Developing Science-Based Per Se Limits for Driving under the Influence of Cannabis (DUIC)

Findings and Recommendations by an Expert Panel

Franjo Grotenhermen,[1] Gero Leson,[2] Günter Berghaus,[3] Olaf H. Drummer,[4] Hans-Peter Krüger,[5] Marie Longo,[6] Herbert Moskowitz,[7] Bud Perrine,[8] Jan Ramaekers,[9] Alison Smiley,[10] Rob Tunbridge[11]

[1]nova-Institut, Hürth, Germany, franjo.grotenhermen@nova-institut.de; [2]Leson & Associates, Berkeley, USA; [3]University of Cologne, Germany; [4]Victorian Institute of Forensic Medicine and Department of Forensic Medicine, Monash University, Melbourne, Australia; [5]University of Würzburg, Germany; [6]Drug & Alcohol Services South Australia, Parkside, Australia; [7]University of California, Los Angeles, USA; [8]Vermont Alcohol Research Center, USA; [9]Maastricht University, The Netherlands; [10]Human Factors North Inc., Toronto, Canada; [11]Independent Consultant, Sandhurst, UK

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Executive Summary

This report presents the findings, conclusions and recommendations of a panel of experts on the issue of driving under the influence of cannabis (DUIC) and on strategies for controlling its potential impact on traffic safety. The panel's primary objective was to develop, on the basis of scientific evidence on DUIC, recommendations for objective criteria that allow for meaningful and reasonably accurate determination of a driver's impairment by cannabis.

Background and Legal Trends

Because of its potential impact on traffic safety, driving under the influence of illegal and medicinal drugs (DUID) increasingly receives attention by media, scientists and policy makers in many countries. As the second most commonly used recreational drug after alcohol, cannabis, i.e., marijuana and hashish, causes particular concern. Most states in the United States still use an impairment-based approach to detect and penalize DUID. In principle, this approach best complies with the intention of DUID laws in that it assesses and potentially penalizes the actual impairment of a driver. However, current testing methods for drugs, such as standard sobriety tests, which have been used successfully to identify drivers under the influence of alcohol, are somewhat insensitive and rely on the subjective judgment of an enforcement officer. As a result, impairment by drugs is generally difficult to prove in court. This routinely frustrates law enforcement, and many jurisdictions are now adopting per se laws. As for alcohol, such laws specify legal limits for the drug in blood or other body fluids. A driver is assumed to be "impaired" or "under the influence" if he or she exceeds that limit.

Many recent per se laws for DUID prescribe a *zero tolerance* for specific drugs, classifying drivers as being under the influence of a drug if *any amount* of a listed drug or its metabolites can be detected in blood or other body fluids. This approach effectively sets the legal limit at the technically achievable *limit of detection* (LOD), making the legal limit a function of the detectability of a drug, rather than the impairment caused by it. For example, under German federal law the LOD is about one nanogram per milliliter (1 ng/mL) THC in blood serum has been the de facto legal limit since 1999. This strict approach facilitates law enforcement, but is not based on science and does not only target impaired drivers. For example, delta-9-tetrahydrocannabinol (THC), the main psychoactive constituent of cannabis-based drugs, is detectable in blood and urine for several hours to about two days after cannabis use, and its metabolites are detectable for days or weeks, whereas even a strong smoked cannabis dose will affect driving skills for only a few hours. Thus, zero-tolerance laws will classify many cannabis users as impaired drivers even if they separate drug use and driving by many hours. The same applies to the increasing number of individuals who legally use cannabis for medicinal purposes and, while not acutely impaired, may present with measurable THC concentrations at all times.

Project Objectives and Approach

Per se laws specifying nonzero limits may offer a fairer and possibly more effective alternative for DUIC control than zero-tolerance laws, provided these limits are, as for alcohol, derived rationally from scientific evidence. While current empirical evidence on cannabis and driving is still much less conclusive than that for alcohol, it is sufficient to permit the setting of boundaries for a rational and enforceable legal limit. To develop and recommend such a range of limits for DUIC control, an international expert panel of physicians, forensic toxicologists and traffic scientists convened in 2004. The panel reviewed evidence from experimental and epidemiological studies on DUIC, on the pharmacology of THC, testing for cannabis use and concepts of DUI control.

Findings and Conclusions

Following several rounds of discussion, panel members agreed that a legal limit for THC in the 7–10 ng/mL range (measured in blood serum or plasma, equivalent to about 3.5–5 ng/mL measured in whole blood) may achieve a reasonable separation of unimpaired from impaired drivers, who pose a higher risk of causing accidents. The panel further arrived at the following findings and conclusions.

Epidemiological Studies

- Epidemiological studies on DUI examine the association between rare events (traffic crashes, injury or death) and a risk factor, such as the consumption of alcohol or a drug. The results of some 20 studies on cannabis and driving are somewhat inconsistent. The most meaningful recent culpability studies indicate that drivers with THC concentrations in whole blood of less than 5 ng/mL have a crash risk no higher than that of drug-free users. The crash risk apparently begins to exceed that of sober drivers as THC concentrations in whole blood reach 5–10 ng/mL (corresponding to about 10–20 ng/mL in blood serum or plasma). Because recent studies involved only a few drivers with THC concentrations in that critical range, a reliable assessment of the associated crash risk is still lacking.
- Even frequent users of cannabis do not seem to have a higher accident risk than nonusers, as long as they are not under the acute influence of the drug, i.e., there appear to be no extended effects of cannabis use on traffic safety beyond the period of acute impairment.

Experimental Studies

- More than 120 experimental studies have evaluated the impact of cannabis on physical, mental and psychological skills critical to driving performance. These studies included laboratory tests of single skills and driving-simulator and on-road studies. Together, they demonstrate that cannabis use may acutely impair several driving skills, including cognition and psychomotor performance. As is the case with alcohol, impairment generally increases with dose and the effect of a given THC dose varies considerably between individuals. The main causes of that variability are the development of tolerance with regular use, different smoking techniques causing differences in systemic bioavailability and differences in absorption of THC, especially with oral use.

