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ASSESSMENT OF FUNCTIONAL IMPAIRMENT OF DRIVERS AFTER THE USE OF CANNABIS: POSSIBILITIES AND LIMITATIONS OF FIELD AND LABORATORY METHODS

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Abstract: Driving after cannabis use represents a significant road-safety challenge, particularly because of the difficulty in distinguishing the presence of tetrahydrocannabinol (THC) in the body from actual psychophysical impairment. Unlike alcohol, there is no simple and universally accepted relationship between THC concentration in a biological sample and the degree of a driver's functional impairment. This paper analyses the possibilities and limitations of roadside and laboratory methods for detecting THC, as well as their importance in assessing a driver's actual ability to operate a vehicle safely. A descriptive-analytical review of relevant scientific and professional literature was conducted. Blood, urine and oral-fluid testing methods were analysed, together with the characteristics of roadside screening devices used to detect psychoactive substances. Particular attention was paid to the problem of residual THC, the differences between the "impairment" and "per se" approaches, and the need to combine toxicological, behavioural and clinical indicators. The analysis shows that a positive test result, particularly in urine, does not necessarily confirm that a driver was actually impaired at the time of the traffic check. The most reliable approach involves combining behavioural observation, roadside screening, laboratory confirmation and professional assessment of the driver's psychophysical condition. Such an approach may contribute to improving driver control and preventing road traffic accidents.

Keywords: cannabis, THC, drivers, impairment, road safety

1. INTRODUCTION

The cannabis plant (lat. Cannabis sativa L.) is one of the most famous psychoactive plants used for industrial, medical and recreational purposes. The plant produces over 70 phytocannabinoids, of which THC (tetrahydrocannabinol) shows the greatest psychoactivity, while CBD (cannabidiol) is not psychoactive (Hartman & Huestis, 2013; Memedovich et al., 2018). THC is the main psychoactive ingredient that acts on the central nervous system, while CBD has the opposite effect, i.e. relieves anxiety, spasms and partially neutralizes the effect of THC (European Monitoring Centre for Drugs and Drug Addiction, 2023; Hartman & Huestis,

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2013). The content of these substances varies depending on the variety of the plant: in industrial hemp, the THC content is below 0.3%, while in recreational species it can reach over 20%, with a smaller proportion of CBD (European Monitoring Centre for Drugs and Drug Addiction, 2023). According to data for Europe, the average THC content in cannabis resin was between 3% and 17%, and in the plant mass between 1% and 12% (European Monitoring Centre for Drugs and Drug Addiction, 2023; Schulze et al., 2012). It is the ratio of these substances that determines the degree of psychoactive effect and the level of risk for the driver's cognitive functions (Hartman & Huestis, 2013).

When it comes to the effect of cannabis on driving ability, the results of the DRUID project show that even relatively low levels of THC in the blood (around 2 ng/ml) cause impaired concentration, increased reaction time and reduced ability to judge distance and speed – effects comparable to 0,5 g/L blood alcohol, which is the legal limit for driving under the influence of alcohol in most countries. The combination of THC with alcohol or lack of sleep further increases the risk of traffic accidents, as it leads to overestimation of one's abilities and wrong decisions in dangerous situations (Caplan & Goldberger, 2001; European Monitoring Centre for Drugs and Drug Addiction, 2012; Schulze et a., 2012a; Schulze et a., 2012b).

2. METHODOLOGICAL FRAMEWORK

A descriptive method was used in the paper, based on a review of scientific and professional literature. Papers dealing with field driver testing methods, types of biological samples, and laboratory methods for confirming the presence of THC, as well as its pharmacokinetics, were analyzed. It also explained how THC behaves in the body and why a positive finding does not always mean that the driver was under the influence of cannabis while driving at that moment. Special attention is paid to the limitations in the interpretation of a positive finding and the assessment of the driver's actual impairment through the impairment and per se approach. The paper does not present new experimental results. The acute effects of cannabis and the effects of the simultaneous use of cannabis and alcohol were analyzed based on the existing literature review, from the point of view of their application in driver control and traffic accident prevention.

