment.

  [See Sections *XIV: State of Science: Detecting Cannabis Cannabinoids*, subsections: *What is the difference between detection and impairment?, How quickly is cannabis ingested in the body?, How does cannabis measurement compare to alcohol measurement (blood alcohol content (BAC)*? and all subsections under the *Blood* subsection of *XIV: State of Science*. Additionally, please see Sections: *IV: Law Enforcement Trainings*, subsection: *Drug Evaluation and Classification Program Drug Recognition Expert Training* and the validity of the DRE training included in section *XIII: State of Science: Detecting Impairment*, subsection: *Can Drug Recognition Experts measure impairment by cannabis? Which parts of the process are more or less effective?*].

Law Enforcement, Criminal Justice, and Emergency Service Resources

- **Consideration 1:** All law enforcement officers (LEOs) be certified in Advanced Roadside Impaired Driving Enforcement (ARIDE) training after 1-year field patrol experience to reduce quantity of impaired drivers on public roadways.

  [See Section *IV: Law Enforcement Trainings*, subsection: *Advanced Roadside Impaired Driving Enforcement Training*].

- **Consideration 2:** Additional LEOs to be certified in the Drug Evaluation and Classification Program training to eventually have a minimum of one DRE-trained LEO per municipality.

  [See Sections: *IV: Law Enforcement Trainings*, subsection: *Drug Evaluation and Classification Program Drug Recognition Expert Training* and Section *XIII. State of Science: Detecting Impairment*, subsection: *Can Drug Recognition Experts measure impairment by cannabis? Which parts of the process are more or less effective?*].

- **Consideration 3:** Research collaboration among law enforcement agencies, state agencies, and researchers to:
    - Assess 1-3 empirically validated questions for LEOs to ask drivers roadside to assist in discerning impairment of: alcohol, cannabis, or any substance or substance(s) used in combination; and
    - Test and validate sensitivity and specificity for alcohol and cannabis co-use: (1) impairment and (2) metabolite thresholds in human biological specimen(s).

        [See Sections: *IV: Law Enforcement Trainings* and Section *XIII. State of Science: Detecting Impairment*, subsections: *Can Standardized Field Sobriety Tests measure impairment by cannabis? Which parts of the test are more or less effective?* and *Can Drug Recognition Experts measure impairment by cannabis? Which parts of the process are more or less effective?*].

- **Consideration 4:** DRE training for Emergency Medical Services (EMS) personnel and Continuing Medical Education (CME) credit(s) for successful completion, including:
    - DRE-training specified for EMS personnel; and
    - Training on detecting the seven categories of drugs (DRE training).

        [See Sections: *VI: Baseline Data, subsection: Massachusetts Drug Recognition Expert (DRE) Data* and *VIII. Data Limitations and Future Directions]*.

- **Consideration 5:** Training for Criminal Justice Professionals (*e.g. Prosecutors, Judges, Toxicologists etc*.) on cannabis-impaired driving detection processes to support enforcement and prosecution efforts.

    [See Section *VI: Baseline Data*, subsections: *Massachusetts Drug Recognition Expert (DRE) Data* and *Drug Recognition Expert (DRE) Municipality and State Law Enforcement Survey*].

- **Consideration 6:** Toxicology training for LEOs and other personnel tasked with collecting human biological samples, including: urine, oral, blood, or other sampling mechanisms to send to toxicology laboratories to ensure validity.

Data Collection and Monitoring

Public Safety

- **Consideration 1:** LEAs to systematically change the mechanisms for coding OUI cases to additionally include a subsection for 'Cannabis' (in addition to 'Alcohol' and 'Other Drugs') so research can compare across substance categories, jurisdictions, and years of data.
    - If the OUI case includes multiple substances, these systematic and mandatory data collection mechanisms should include a mandatory designation of the primary and secondary drug category of impairment (*e.g. Two substances in OUI case: Alcohol [primary], Cannabis [secondary]* etc.).
    - Additionally, ensuring the fidelity of implementation of these mechanisms will be important to ensure data comparability and validity.