- Smoking cannabis impairs driving skills most severely during an acute phase, which typically lasts for up to 60 minutes after smoking. A post-acute phase (60–150 minutes after onset of smoking) and a residual phase (more than 150 minutes after smoking) follow, during which impairment subsides rapidly. The duration of the post-acute phase and the degree of impairment during the residual phase both increase strongly with the consumed dose. After smoking "typical doses" of about 20 mg THC, the residual phase lasts 2–3 hours. The effects of oral cannabis occur later than do those of smoking and typically peak 2–3 hours after ingestion.
- Several studies have compared the degree of impairment caused by cannabis and alcohol. The results of a meta-analysis of about 90 experimental studies of the impact of smoked and oral cannabis on driving suggest that mean THC concentrations in serum correlate well with impairment in performance during the post-acute and residual phases. Comparison with the results of a meta-analysis on alcohol and driving suggests that a THC concentration in serum of about 4 ng/mL, caused by smoking or oral use of cannabis, is associated with the same overall performance impairment as a blood alcohol content (BAC) of 0.04% (percent by weight). In a similar sense, a BAC of 0.08% corresponds approximately to a THC concentration in serum of 9–10 ng/mL.
- Even such "equivalent" blood alcohol and THC concentrations affect driving skills in different ways. Low doses of alcohol impair complex driving functions most and automatic functions least. In contrast, at THC serum concentrations of about 5 ng/mL, THC affects highly automated driving functions such as tracking performance most, while more complex driving tasks that require conscious control (e.g., overtaking, interpretation and anticipation of traffic) are less affected. This may explain why drivers under the influence of cannabis in driving studies generally show more awareness of their impairment than drivers on alcohol and are able to make the correct response if given a warning. However, where events are unexpected such compensation is not always possible.
- Depending on the dose, most acute effects on driving skills subside within 3–4 hours after smoking a cannabis cigarette, i.e., during the residual phase. Larger doses extend the period of impairment. Most studies found no effect of cannabis on psychomotor functions after 4 hours. The studies that did find some impairment for up to 24 hours after the last consumption involved demanding flight-simulator tests. This suggests that a waiting period of about three hours after smoking a medium to strong social dose (15–20 mg) will be sufficient to reduce a driver's impairment to that comparable to a BAC of less than 0.03%.
- Cannabis is often consumed together with alcohol. Both impair performance and their effects are additive. The presence of even low doses of alcohol together with THC must be considered when setting limits for THC in blood.

<u>Pharmacokinetics of THC and Testing for Cannabis</u>

- Blood concentration of THC correlates with impairment of driving skills during the post-acute and residual phases of a cannabis high, which typically extends from 1–4 hours after consuming cannabis. In contrast, the presence of the slowly excreted THC metabolite THC-COOH in blood and particularly in urine does not indicate acute impairment, but rather only the use of cannabis in the last few days or weeks. Furthermore, THC-COOH concentrations in blood and urine rise only slowly after smoking or ingesting cannabis, for example via cookies, and may fail to

indicate the period of greatest impairment. Thus, blood THC concentrations are currently the most meaningful indicator of and testing parameter for impairment by cannabis.

- Breath alcohol is a reliable indicator of BAC and can be measured in a noninvasive way. In contrast, there is currently no reliable proxy for THC concentrations in blood. The testing of saliva for THC by immunoassay is emerging as a technique for estimating time and severity of the most recent use of cannabis. Results of saliva tests are prone to inaccuracy, however, and should not be used as sole evidence for determining impairment of a driver by cannabis.
- Frequent users of cannabis may show THC serum concentrations of more than 2 ng/mL for up to 48 hours after the last use. This may also cause a background THC concentration in regular users unrelated to that absorbed by acute smoking. Depending on exposure, secondhand cannabis smoke may also produce THC peak concentrations of several nanograms per milliliter. Finally, comparative proficiency testing shows that forensic laboratories may report considerably different results when testing identical samples for THC. The impact of these factors on the results of a blood test for THC must be considered when selecting an enforceable numerical THC limit.

Recommendations

- Principles of DUIC Control

  Traffic safety laws regulating driving under the influence of any drug should deter irresponsible drug use and driving. At the same time, such laws should encourage drivers to consider responsible alternatives to DUI. Panel members agreed that DUIC laws should consider the following principles to effectively achieve these goals:

  1. *DUIC laws and regulations should be rationally derived from the best available scientific evidence on the impairment and traffic risk caused by the use of cannabis.*
  2. *Regulations should be clear and transparent to drivers and enforceable by police and the courts.*
  3. *DUIC control laws should give drivers an incentive to separate cannabis use and driving.*
  4. *DUIC control laws should focus on improving traffic safety and not at achieving other societal goals.*

- Choice of a Per Se Limit

  Based on the results of culpability studies and from meta-analyses of experimental studies, per se laws for DUIC should specify a legal limit for THC in blood serum of 7–10 ng/mL as a reasonable choice for determining relative impairment by cannabis. This corresponds to THC concentrations in whole blood—the parameter commonly used in U.S. jurisdictions—of 3.5–5 ng/mL. A limit in that range will clearly separate unimpaired drivers with residual THC concentrations of 0–2 ng/mL (serum) from drivers who consumed cannabis within the last hour or so. The latter are likely to be impaired and typically present with THC concentrations in serum greater than 20 ng/mL.

  When selecting a numerical enforceable THC limit, the risks of false positives and negatives must be balanced. A higher limit will result in a high proportion of false negatives, especially if the time lag between roadside detention and collection of a blood sample is long. A lower limit

will increase the number of false positives, e.g., in drivers who consumed cannabis within the preceding 48 hours, who still have THC serum concentrations of several nanograms per milliliter but are no longer impaired, and those drivers who were exposed to secondhand cannabis smoke.

Legislators must also consider the variability in THC concentrations measured by various forensic laboratories in identical blood samples. The authors suggest that a safety margin equal to the standard deviation observed in a comparative proficiency test of forensic laboratories be added to any impairment-based limit. The results of a recent proficiency test in Germany suggest that this safety margin may be 3–4 ng/mL (serum) at a concentration of 10 ng/mL, higher than with other drugs.