3. THC DETECTION METHODS IN DRIVERS

Driving under the influence of cannabis (DUIC) is a serious risk, as it reduces driving ability and increases the likelihood of traffic accidents. Due to the legalization of recreational cannabis in some countries, concerns about traffic safety have increased, which has sparked the authorities' interest in new preventive measures.

Roadside detection of DUIC could be effective, but there are concerns about the effectiveness of screening tests (such as sobriety tests or oral fluid tests) (Asbridge et al., 2012; Hartman & Huestis, 2013; Li et al., 2012; Rogeberg & Elvik, 2016). Laboratory blood testing for THC (delta-9-tetrahydrocannabinol) is currently the standard in legal practice, although the presence of THC in the blood alone is not a reliable indicator of actual driving impairment, although THC in blood and oral fluid are well correlated (Ginsburg, 2019; Johnson et al., 2022).

3.1. Cannabinoids (delta 9-tetrahydrocannabinol - THC) and its retention in the body

Cannabinoids are the most widely abused drug worldwide. They are also considered the most harmless drug that individuals use. Side effects of cannabinoid use range from memory loss, cognitive problems, and even lung cancer in heavy users. An overview of 68 systematic reviews

reported harm for most outcomes, including psychosis, cognitive impairment and testicular cancer, while evidence for lung and head and neck cancers remained inconclusive (Memedovich et al., 2018). Cannabinoids refer to the chemical compounds characteristic of cannabis plants, the main pharmacologically active ingredient being delta 9-tetrahydrocannabinol (THC) [1,10].

THC is a central nervous system depressant. It can cause a number of problematic effects such as dizziness, confusion, hallucinations, speech and vision problems, ataxia, euphoria, lack of strength and fatigue. Tests have shown that if an individual takes just one dose of THC, either by swallowing or smoking, it can have a significant detrimental effect on psychomotor performance. This has been observed for 3 hours in those who drive, and up to 24 hours in volunteers in laboratory studies (Alhefeiti et al., 2021; Hartman & Huestis, 2013).

However, after the advent of synthetic cannabinoids at the beginning of this century, there was a sharp increase in the number of synthetic cathinones, benzodiazepines and opioids, which now number in the hundreds. Toxicology laboratories have previously focused on a fairly narrow range of compounds, including amphetamines, cocaine, opioids, cannabinoids, salicylate, antidepressants, and acetaminophen (Huestis et al., 2017).

3.2. Methods of determination in the field

- Rapid saliva tests

Police in the field most often use rapid tests from a saliva sample to check for the presence of psychoactive substances, including cannabis (THC). In Serbia, the device Drager Drug Test 5000 is in use, which analyzes the driver's saliva on the spot with the help of a special cassette. The procedure lasts about 10 minutes, and detects 7 groups of psychoactive substances, including cannabis (THC), amphetamines, cocaine, opiates, etc.

The driver puts the insert (swab) in the mouth, usually under the gums where the saliva is most concentrated, and then the insert is placed in the analyzer that reads the results. Such screening tests are suitable for determining the presence of narcotics in the body. In addition to this type of test, police officers pay attention to physical and psychomotor signs that may indicate that the driver is under the influence of cannabis. This includes the driver's appearance and behavior – eg. red eyes, dilated or glassy pupils, slowed reactions, impaired coordination of movements, drowsiness or euphoria, as well as the smell of cannabis in the vehicle.

In many countries (such as the Netherlands) the police can also apply standardized tests of psychomotor abilities in the field. These tests are similar to the classic alcohol sobriety tests: walking in a straight line, standing on one leg, time estimation (eg balance test with eyes closed - Romberg test), finger tracking with eyes (horizontal gaze nystagmus test), etc.