      [See Sections: *VI: Baseline Data*, subsection: *Massachusetts State Police (MSP) Operating under the Influence (OUI) Data* and Section *VII. Data Limitations and Future Direction: Data to Assess Cannabis-Impaired Driving*].

- **Consideration 2:** Sending DREs or other personnel trained in collecting human specimen cannabinoid samples to systematically collect human specimen samples at all crashes (fatal and non-fatal) to assist in determining whether any substance or combination of substance(s) were in the driver's system at time of crash.

  [See Sections *VII. Data Limitations and Future Direction: Data to Assess Cannabis-Impaired Driving* and *XIV: State of Science: Detecting Cannabis Cannabinoids,* subsection*: Blood*].

- **Consideration 3:** The Office of Emergency Medical Services (OEMS) to add tracking mechanism for "substance impairment" or "substance use and impairment expected" call to form.

  [See Sections: *VI: Baseline Data, subsection: Massachusetts Drug Recognition Expert (DRE) Data* and *VIII. Data Limitations and Future Directions]*.

- **Consideration 4:** Tracking the race/ethnicity of all persons pulled over for suspected cannabis impairment stops, as well as arrests, citations, and prosecutions for suspected cannabis-related incidents.

  [See Section *XII: Social Equity*, subsection*: Accountability: Data Collection, Monitoring, and Policy Considerations*].

- **Consideration 5:** Tracking DRE and ARIDE-trained LEO rates per municipality to ensure parity between low-income and disproportionately impacted communities with municipality averages. Additionally, DRE and ARIDE-trained LEO demographics, including: race/ethnicity should be tracked and compared to the overall demographic rates in the department or agency.

[See Section *XII: Social Equity,* subsection*: Accountability: Data Collection, Monitoring, and Policy Considerations*].

Patterns of trends of driving and riding behaviors

- **Consideration 1:** The Commonwealth to add state-added measures to the Massachusetts-Behavioral Risk Factor Surveillance System (BRFSS) to assess:
    - Past 30-day driving after any cannabis consumption behaviors (*e.g. smoke, eat, drink, vaporize, dab, other methods of consumption*);
    - Past 30-day riding with a driver who had recently consumed any cannabis product behaviors (*e.g. smoke, eat, drink, vaporize, dab, other methods of consumption*);
    - Perceived social norms of driving after cannabis use (*i.e. how often do people you know drive a motorized vehicle after cannabis consumption etc*.); and
    - Perceived risk of harm from driving after cannabis consumption (*i.e. how risky do people perceive driving after cannabis consumption to be etc*.).

      [See Section *VIII. Data Limitations and Future Direction: Youth Risk Behavior Surveillance System (YRBSS)* and *Behavioral Risk Factor Surveillance System (BRFSS)* for detailed information].

- **Consideration 2:** The Commonwealth to add state-added measures to the Massachusetts-Youth Risk Behavioral Surveillance System (YRBSS) to assess:
    - Past 30-day driving after any cannabis consumption behaviors (*e.g. smoke, eat, drink, vaporize, dab, other methods of consumption*);
    - Past 30-day riding with a driver who had recently consumed any cannabis product behaviors (*e.g. smoke, eat, drink, vaporize, dab, other methods of consumption*);
    - Perceived social norms of driving after cannabis use (*i.e. how often do people you know [e.g. friends, peers, relatives] drive a motorized vehicle after cannabis consumption etc*.); and
    - Perceived risk of harm from driving after cannabis consumption (*i.e. how risky do people perceive driving after cannabis consumption to be etc*.).

      [See Section *VII. Data Limitations and Future Direction: Youth Risk Behavior Surveillance System (YRBSS) and Behavioral Risk Factor Surveillance System (BRFSS)* for detailed information].