- Cannabis and Alcohol
  The concurrent use of cannabis and alcohol impairs driving skills more than does the use of either drug alone. Setting a lower THC limit may be appropriate if a BAC of more than 0.03% is also detected in the blood sample of a suspect driver.
- Testing for Cannabis Use
  Recently commercialized techniques for detecting THC and other drugs in saliva could be used by law enforcement as a roadside screening tool, in addition to or in lieu of field sobriety tests for suspect drivers. Ultimate determination of impairment by cannabis should be based only on blood THC concentrations measured by properly certified forensic laboratories.
- Communication of Per Se Limits and Their Implications
  As they do now for alcohol, government agencies should effectively communicate to drivers how a legal THC limit will affect their risk of being detected and penalized and how they should adjust consumption to avoid impairment and detection. Recommending to drivers a waiting period of at least three hours after the last consumption is a practical tool for avoiding residual impairment by cannabis, provided the driver did not consume alcohol at the same time.
- Research Needs
  To strengthen the scientific basis for a per se limit for THC, stronger empirical evidence is needed in the following areas:
  - Additional culpability studies with a higher number of cases in the THC concentration range of 5–15 ng/mL (serum),
  - Simulator and on-road studies on driver performance after consuming higher doses of THC and during the later phases of a cannabis high, i.e., 2–5 hours after smoking or ingesting cannabis.

1. Introduction

Since the 1950s, numerous scientific studies have shown that driving under the influence (DUI) of alcohol poses a significant risk to traffic safety. Experimental studies in driving simulators and on the road have demonstrated that alcohol impairs important driving skills; epidemiological studies evaluating the presence of alcohol in highway crashes have shown that drivers with an elevated blood alcohol content (BAC) also have a significantly higher risk of causing an accident and that the risk correlates with the BAC (Ogden and Moskowitz 2004). Moreover, these epidemiological studies showed that the accident risk begins to increase at BAC values well below 0.1%, i.e., values at which field sobriety tests (that is, tests for actual behavioral impairment) routinely failed to detect impairment. To deter drunk driving through law enforcement, most jurisdictions worldwide subsequently adopted *per se* laws. These laws specify BAC limits above which a driver is categorically considered "impaired" (in Germany at a BAC of 0.11%) or "under the influence" (in Germany at a BAC of 0.05%), and law enforcement does not have to prove actual behavioral impairment.

Numerical BAC limits were primarily derived from epidemiological studies. Following a gradual decline in BAC limits, most jurisdictions now consider BAC concentrations of 0.03–0.08% indicative of some impairment, yet enforcement provisions vary. Depending on the actual BAC measured, whether a driver was reckless or caused a serious accident, driving under the influence (DUI) of alcohol may be punished as a misdemeanor, by fines and temporary license suspension or as a crime, by punishments including imprisonment.

Overall, per se laws have been effective in addressing the problem of drunk driving and have apparently contributed to a dramatic decline in drinking and driving in the industrialized world (Begg et al. 2003; Sweedler et al. 2004). In the United States, a study by the National Institute on Alcohol Abuse and Alcoholism suggests that between 1977 and 2001 the percentage of *traffic crash fatalities* that were considered "alcohol related" fell from 36% to 30%. During the same period, the alcohol-related *traffic fatality rate* fell from 1.19 fatalities per 100 million vehicle miles traveled to 0.46, i.e., by 62% (Yi et al. 2003).

Approaches to Control of Driving Under the Influence of Drugs

Despite this progress, drunk driving is still responsible for approximately 15,000 traffic deaths per year in the United States alone. Recent research also shows that driving under the influence of illegal and medicinal drugs is now common in many industrialized countries, particularly among young drivers (Walsh et al. 2004). Widely used drugs, including amphetamines, antihistamines, cannabis, tranquilizers and tricyclic antidepressants are known to impair driving skills (Robbe 1998; Smiley 1987). This has caused concern that driving under the influence of drugs (DUID) may pose a significant traffic safety risk. Media and law enforcement now frequently criticize existing laws as ineffective—for an example, see the front-page article in USA Today (Oct.21, 2004) – and legislative efforts to adopt stricter laws are under way in several U.S. states, in the U.S. Congress and in EU countries (The Walsh Group 2002).

Currently, DUID laws employ one of three basic approaches to determining whether a driver is *impaired* or *under the influence* (Krüger et al. 1999): (1) the *impairment or effect-based approach*

and the *per se concentration limit approach*, using either (2a) science-based limits or (2b) zero limits.

1. The Impairment or Effect-Based Approach

This approach is still used in most U.S. states (see Appendix A) and in fact in most jurisdictions around the world. It requires that law enforcement and prosecution prove a driver's impairment on a case-by-case basis. Admissible evidence may include roadside sobriety tests, testimony by officers, and the collection and testing of blood samples for drug residues.

In principle, this approach best complies with the intention of DUID laws in that it assesses and potentially penalizes the *actual* impairment of a driver, which may be the result of multiple, often synergistically acting factors, including fatigue and the consumption of multiple drugs. The basic handicap of the impairment approach is that evidence of reduced fitness caused by drug consumption is difficult to obtain and evaluate. Sobriety tests for drugs routinely fail to detect modest impairment (see, e.g., Papafotiou et al. 2004), and defense attorneys often question the expertise of law enforcement officers who assess impairment by drugs. This situation frustrates law enforcement, and prosecutors often charge a crash-involved driver with alcohol use or other offenses to obtain a conviction, even though another drug may have impaired the driver most. Improving the effectiveness of the impairment approach will, at a minimum, require the development of objective and generally accepted indicators of impairment, the implementation of devices for their accurate measurement and exclusive use of these devices by trained enforcement personnel.

2. The Per Se Concentration Limit Approach

The difficulties with enforcing impairment-based laws have motivated adoption of per se laws that, similar to those for alcohol, specify limits for the drug in blood or other suitable body fluids as objective criteria for the evaluation of a driver. A driver is assumed to be "impaired" or "under the influence" if that limit is exceeded. For selection of a numerical limit, legislators may use a "science-based" or a "zero-tolerance" approach. Table 1 summarizes and compares major attributes of these two approaches.

2a. Science-Based Limits

As for alcohol, science-based legal limits for drugs, both illegal and medicinal, are developed on the basis of epidemiological and experimental studies. Science-based limits offer the fairest and most rational approach to DUID control, in that they attempt to identify only impaired drivers, not just users. However, developing such limits is complicated by the large number of drugs in use, by the potential for interaction between drugs and alcohol, by the generally more complex pharmacokinetics of most common drugs and, in particular, by the as-yet limited number of epidemiological studies on the increased accident risk resulting from the use of these drugs.