However, it is worth noting that standard coordination tests designed for alcohol are not always reliable indicators of cannabis intoxication – for example, an eye movement test that detects pupil twitching in drunk drivers does not show the typical changes after consuming marijuana. Police can still use them to get a general impression, but their accuracy for cannabis is limited. Therefore, if there are suspicious signs, a positive rapid saliva test is usually the key evidence to take further steps (taking a sample for the laboratory).

- New detection technologies

In addition to saliva, other field tests are being developed. For example, a prototype "marijuana alco-test" was developed in the USA - a device for detecting THC in a driver's breath. This device works similarly to a breathalyzer for alcohol: the driver blows into a dedicated cartridge that then analyzes the presence of THC.

The manufacturer (Hound Labs) claims that their "breathalyzer" can detect if the driver has consumed marijuana in the last ~2 hours, which covers the period of peak THC intoxication. If

THC is detected in exhaled air, this practically confirms that the person consumed cannabis very recently (within a few hours). Such devices are still in the testing and approval phase, but they represent a potentially useful tool for police in the future, as they would allow even faster identification of recent marijuana use.

4. TYPES OF BIOLOGICAL SAMPLES

The body fluid sample that is collected usually depends on how easy it is to obtain the sample and on the analytical and test implications of the results. Typically, roadside testing involves collection of oral fluid, urine, blood, or breath (Alhefeiti et al., 2021; Caplan & Goldberger, 2001; Schulze et a., 2012a; Ginsburg, 2019).

There are numerous advantages and disadvantages to each type of specimen when testing in roadside conditions. Blood and urine samples are usually collected at the police station instead of at the roadside. Blood, urine and oral fluid are most often used in driver control. Blood is most suitable when recent use needs to be determined, while urine can indicate the presence of metabolites long after cessation of action, which is why it cannot be used alone to assess current intoxication. Oral fluid is often used for rapid field testing (Caplan & Goldberger, 2001). The method of analyzing urine and oral fluid and their interpretation are presented in more detail in the next chapter.

In contrast, hair has a detection time of days to years and indicates a longer-term pattern of use, but cannot prove recent ingestion and intoxication at the time of control. The interpretation of results from hair analysis should follow standardized international protocols to ensure forensic reliability (Cooper et al., 2012). Furthermore, sweat can be detected from minutes to weeks and has the advantage of non-invasive monitoring over a longer period, but it has a high variability in quantity and no standard for the interpretation of results (Caplan & Goldberger, 2001).

5. LABORATORY METHODS AND PHARMACOKINETICS

Laboratory blood analysis is the most reliable method for determining the presence and amount of active THC in the driver's body. If the driver on the field "fails" the rapid test or there is a strong suspicion, the police can refer him to a medical institution for a professional examination (in Serbia, this would be the Center for Poison Control at the VMA), where the medical staff takes a blood sample for toxicological analysis.

In the laboratory, sophisticated methods (such as gas chromatography with mass spectrometry - GC/MS) are applied to quantitatively measure the concentration of THC and its metabolites in the blood.

Blood THC reference limits for forensic purposes are very low – often any detectable amount of THC is considered a positive finding in zero-tolerance countries, while some states prescribe a certain threshold (eg 1–3 ng/mL) as the tolerance limit. THC is metabolized relatively quickly: after smoking cannabis, the concentration of THC rises quickly and then drops sharply in the first hours.

Studies show that within 3–4 hours of consumption, THC levels in the blood drop to about 1–4 ng/mL (parts per million of g per milliliter), due to the rapid breakdown and distribution of THC throughout the tissues. This is why it is important to take a sample quickly - a delayed blood draw can give a result that does not reflect the actual level while driving.

Depending on the frequency of use, THC can remain detectable in the blood from several hours to several days after the last use. Active THC (ψ-9-THC) is usually detectable for up to a few hours or up to a day in occasional users, while in daily users traces of THC may persist for a longer time due to accumulation in adipose tissue and slow release.

5.1. Urinalysis (metabolites)

A urine test is often used to detect THC metabolites (primarily THC-COOH), which remain in the body much longer than THC itself. A driver who is suspected can also be sent for a urine analysis in the laboratory (often along with blood). Urine tests generally do not look for THC itself (except perhaps in trace amounts), but rather inactive products of metabolism that result from the breakdown of cannabis in the liver.