Education

- **Consideration 1:** Massachusetts Cannabis Control Commission with collaboration with the Executive Office of Public Safety and Security and varying relevant state agencies to continue public education via public awareness campaigns targeting youth, Massachusetts constituents, and drivers at risk, including efforts to educate on:
    - Laws and statutes of OUI-cannabis, especially if there are changes to Massachusetts General Law, C. 90, section *24* and the implied consent law;
    - Dangers of driving after cannabis use;
    - Differential effects of varying products and methods of consumption; and
    - Common misconceptions (*e.g. subjective perception of better ability to drive after cannabis use)*

        [See *Section VI. Baseline Data, subsection: Public Health Framework for Cannabis-Impaired Driving Prevention: Cannabis Public Awareness Campaign: Massachusetts*].
    - All education materials should be inclusive, multi-lingual, and reach all affected communities.

        [See Section *XII: Social Equity,* subsection*: Accountability: Data Collection, Monitoring, and Policy Considerations*].

XVII. Appendices

Table 1. Terminology

Term	Definition
Acute impairment	Acute impairment refers to adverse psychomotor and cognitive effects following a consumption period
Advanced Roadside Impaired Driving Enforcement (ARIDE)	ARIDE is considered the "bridge" training between the Standard Field Sobriety Test and Drug Recognition Expert training and provides a level of awareness to both law enforcement officers and other criminal justice professionals in detecting drug impairment and assists to get drug-impaired drivers off public roads or further examination by a Drug Recognition Expert (DRE) trained officer.[34]
Attention	Attention is the ability to concentrate and process information.
Balloon Analog Risk Task	The Balloon Analog Risk Task measures risk taking and impulsivity. This task shows a balloon on screen and asks participants to click which slightly inflates the balloon. Every click earns the participant a cent and the number of clicks needed to pop the balloon are randomized. The test is validated and shown to correlated with risk-taking behaviors.[131]
Butane hash oil product (BHO)	Butane hash oil products refer to cannabis concentrates that were extracted through a method involving butane (e.g. "dabs")
Cannabinoid	Cannabinoids are active chemical agents[174] and important biological markers that refer specifically to a group of varying molecules (terpenophenolic compounds) that bind to cannabinoid receptors in the body. There are more than 100 known cannabinoids.[175]
Cannabis	Cannabis ("marijuana") is the term often used in the United States (U.S.) to define the crude drug consisting of dry, shredded components of several Cannabis plant varietals, including: Cannabis Indica and Cannabis Sativa, the two most common varietals consumed in the United States (U.S.)[4]
Cannabis use history	In this report, cannabis use history refers to an individual's: age of onset, length of time, frequency, and method of cannabis use.
Concentrate	Concentrates are extremely THC potent products produced by extracting THC from cannabis flower.[211]
Confidence Interval	a range of values so defined that there is a specified probability that the value of a parameter lies within it (usually defined at the 95% confidence interval [CI])
Critical Tracking Task	The Critical Tracking Task has participants use a joystick counteracting movements to maintain an on-screen bar in its central location.[127] Researchers measure how frequently control is lost.[135]
Detection	In this report, detection of cannabis refers to identifying any past cannabis use.
Divided Attention Task	The Divided Attention Task asks participants to perform the Critical Tracking Task in addition to monitoring numbers on the screen and