2b. Zero Limits

Thus, law enforcement and policy makers often call for the adoption of per se laws with a zero limit for major illicit drugs. Such laws are already in place in several U.S. states and in other countries, such as Germany. If applied strictly, zero-limit laws, often referred to as *zero-tolerance laws*, consider drivers as being under the influence of a drug if *any measurable quantity* of a listed active ingredient or even its metabolites is present in blood or other body fluids. This approach obviously

facilitates law enforcement and avoids the need to develop science-based limits for a large number of drugs, possibly taken in combination. A fundamental weakness of zero-limit laws is that, for many drugs, low but measurable concentrations of active drug ingredients and their metabolites may be present in blood and urine far beyond the duration of psychic effects and psychomotor impairment.

This is a problem particularly with driving under the influence of cannabis (DUIC), i.e., marijuana and hashish. Delta-9-tetrahydrocannabinol (THC), the main psychoactive constituent of cannabis-based drugs, and its metabolites, may be detectable in blood and urine for days or even weeks after use, yet significant psychoactive effects and impairment of driving skills cease within hours. Thus, zero-limit laws for DUIC by their very nature detect past use of, rather than impairment by, cannabis and are prone to misclassifying drug users as impaired drivers, even if they responsibly separate drug use and driving. Zero-limit laws may also penalize persons who have been exposed to secondhand cannabis smoke, which is known to produce measurable THC concentrations in blood (Cone and Johnson 1986). The same applies to the increasing number of individuals who legally use cannabis or THC (dronabinol) for medicinal purposes and, while not acutely impaired, may present with measurable THC concentrations at all times.

Table 1. Comparison of zero-tolerance and science-based DUIC limits

	Type of Per Se Limit	
Advantages / Disadvantages	**Zero-Tolerance**	**Science-Based**
Facilitates law enforcement / no need to prove impairment	Yes	Yes
Motivates drivers to separate cannabis use and driving	Unclear	Yes
May classify sober drivers as “impaired” for hours or days after the “high” ends (risk of *false positives*)	High	Depends on choice of legal limit
May classify strongly impaired drivers as sober (risk of *false negatives*)	Low	Depends on choice of legal limit

Cannabis is the most commonly used illicit drug in the United States (Goodwin Gerberich et al. 2003) and in many other industrialized countries. In several studies, its prevalence in the blood of accident victims was found to be second only to alcohol (Movig et al. 2004; Mura et al. 2003; Drummer et al. 2003). Furthermore, experimental and epidemiological studies suggest that driving

under the acute effects of higher doses of cannabis may in fact increase accident risk and thereby indicate the need to prioritize DUIC control. Yet, the results of epidemiological studies are somewhat inconsistent, and their statistical basis is generally weak (Ramaekers et al. 2004).

In the United States, 13 states have adopted per se laws for DUID. Most of them are zero-tolerance laws, yet their provisions regarding cannabis may vary in whether only THC or also metabolites are considered and in their choice of a detection limit. Only two states, Nevada and Pennsylvania, have adopted nonzero limits for THC (see Appendix A). In Germany, a 1998 DUID law considers a driver impaired by cannabis if THC is found in blood. This provision in effect sets the legal limit at the limit of detection (LOD), about one nanogram per milliliter (1 ng/mL) in blood serum. However, in December 2004 the German Supreme Court (Bundesverfassungsgericht) ruled that the more recently achievable lower LOD of 0.5 ng/mL is not automatically a suitable indicator of impairment. This ruling supports the position that a THC limit should be based on actual impairment by a drug not the sensitivity of analytical techniques used to detect it.

This review presents current approaches to DUID and highlights the need to develop science-based per se limits for cannabis, which facilitate law enforcement while avoiding or minimizing the above-mentioned disadvantages of zero-limit laws.

Project Objectives, Approach, Activities and Participants

To address this need for a science-based numerical THC limit in the absence of strong epidemiological data, an international expert panel of physicians, traffic scientists and forensic toxicologists convened in 2004 at the initiative of Dr. Grotenhermen. Panel members were selected to represent the various scientific disciplines relevant to the issue of DUIC. All are recognized in their field and have published extensively in peer-reviewed journals. The expert panel's mandate was to accomplish the following:

- Review current scientific evidence on DUIC and assess whether it is sufficient to permit the development of rational per se limits for THC,
- Recommend a range of per se limits for DUIC and discuss other aspects relevant to enforcement,
- Identify gaps in knowledge and corresponding research needs.

The panel reviewed experimental studies on the impairment of driving skills by cannabis, epidemiological studies on the prevalence of cannabis among drivers and their culpability in accidents, and studies on the pharmacology and pharmacokinetics of THC. The panel also discussed issues related to the testing for cannabis use and impairment and the enforcement of DUI laws. Consensus statements on each of these areas were developed, critically reviewed and finalized. On the basis of its findings, the panel suggested several guiding principles for, and elements of, a DUIC control system and offered an initial range of per se limits for THC in blood.

2. Pharmacokinetics of THC and Testing for Cannabis

The enforcement of per se laws for DUID invariably requires the testing of a suspected driver for the presence of a reliable indicator of impairment by a drug. For alcohol, the BAC is such an indicator. Because alcohol is water-soluble and is rapidly and evenly distributed throughout the body, the alcohol content of the water vapor in human breath is a reliable proxy for BAC. Unfortunately, no

such proxy exists for cannabis. The utility of potential indicators of the past use of or impairment by cannabis is determined by the pharmacokinetics of THC, i.e., its distribution in the body and the resulting time courses of psychoactivity, metabolism, and excretion. This section summarizes the pharmacokinetics and pharmacology of THC and established and emerging approaches to testing for its presence. For more details, refer to the works of Grotenhermen (2003) of Jenkins and Cole (1997) and to the overview of test methods for cannabis by Grotenhermen and Leson (2004).