The detection period in urine is significantly longer: metabolites are not present immediately after consumption (they usually appear only after a few hours), but therefore they can remain for days, weeks, even months after use - depending on the amount and frequency of use. In one-time or infrequent users, the THC-COOH metabolite is typically detectable for up to ~3–7 days. In regular, frequent users of marijuana, metabolites can accumulate in fatty tissues and be excreted gradually, so that a urine test can be positive even four to six weeks after cessation of use.

Because of such a long time frame, a positive urine test only means that a person has used cannabis in the past, but not necessarily that they were under the influence at the time of driving. In practice, the urine test is used as additional evidence or to sanction the illegal use itself, while we rely more on blood and clinical findings to assess the ability to drive.

5.2. Saliva analysis (laboratory confirmation)

In addition to rapid field saliva tests, a saliva sample can also be analyzed in the laboratory for confirmation and quantification. The advantage of saliva analysis is that, unlike urine, it generally detects only the active substance (THC) and not permanent metabolites. Also, the metabolite THC-COOH is practically not present in saliva, so a longer period of use does not give a false positive result due to "old" metabolites. The detection period is relatively short - it is measured in hours to (maximum) a couple of days after taking cannabis. When smoking marijuana, the oral cavity is directly exposed to smoke with high concentrations of THC, leading to a spike in THC in saliva. Very high concentrations of THC have been measured in saliva immediately after smoking (eg over 5000 ng/mL immediately after consumption), but then there is a rapid elimination during the first 30 minutes and then a slower decline. Typically, THC in saliva becomes negative within 12-24 hours in casual users. However, there are reports that in frequent users, THC can be detected in the saliva several days after the last use.

5.3. Pharmacokinetics of THC in the body

Pharmacokinetics describes how THC is absorbed, distributed, and eliminated, which is critical to understanding the drug test. THC is highly liposoluble - it dissolves easily in fat, so after entering the blood it is quickly distributed in tissues rich in fat (brain, adipose tissue). When smoking, THC reaches the brain in a few minutes, and reaches its peak in the blood very quickly (while still smoking).

After smoking cessation, blood levels decline exponentially – most rapidly in the first ~30 minutes, then more slowly as the THC is redistributed and metabolized. The elimination half-life of active THC from the blood is relatively short (several hours in the initial phase), but the total elimination of metabolites can take a long time. THC is broken down primarily in the liver to 11-OH-THC (active metabolite) and then to THC-COOH (inactive) which binds to glucuronides and is excreted in urine and feces. THC-COOH has a long retention time in the body, especially in chronic users - it can be detected in the blood for more than 7 days with frequent use, and in the urine for as long as 30+ days.

In chronic users, you can find a constant presence of low levels of THC in the blood several days after stopping use (due to release from fat depots), while in naive users the blood clears much faster.

These pharmacokinetics mean that the THC concentration in the blood does not simply correlate with the level of intoxication, as it does with alcohol. Alcohol has a relatively stable relationship between blood concentration and degree of drunkenness and a very predictable metabolism.

In contrast, THC exhibits high inter-individual variability and non-linear elimination. For example, one person may have negligible cognitive impairment at a THC level that would cause severe impairment in another. Also, THC can be found in the blood long after the psychophysical effects have stopped (detection for up to 30 days, while the acute effect lasts for several hours). Due to these peculiarities, when interpreting the laboratory results, it is important to take into account the time that has passed since consumption, the frequency of use and the clinical condition of the driver at the time of the stop. A summary of detection times for blood, urine and saliva is given in Table 1.