	moving their foot off of a pedal each time the target number appears.[135] Tracking errors and correct petal responses to target number are measured.[135]
Dose-response	Dose-response relationships refer to relationships where the magnitude of the variable affects the magnitude of an outcome (For example: a low dose of medication may cause someone to feel a little drowsy, but a larger dose may make them very drowsy-this would be a dose-response relationship)
Drug Recognition Expert (DRE)	A DRE is a police officer who successfully completes all phases of the DEC Program and is up-to-date on all other requirements. DRE officers are trained to identify causes of driver impairment and identify drug categorie(s) of impairment if relevant.
Driving simulator	Laboratory models that aim to mimic driving or components of driving in a safe environment. Simulators range in quality.
Episodic memory	Episodic memory is recollection of specific experiences and events including autobiographical events.
Executive functioning	Executive functioning refers to higher order cognitive processes, including but not limited to: attention, decision making, risk taking, and memory.[125]
Finger to nose	The finger to nose task has participants close their eyes and bring their index finger to touch their nose.[156]
Go/no go task	The go/no go task measures motor impulsivity and inhibition.[129] In this task, participants respond quickly to visual cues. Most cues are "go" cues in which the participants press a left or right button. Fewer clues are "stop" cues in which the person is not supposed to hit anything. Accuracy and reaction time are measured.[129]
Headway maintenance	Headway maintenance is the amount of space left between the front of driver's car and back of the car in front of it.
Hippus	Hippus is "rhythmic change in the pupil size of the eyes, as they dilate and constrict when observed in darkness independent of changes in light intensity, accommodation (focusing), or other forms of sensory stimulation. Normally only observed with specialized equipment."[172]
Horizontal gaze nystagmus (HGN)	The HGN test is typically conducted with a suspected driver standing, feet together and arms at the side and requires the driver to follow the movement of a stimulus with his/her eyes.[31] This test has a participant follow a stimulus with their eyes that moves side to side while the test administers watches the individual's eyes for cues indicating impairment.
Impairment	In this report, impairment refers to identifying a person who is currently under the influence of cannabis.
Iowa Gambling task	The Iowa Gambling task measures decision making and risk taking through a validated risk/reward card game.

Lack of convergence (LOC)	Lack of convergence is, “the inability of a person's eyes to converge, or ‘cross’ as the person attempts to focus on a stimulus as it is pushed slowly toward the bridge of his or her nose.”[172]
Lateral acceleration	Lateral acceleration is the rate at which a car moves toward one edge of the road.
Mean	The average of a set of numbers
Median	The middle value in a set of numbers
Memory	Memory includes the processes of encoding, storing, and remembering information and experiences. There are many types of memory, including: working memory, episodic memory, semantic memory, and spatial memory.
Modified Romberg Balance (MRB)	The modified Romberg balance is used to measure balance and time perception. Participants are directed to stand with feet together, head back and eyes closed and estimate 30 seconds. Sway, eye tremors, and time estimation are observed.[133]
Monitored abstinence	Monitored abstinence refers to studies where participants remained on a secure laboratory under supervision to ensure they did not consume cannabis.
Motor control	Motor control is ability to execute coordinated body movements.
Motor Impulsivity	Motor impulsivity is the failure to stop a pre-supposed action or process.[137]
N-back Task	The spatial n-back test is one measure of spatial working memory. This task asks participants to identify whether a “stimulus matches a stimulus presented in either the previous trial (1-back), two trial previously (2-back) or three trials previous (3-back).”[131] Comparing between trials allows researchers to measure whether a more difficult cognitive load impacts outcomes. Accuracy, reaction time and errors are measured.
Negative Predictive Value	Probability that a driver testing negative is actually negative
Normative data	Normative data refers to a known baseline for a certain population or group. For example, an average of sober baselines scores for college students in a memory test to compare to average scores while impaired.
One Leg Stand (OLS)	The One Leg Stand is a test used in roadside impairment detection to measure divided attention.[31] In the one leg stand test, the driver is instructed to stand with one foot approximately six inches off the ground and count aloud by ones beginning with one thousand until told to put the foot down. The officer than observes the driver for 30 seconds assessing four indicators of impairment, including: (1) swaying while balancing, (2) using arms for balance, (3) hopping to maintain balance, and (4) putting his/her foot down.
Oral fluid	Oral fluid includes saliva, mucus, and food particles in the mouth.[217]
Oral mucosa	Oral mucosa refers to the membrane lining the mouth.
Oral mucosa contamination	Oral mucosa contamination refers to physical chemicals that transfer from cannabis to the mouth during the act of consumption.