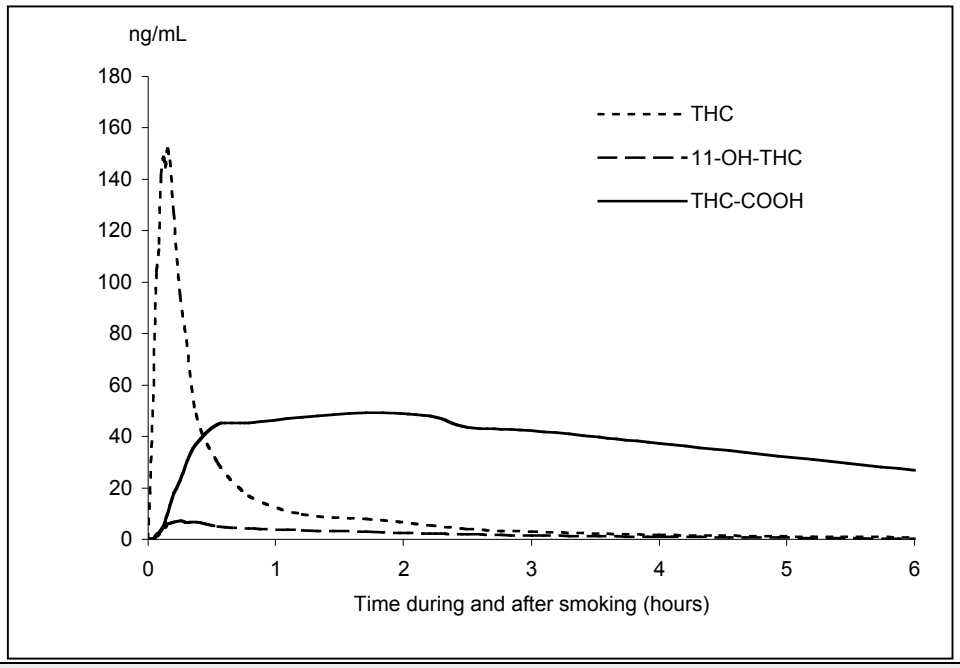

Figure 1 Mean plasma concentrations of THC and its metabolites 11-OH-THC and THC-COOH for six subjects smoking a cannabis cigarette containing 34 mg THC (drawn from data in Huestis et al. 1992).

During studies of the pharmacokinetics of THC, participants smoke or ingest (eat) cannabis containing a known amount of THC. The THC doses consumed during these studies are typically 10–35 mg for smoking and 2.5–20 mg for ingestion, corresponding to "joints" of low to high strength and to oral doses of low to medium strength, respectively. Like intravenously injected THC, smoked THC enters the blood stream immediately, and THC concentrations in blood rise sharply within minutes after inhalation (see Figure 1). THC concentrations in blood typically peak after 5–10 minutes and then fall off. Varying with the dose, peak THC concentrations typically exceed 100 nanograms per milliliter (100 ng/mL) of blood serum.[1] In contrast, cannabis ingested, for example in

[1] When reporting THC levels in blood or when adopting legal limits, one must always specify the reference fluid. Forensic laboratories may report the concentration of THC or its metabolites in ng/mL in whole blood, in plasma or in serum. Blood plasma is the liquid portion of the blood without the blood cells. Blood serum is the clear liquid that separates out when blood is allowed to clot completely. Serum is blood plasma after removal of fibrinogen by clotting. THC concentrations measured in serum and plasma of a given sample are virtually identical and are typically 1.6–2.2 times higher than those measured in whole blood (Giroud et al. 2001). For example, 5 ng/mL of THC in whole blood corresponds to 8–11 ng/mL in serum or plasma. For simplicity, this report will use a factor of 2 to convert whole blood THC concentrations into serum concentrations.

cookies, causes blood THC concentrations to rise more slowly and to peak later and at lower concentrations than does smoking a comparable dose. In both cases, THC concentrations in serum typically drop to 1–4 ng/mL within 3–4 hours after consumption.

However, it is important to note that the data shown in Figure 1 are for THC concentrations after a single cannabis cigarette (joint), following several days of abstinence, reflecting the situation of an occasional cannabis user. In contrast, the blood serum of moderate or heavy users of cannabis may contain more than 2 ng/mL of THC at 24–48 hours after smoking a single joint (Skopp et al. 2003) because of the storage in tissue and slow release of the fat-soluble (lipophilic) THC. Another factor of uncertainty when setting legal THC limits is the great variability of THC concentrations produced by the same THC dose and the variable correlation between THC concentrations and effects. Also note that THC in blood may originate from sources other than smoking and ingesting cannabis. Several studies have shown that exposure to secondhand cannabis smoke may, depending on intensity, produce peak THC concentrations in serum of several nanograms per milliliter (Cone and Johnson 1986).

Peak psychotropic effects (subjective "high") from smoking a single joint occur after 20–30 minutes. Effects typically subside to low levels after 2–3 hours and to baseline after 4 hours. Ingesting cannabis delays the onset and extends the duration of a high (see Figure 2). For both smoking and ingestion, higher doses intensify and prolong the psychoactivity.

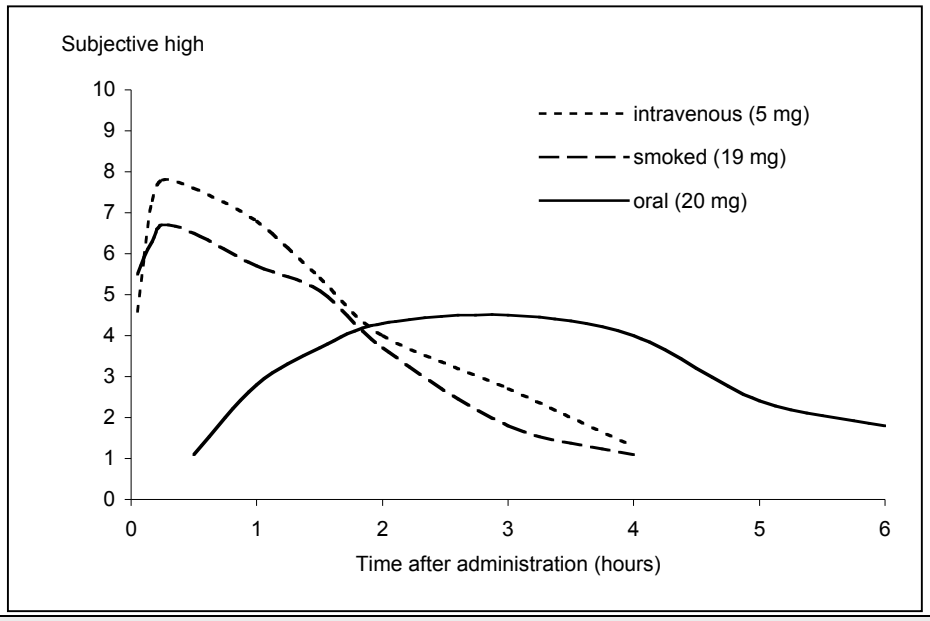

Figure 2. Time course of subjective effects following three modes of cannabis administration. Subjects rated their "high" on a 0–10 scale (estimated from figures of Hollister et al. 1981 and Ohlsson et al. 1980).