Table 1. Sample type and post-use THC detection

Sample type	Detection of THC after use
Blood (active THC)	• Hours to a few days; • After 3–4 hours of ingestion, THC drops below ~1–4 ng/mL; • In occasional users, often negative after 12–24 hours; • Chronic users may remain low for >24 hours.
Urine (metabolite THC - COOH)	• Days to weeks; • Metabolites appear only 3-4 hours after ingestion; • Detection ~3–7 days (occasional), up to 30 days or more (frequent users).
Saliva (THC)	• Hours to several days; • Reflects recent use (positive mostly <24 hours).

Note: The indicated intervals are approximate and vary depending on the dose, frequency of use and individual metabolism. The duration of detection does not necessarily mean the duration of psychophysical effects (intoxication), which for THC last much shorter (usually 2–6 hours).

6. ASSESSMENT OF ACTUAL NERVOUSNESS AND THE PRESENCE OF THC

Determining whether a driver is functionally unfit to drive due to cannabis presents a particular challenge. The mere presence of THC or metabolites in the body does not automatically mean that the driver is currently under the influence to the extent that it is dangerous to drive. This is a key difference: a positive test indicates that a person has used cannabis relatively recently, but the degree of psychophysical impairment must be assessed through a combination of factors. Unlike alcohol, where there is a clear connection between blood alcohol concentration (eg 0.5‰) and the level of incapacitation, with cannabis, such a direct correlation is weak.

Research has shown that two people can have completely different levels of intoxication at the same concentration of THC. Also, tolerance plays a big role - regular users can function almost normally with concentrations that would significantly disturb an inexperienced user.

6.1. Practical assessment in police application

In practice, the police assess intoxication combined: they observe the driver's behavior and abilities (zig-zag driving, delayed reactions, excessively slow driving or uncertainty), then physical signs (e.g. eyes, speech, motor skills), and confirm with tests, if both the behavior and the test are positive, it is clear that the person is under the influence. However, a scenario can occur where the test is positive for THC and the driver shows no visible impairment – eg. if he used cannabis the previous day.

From a legal point of view, in such cases, many states still consider the driver to be "under the influence" because they have an illegal substance in their system, and will be sanctioned based on their presence.

However, a professional expert can take into account the concentration of THC in the blood and assess whether it is compatible with recent use or can be left over from before. Concentrations of active THC greater than 5 ng/mL in the blood are considered to indicate use within a few hours and may be associated with impairment, while very low (1–2 ng/mL) may result from earlier consumption without immediate effect (European Center of Consumption).

In the Netherlands, for example Thresholds are set precisely to distinguish a functionally intoxicated driver from one who has only traces: the limit is 3 ng/mL THC in the blood for cannabis alone, and 0 ng/mL (zero tolerance) if it has been combined with other drugs or alcohol. Similarly, the United Kingdom has a threshold of 2 ng/mL THC, while some US states (such as Colorado) use 5 ng/mL as an indication of impaired ability.

6.2. The "residual THC" problem

Due to the long retention of metabolites, a person can test positive even when they are no longer under the influence. This is especially the case with urine tests - someone who smoked a week ago will have no effect, but the urine will still be positive. For this reason, a blood test for active THC is the gold standard for proving actual intoxication while driving. However, blood can also detect residual amounts of THC (below the threshold of stupor) in chronic users.

Scientific studies and regulatory agency reports warn of this difference: the acute effects of cannabis last for several hours, while THC-COOH can be found up to 30 days later. Thus, functional incapacity is assessed as a whole - by a combination of objective tests (e.g. coordination, reaction test), biological measurements (THC concentration in the blood) and clinical evaluation by the doctor (if an examination of the state of consciousness, reflexes, etc. was carried out during blood sampling). In some countries, there are specialized "Drug Recognition Expert" (DRE) police officers who check pulse, blood pressure, pupils' reactions to light, balance, etc. in order to determine whether the driver is under the influence of drugs and what class, before the results of the analysis arrive. It is an attempt to assess functional status independent of the test itself.