Passive exposure	Passive (or second-hand) exposure refers to cannabis smoke contact by people who are not smoking themselves
Per Se	Per se limits are numeric thresholds (*i.e. cut-offs*) for a drug or drug metabolite concentration in the body.[214]
Permissible Inference	A permissible inference allows a judge/jury to draw an inference that a driver was driving impaired at specified threshold level; However, the driver can rebut that presumption by presenting evidence to demonstrate that the driver was not impaired.
Pilot study	Pilot studies are preliminary studies, that may be exploratory and assess feasibility of methods for future studies.
Placebo	A placebo is non-active condition given to a participant so that they are unaware if they are in an active or non-active treatment condition.
Poly-drug drivers	Poly-drug drivers refers to those who have consumed two or more impairing substances
Positive Predictive Value	Probability that a driver who tests positive actually is positive
Prose Recall	The Prose Recall is one measure of episodic memory. In this task, participants hear a passage and recall it immediately and again after a delay.[132]
Reaction time	Reaction time is how long it takes to respond to a stimulus
Rebound dilation	Rebound dilation is "a period of pupillary constriction followed by a period of pupillary dilation where the pupil steadily increases in size and does not return to its original constricted size."[172]
Sensitivity	Sensitivity is the proportion of cases who are impaired being correctly classified as impaired.
Specificity	Specificity is the proportion of cases who are not impaired being correctly classified as not impaired.[170]
Standard Deviation of Lateral Position (SDLP)	Standard Deviation of Lateral Position measures weaving.[145] It is calculated by taking the difference between the road center and the car center throughout the driving condition.[144]
Stopping clearance space	Stopping clearance space is the amount of space left between the driver's car and the car in front of them.
Stop-signal Task	The stop-signal task measures motor impulsivity. In this task, participants must make rapid judgments in response to "stop" or "go" visual cues.[135] The main outcome is number of commission errors for stop conditions.[135] Accuracy and reaction time are also measured.
Sustained attention	Sustained attention refers to vigilance and the ability to concentrate on task over a period of time.
Tolerance	Tolerance refers to users showing a more muted effect to a stimulus due to repeated exposure.
Tower of London	The Tower of London task measures executive functioning and planning. This task asks users to indicate how many steps it would take to rearrange three colored balls into a shown end-result. The number of correct answers are measured.[135]

Useful Field of Vision	The Useful Field of View (UFOV) task measures processing speed, divided attention, and sustained attention.[134] The task gets increasing complex and is validated to predict crash risk.
Vertical gaze nystagmus (VGN)	The VGN test has a participant follow a stimulus with their eyes that moves up and down while the test administers watches the individual's eyes for cues indicating impairment.
Walk and Turn (WAT)	The Walk and Turn is a roadside test of impairment. In the walk and turn test, the suspected driver is directed to take nine steps, touching heel-to-toe, along a straight line, turn on one foot in complete the same task in the opposite direction.[31] The officer than observes eight indictors of impairment: (1) if the driver cannot keep balance while listening to the instructions, (2) begins before the instructions are finished, (3) stops while walking to regain balance, (4) does not touch heel-to-toe, (5) uses arms to balance, (6) steps off the line, (7) takes an incorrect number of steps, and/or (8) makes an improper turn. Two or more errors indicate impairment.
Working memory	Working memory is the ability to briefly hold information while processing, reasoning, comprehending, and/or learning information.
Zero-tolerance laws	Per se limits are numeric thresholds (*i.e. cut-offs*) for a drug or drug metabolite concentration in the body.[214]