Comparing Figures 1 and 2 shows that maximum THC blood concentrations have already dropped significantly before maximum psychotropic effects occur. Consequently, during the first hour after taking cannabis, during which THC is distributed in the body, there is no unambiguous relationship between subjective high and blood THC concentration. However, during the period 1–4 hours after smoking cannabis, such a correlation exists, allowing the use of THC blood concentrations as indicator of impairment of driving skills (Sticht and Käferstein 1998).

Several experimental studies have evaluated by how much and for how long smoking cannabis impairs skills that are relevant to driving. Based on their meta-analysis of such studies, Berghaus et al. (1998a) concluded (see below) that smoking cannabis affects many of these skills during an acute phase (0–60 minutes), during which more than half of the tested skills were significantly impaired, a post-acute phase (60–150 minutes) and a residual phase (more than 150 minutes after smoking), during which impairment subsided rapidly. The actual duration of the post-acute phase and the intensity of impairment during the residual phase both increase with the consumed dose. After "typical" smoked doses of about 20 mg THC, the residual phase lasts about 2 hours.

Thus, the pharmacokinetic characteristics of THC combined with the findings from experimental studies suggest that THC concentrations in blood are a meaningful indicator of impairment by cannabis during the latter phase of a high, starting typically 1 hour after consumption. In contrast, the use of THC metabolites as indicators of impairment, although common in workplace drug testing in the U.S., is problematic. Figure 1 shows that high concentrations of 11-nor-9-carboxy-delta-9-tetrahydrocannabinol (THC-COOH) the main and terminal metabolite of THC, which is non-psychoactive, are present in blood long after psychoactivity from smoking cannabis has subsided. Furthermore, the study by Huestis (1992), which provided the data for Figure 1, showed that low concentrations of THC-COOH may be detected in blood for more than 3 days after a single joint, and even longer and at higher concentrations in the blood of moderate and frequent cannabis users.

The vast majority of smoked or ingested THC is excreted in the form of THC-COOH via urine and feces. As shown in Figure 3, THC-COOH appears in urine with a delay of several hours. Depending on the dose, frequency of cannabis use, mode of consumption and detection limit of the analytical method, THC-COOH can be found in urine for days to weeks. Because of its slow appearance and its long half-life, THC-COOH in urine is not a meaningful indicator of the impairment of driving skills. Rather, the testing of urine samples for THC-COOH is intended as a less intrusive method than blood testing for detecting the use of cannabis within the last several days, not hours.

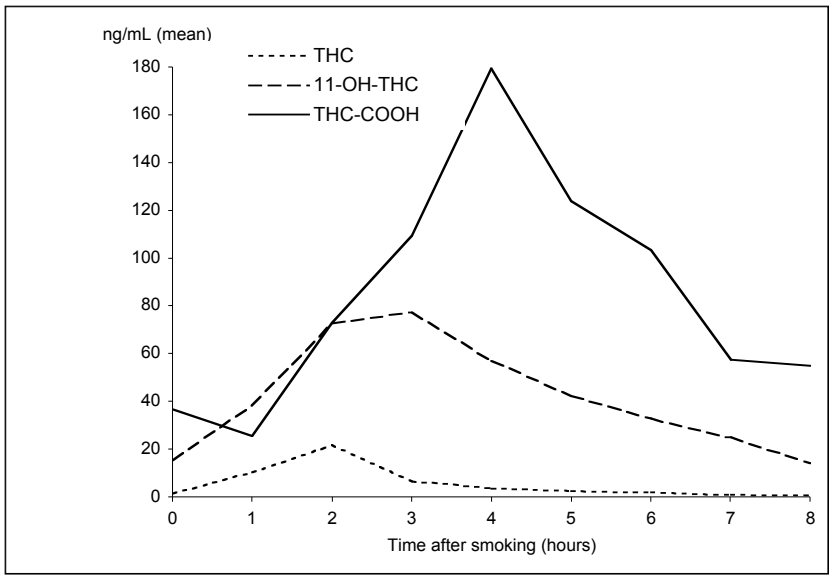

Figure 3. Mean urine concentrations of THC and its major metabolites after smoking a cannabis cigarette containing 27 mg THC by eight subjects with self-reported history of light cannabis use (1–3 cigarettes per week). One subject later admitted regular use and presented with high baseline concentrations of 11-OH-THC and THC-COOH (drawn from data in Manno et al. 2001).

THC concentrations in saliva correlate with those in blood, suggesting their utility for nonintrusive roadside testing for impairment. There is evidence (Menkes et al. 1991) that subjective peak impairment at 20–30 minutes after smoking correlates well with saliva THC concentrations, probably because of sequestration of THC in the buccal cavity. However, large intra- and interindividual variation in saliva THC concentrations and the required high sensitivity of the tests appear to make saliva testing prone to both false positives and false negatives. This suggests that saliva testing may be useful for screening but not suitable as the sole means of determining impairment. Because of their long detection window, sweat and hair samples are not suitable for detection of recent use and impairment (Verstraete and Puddu, 2000). In summary, this review of the pharmacokinetics of THC suggests that THC concentrations in whole blood or serum currently represent the most meaningful indicator of impairment by cannabis during the later phase of a high, i.e., about 1 hour after smoking and 2–3 hours after ingesting cannabis.