6.3. Impairment vs. per se approach

State approaches vary: "Impairment" legislation requires proof that driving ability is impaired by drugs (hence the focus on behavior and proof of impairment), while "per se" legislation sets a drug concentration limit - if exceeded, the driver is automatically guilty regardless of visible symptoms. Many European countries introduce "per se" limits for THC (eg 1 ng/mL, 3 ng/mL) to facilitate law enforcement and limit the alcohol model. On the other hand, zero tolerance (which Serbia and some other countries have) means that any amount of illegal drugs in the body is a violation, which practically ignores the question of the degree of intoxication - presence = violation.

This strict approach is understandable from a safety perspective (because cannabis is not allowed, so there is no "permitted dose"), but it is not in line with the pharmacological reality that a positive person does not have to be really under the influence. Therefore, in states that have legalized cannabis or where it is medically permitted, there is more effort to define a threshold in ng/mL that is associated with significant driving risk. One large European study (the DRUID project), as mentioned above, suggested a threshold of about 3,8 ng/mL THC in serum (which is ≈2,0 ng/mL in whole blood) as the risk equivalent of 0,5‰ alcohol. This would mean that below that level the risk is no greater than usual, while more would indicate possible stupor. In practice, however, the figures vary and are still the subject of scientific and legal debates.

7. PROPOSAL OF A COMBINED MODEL FOR DRIVER CONTROL

The stages of the proposed control model are shown in Table 2.

Table 2. Proposal of a combined model for driver control

Phase	Name of the phase	Contents / activities
1	Observation of behavior	Maintaining the direction of movement of the vehicle, unusually slow or uneven driving, delay in reactions, inadequate response to traffic situations, problems in communication with the police officer.
2	Assessment of physical and psychomotor signs	Eye appearance, speech, coordination, balance, behavior and general condition of the driver. It is not sufficient by itself, but it justifies further testing.
3	Field screening	Oral fluid test (eg Dräger DrugTest 5000). The results, time and conditions of sampling are recorded.
4	Laboratory confirmation	Blood and/or oral fluid sample for confirmation. Blood and oral fluid are more important for assessing recent use, urine is not interpreted as an indicator of current intoxication.
5	Unified expert assessment	Final conclusion based on: behavior, psychomotor signs, field test, laboratory analysis, time since possible use, frequency of use and clinical findings.

Note: The presented model is a conceptual framework based on a literature review and is not directly taken from the legal procedure of any country. The applicability of individual stages depends on national legislation (police powers, mandatory testing, types of samples accepted as evidence), device availability and laboratory capacity. The model is aligned with the principles of a safe system because it assesses the risk through several connected elements, and not on the basis of a single indicator.

8. CONCLUSION

Driving after using cannabis represents a specific challenge for traffic safety because the presence of THC in the body does not automatically mean that the driver was functionally intoxicated at the time of the control. Unlike alcohol, with cannabis there is no simple relationship between the concentration in a biological sample and the degree of impairment of driving abilities.

The analysis shows that field methods have an important role in early recognition of suspicion and singling out drivers for further checks, but they are not sufficient in themselves to prove intoxication. Observation of driving behavior and physical and psychomotor signs provides a basis for further action, while a rapid oral fluid test provides a quick on-the-spot check of recent use.

Laboratory analysis remains crucial to confirm findings. Blood is most important for assessing recent use because it shows active THC, while urine shows metabolites that remain long after the effects have stopped and therefore cannot independently prove that a driver was under the influence while driving. Oral liquid is suitable for detecting recent use, but has a shorter detection window.

A particular problem is residual THC in chronic users, due to accumulation in adipose tissue and slow release, which explains why a positive finding can persist even after the acute effects no longer last. For this reason, the paper pointed out the difference between the impairment approach, which requires proof of reduced abilities, and the per se approach, which relies on the prescribed limit concentration.

The proposed combined five-stage model links behavioral observation, sign assessment, field screening, laboratory confirmation, and unified expert assessment into a single unit. Such an approach enables a more reliable assessment than relying on a single indicator and can contribute to the improvement of driver control and the prevention of traffic accidents. The analysis relies on international literature due to the limited availability of systematic national data. This indicates the need for future research in domestic conditions.

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