Table 2. Acronyms

Acronym	Meaning
11-Nor-9-carboxy-THC glucuronide	11-Nor-9-carboxy-THC glucuronide
11-OH-THC	11-hydroxy-THC
ACLU	American Civil Liberties Union
ARIDE	Advanced Roadside Impaired Driving Enforcement
BAC	Blood Alcohol Content
BHO	Butane Hash Oil Product
BrAC	Breath Alcohol Concentration
BRFSS	Behavioral Risk Factor Surveillance System
BSAS	The Bureau of Substance Abuse Services
CBD	Cannabidiol
CBG	Cannabigerol
CBN	Cannabinol
CI	Confidence Interval
CME	Containing Medical Education
CNB	Massachusetts Cannabis Control Commission
CNS	Central Nervous System
CUD	Cannabis Use Disorder
DEA	United States Drug Enforcement Agency
DEC	Drug Evaluation and Classification Program
DESE	Department of Elementary and Secondary Education
DPH	Massachusetts Department of Public Health
DRE	Drug Recognition Expert
DUIC	Driving under the influence of cannabis
DUII	Driving under the influence of intoxicants
EOPSS	The Executive Office of Public Safety and Security
FARS	Fatality Analysis Reporting System
FBI	Federal Bureau of Investigation
FCSA	Federal Controlled Substance Act
FDA	United States Food and Drug Administration
HGN	Horizontal Gaze Nystagmus
HMJ	Head Movement and Jerks
HS	High School
IACP	International Association of Chiefs of Police
LEA	Law Enforcement Agencies
LOC	Lack of Convergence
LOQ	Limit of Quantification
MA	Massachusetts
MBR	Modified Romberg Balance
MMJ	Medicinal Marijuana
MS	Middle School
MSP	Massachusetts State Police

NESARC	National Epidemiologic Survey on Alcohol and Related Conditions
NHSA	National Highway Safety Administration
NHTSA	National Highway Traffic Safety Administration
NIDA	The National Institute on Drug Abuse
NPV	Negative Predictive Value
NSDUH	The National Survey on Drug Use and Health
OEMS	Office of Emergency Medical Services
OLS	One Leg Stand Test
OUI	Operating Under the Influence
PCP	Phencyclidine
PD	Police Department
PPV	Positive Predictive Value
RMD	Registered Marijuana Dispensaries
RUIC	Riding with Someone Under the Influence of Cannabis
SAMHSA	Substance Abuse and Mental Health Service Administration
SDLP	Standard Deviation of Lateral Position
SFST	Standardized Field Sobriety Test
SUD	Substance Use Disorder
SJC	Supreme Judicial Court
THC	Delta 9-Tetrahydrocannabinol
THC-A	Tetrahydrocannabinolic Acid
THC-COOH	11-nor-0-carboxy-THC
THCV	Delta9-tetrahydrocannabivarin
UFOV	Useful Field of View
US	United States
VGN	Vertical Gaze Nystagmus
WA	Washington (State)
WAT	Walk and Turn Test
YRBSS	Youth Risk Behavior Surveillance System

Table 3. U.S. Census Data definitions of inclusion for race/ethnicity

White	A person having origins in any of the original peoples of Europe, the Middle East, or North Africa. It includes people who indicate their race as "White" or report entries such as Irish, German, Italian, Lebanese, Arab, Moroccan, or Caucasian
Black or African American	A person having origins in any of the Black racial groups of Africa. It includes people who indicate their race as "Black or African American," or report entries such as African American, Kenyan, Nigerian, or Haitian.
American Indian and Alaska Native	A person having origins in any of the original peoples of North and South America (including Central America) and who maintains tribal affiliation or community attachment. This category includes people who indicate their race as "American Indian or Alaska Native" or report entries such as Navajo, Blackfeet, Inupiat, Yup'ik, or Central American Indian groups or South American Indian groups.
Asian	A person having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian subcontinent including, for example, Cambodia, China, India, Japan, Korea, Malaysia, Pakistan, the Philippine Islands, Thailand, and Vietnam. This includes people who reported detailed Asian responses such as: "Asian Indian," "Chinese," "Filipino," "Korean," "Japanese," "Vietnamese," and "Other Asian" or provide other detailed Asian responses.
Native Hawaiian and Other Pacific Islander	A person having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands. It includes people who reported their race as "Fijian," "Guamanian or Chamorro," "Marshallese," "Native Hawaiian," "Samoan," "Tongan," and "Other Pacific Islander" or provide other detailed Pacific Islander responses.

XVIII. References

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