3. Empirical Research on Cannabis and Driving

How do we know that consuming a certain amount of alcohol or cannabis impairs the skills of a driver and, more importantly, that it increases his and her risk of causing an accident? Are there correlations between impairment and accident risk on one hand and measurable indicators, such as the BAC and the THC concentration in blood, on the other? Scientists have used two approaches to measuring the effects of drugs on driving and driving-related skills: the epidemiological and the experimental approach. *Epidemiological research* assesses, on the basis of case-control or culpability studies, the *actual risk* that a driver may cause an accident under the influence of a drug, relative to that of a sober person driving under similar circumstances. That relative risk is expressed as an odds ratio (OR). An odds ratio greater than 1.0 corresponds to an accident risk for the "case group," i.e., drivers under the influence of a drug, that is higher than for the control group.

In contrast, *experimental research* evaluates, under controlled conditions in the laboratory, a driving simulator or on blocked-off or public roads, the impairment of and *potential* risk represented by a driver under the influence. This potential risk does not necessarily translate into *actual* risk, for example if the same driver under real traffic conditions is aware of his diminished performance and, by driving slower, is able to compensate for impairment. Because legal limits are intended to control actual risk, the epidemiological approach is therefore preferred for developing limits.

Unfortunately, the evidence from epidemiological studies on cannabis and accident risk is still much less conclusive than for alcohol and alone is insufficient for adopting a science-based legal limit for THC in blood. As an alternative, several researchers have evaluated *experimental* studies on cannabis and impairment, developed a correlation between THC blood concentrations and potential risk and compared the results to those for alcohol.

Several coauthors of the present report have conducted critical reviews of the experimental and epidemiological studies on cannabis and driving conducted to date. Their findings and conclusions are presented in the following. A current overview of the available evidence can be found in the literature (Ramaekers et al. 2004).

Epidemiological Studies

Far fewer epidemiological studies have evaluated the actual crash risk arising from cannabis than is the case for alcohol. The following sections review the results of prevalence, case-control and culpability studies.

Prevalence and Case-Control Studies

Several surveys have found THC to be present in 4 to 14% of drivers who sustained injury or death in traffic accidents (Ramaekers et al. 2004). However, unless comparable data from an appropriate control group, selected from the general driving population, are also obtained, the results of prevalence studies can never be taken to indicate the role of THC or other drugs in causing traffic crashes. For alcohol, breathalyzers allow noninvasive roadside testing of drivers who are not involved in accidents. In contrast, the findings presented in Section 2 suggest that the meaningful testing of *unsuspicious* drivers from the general population for drug use (e.g., at checkpoints) would require blood sampling, which would lead a high proportion of such drivers to refuse to participate. The proportion of such "nonresponders" would probably be even higher among drivers actually under the influence of a drug. This would introduce an unknown selection bias and might render the results of such case-control studies on DUID unreliable.

Several epidemiological studies have investigated whether drivers under the influence of THC had a higher risk than controls to be involved in an accident, for example by selecting controls from the general driving population not in roadside but in hospital settings. Mura et al. (2003) conducted a case-control study to compare the prevalence of THC among 900 injured drivers and 900 control subjects that were recruited from emergency departments in six French hospitals. For cases and controls less than 27 years of age, THC was detected in 15.3% of the cases and in 6.7% of the controls, giving a significant rise to an odds ratio (OR) of 2.5. In cases where both THC and alcohol (BAC > 0.05%) were present, the OR increased to 4.6. Two studies (Dussault et al. 2002; Movig et al. 2004) used the prospective case-control study design that has historically been the design of choice for epidemiological studies of the role of alcohol in motor vehicle crashes. Crash risk was evaluated by calculating the ratio of the odds that an individual in a crash sample would test positive for cannabis to the odds of an individual testing positive for cannabis in the exposure sample, that is, in a roadside survey sample of non-crash-involved drivers, using the same roads in the same time frame. Cannabis use in cases and controls was determined by measuring THC or THC-COOH in blood or urine. The study by Dussault et al. (2002) suggested that the presence of cannabis is associated with twice the risk of being fatally injured in traffic (OR 2.2). Crash risk furthermore increased with combined use of cannabis and other drugs such as alcohol or stimulant drugs. Data from the study by Movig et al. (2004) did not establish a significant association between crash risk and THC use (OR 1.2). It is noteworthy, however, that Movig et al. (2004) established their odds ratio by comparing all cannabis-positive cases with all cannabis-negative controls, irrespective, in both cases, of other drug use (Mathijssen 2004, personal communication). When comparing the cases that tested positive for cannabis only to controls testing negative for any drugs, the OR was actually as low as 0.3, as shown in a preliminary publication based on the same data by the same group (Mathijssen et al. 2002). However, the data set contained just a single case that was positive for cannabis only. The reason for the discrepancy between the results of the studies by Dussault et al. (2002) and Movig et al. (2004) is largely unknown. Nonresponse in the control groups may have

introduced a selection bias in both studies. Although the fractions of nonresponders in the two studies were about the same, i.e., 15% and 20% respectively, it is possible that differences in legislation and tolerance of cannabis consumption between the two countries made drivers in Canada (Dussault et al. 2002) less willing to participate in the study if they had used cannabis than drivers in the Netherlands (Movig et al. 2004). Thus, the selection bias may have been higher in the Canadian study.

Another approach was taken by Goodwin Gerberich et al. (2003). They conducted a retrospective study in a large U.S. health care program cohort (N = 64,657) to compare the incidences of traffic injury–related hospitalization among THC users and non-drug users. All cohort members completed baseline questionnaires about traffic injury–related hospitalization and health-relevant habits, including cannabis use between 1979 and 1985. An increased risk ratio (OR = 2.3) for motor vehicle injuries was demonstrated in male cannabis users relative to nonusers. Fergusson and Horwood (2001) established a statistically significant relation between self-reported frequency of cannabis use and self-reported accidents rate (OR 1.6) in a birth cohort of young New Zealanders. However, adjusting for risky driver behaviors and unsafe driver attitudes characteristic of cannabis users eliminated the association between cannabis use and crash risk. The latter analysis suggests that an elevated traffic accident risk among cannabis users may be related to their lifestyle rather than to cannabis use per se. Yet, the authors noted that these results might also be taken to support an alternative explanation, i.e., that cannabis stimulates risky driving behaviors and attitudes that increase accident risk. However, a more risk-prone behavior has not been seen in experimental studies, rather these studies have shown decreased risk-taking.

Culpability Studies

To eliminate the problems encountered when selecting a control group from the general driving population, epidemiologists have also analyzed the responsibility, or culpability, of drivers involved in traffic accidents. Culpability studies distinguish between those drivers involved in a crash who were responsible and those who were not. For determining the odds ratio of being responsible for a crash as a result of the use of a drug, the former drivers are taken as cases and the latter as controls. To assess their use of a drug, blood samples are taken from all drivers involved in a crash. To avoid biasing the classification process, a researcher must determine the responsibility for a crash without knowledge of the drug status of the involved drivers.

In this section we review the results of studies that have used responsibility or culpability analyses to assess the effect of cannabis use on accident risk. Tables 2 and 3 give an overview of these studies and summarize their main results. Early studies included those by Terhune et al. (1986, 1992) and by Williams et al. (1985). In a 1982 study, reported by Terhune (1986), drivers with only THC, i.e., no alcohol, present, had a responsibility rate of 76% compared to 42.5% for the control group. Terhune et al. (1991) conducted a responsibility analysis on 1,882 drivers killed in seven U.S. states in 1990 and 1991. In drivers who tested positive only for THC, the responsibility rate was 57.9%, less than the 67.7% for sober drivers. However, the reduction was not statistically significant. It should be noted that this group included only 19 drivers. In a study of California drivers, Williams (1985) also found little evidence that cannabis played a role in accident causation. Yet, again, the number of drivers was small.

Canadian studies in the 1980s tended to suggest that cannabis-users are more likely to be responsible for their crashes than drug-free drivers (Simpson et al. 1982; Simpson 1986; Warren et al. 1981). The OR for cannabis users was 1.7 compared to drug-free controls. However, the method of assessing responsibility was not clear, and other possible interactions were not considered.

An investigation of 168 trucker fatalities in which driver responsibility was assessed by a panel of toxicologists pointed to an adverse effect on crash risk caused by THC concentrations in whole blood of over 1 ng/mL and by other psychotropic drugs (Crouch et al. 1993). This was not a classical responsibility study but was aimed only at assessing whether any increased risk was associated with the use of drugs by truck drivers.

A higher crash responsibility was not observed with cannabis in injured drivers admitted to an urban emergency center in Colorado (Lowenstein et al. 2001). However, the study used the metabolite THC-COOH in urine as marker for cannabis use, rather than THC in blood. Because of the long half-life of THC-COOH, its presence does not indicate impairment, and the lack of an increased crash responsibility suggests that merely the use of cannabis within the last several days does not seem to increase crash risk. The authors suggested that they had used a method due to Robertson and Drummer (1994) to determine responsibility but also referred to several other methods. It was therefore unclear which of these methods was actually used in the study.

A study involving hospitalized injured drivers in the state of South Australia using the method of Robertson and Drummer (1994) showed that cannabis had little adverse effect on crash risk, although there was a tendency to an increased risk at higher concentrations (Longo et al. 2000). Most of the THC-positive cases presented with THC concentrations in whole blood of below 2 ng/mL, quite possibly because of inevitable delays between crash and sample collection. Sampling delays in excess of 1 hour may cause a substantial underestimation of the THC concentration at the time of the crash, but they leave metabolite concentrations largely unaffected.

A 10-year study of fatally injured drivers involved collaboration of centers in three Australian states (Drummer et al. 2004). The study also employed the method for responsibility analysis devised by Robertson and Drummer (1994). It involved a structured process of assessing eight different factors indicative of crash responsibility. This determination, which had been validated for alcohol, was made independent of any legal assignment of culpability. In total almost 3,400 drivers in crashes were included in the study. The possibility of statistically significant interactions was tested by using a logistic regression model.

This extensive study produced the following results for drivers positive for cannabis, but no other drug or alcohol: Those drivers with THC concentrations in whole blood of less than 5 ng/mL, and those with THC-COOH but not THC in their blood, had an OR not significantly different from 1.0, i.e., did not have an elevated crash risk. For the group of cases with THC concentrations in whole blood above 5 ng/mL, the OR was 6.6, similar to that for drivers with a BAC above 0.15%. Overall, drivers in that group had THC blood concentrations higher than in previous studies on cannabis with a median concentration of more than 10 ng/mL. This may explain why the effect of cannabis on crash risk found in this study was more visible than in previous studies. It also supports the findings of Longo et al. (2000) that higher blood-THC concentrations are in fact related to a higher culpability and accident risk. Alcohol was found in 43% of all cannabis-positive cases. In these cases the risk was higher than that attributable to alcohol alone.

Table 2 shows the results of several of the above-mentioned culpability studies on DUIC; Table 3 presents results of the recent, comprehensive study by Drummer et al. (2004). In summary, culpability studies have shown somewhat inconsistent findings on the effect of cannabis on the culpability, or responsibility, of a driver for an accident. The most recent study, which also evaluated the largest population of drivers to date, points to an increased crash risk among cannabis users who presented with THC in whole blood of at least 5 ng/mL, corresponding to 8–10 ng/mL in serum (Drummer et al. 2004). Note that the OR of 6.6 shown in Table 3 represents an average over the concentration range of 5–100 ng/mL. The OR for the 5–10-ng/mL range can be estimated at 2.8.

Table 2. Results of culpability studies on drivers showing THC or THC-COOH in blood or urine without concurrent presence of other drugs or alcohol. THC concentrations are for whole blood. To obtain THC concentrations in serum, multiply by 2.

Authors	Total # of drivers	Specimen	Percentage of drivers with cannabinoids only	Percentage of cannabinoid-only drivers with THC*	Odds ratio (OR)
Lowenstein and Koziol-McLain 2001	414	urine	8.2%	0**	1.1
Longo et al. 2000	2,500	blood	7.1%	28.1%	THC <1.0 ng/mL: 0.36 THC:1.1–2.0 ng/mL: 0.52 THC > 2.0 ng/mL: 1.8
Drummer 1994	1,045	blood	4.1%	4.7%	0.7
Terhune et al. 1992	1,882	blood	1.0%	100%	0.7
Williams et al. 1985	440	blood	4.3%	100%	0.2
Terhune & Fell 1982	497	blood	3.4%	100%	2.1

* For the other drivers, only THC-COOH concentrations had been measured.

** In urine, only THC-COOH was determined.

The generally higher observed blood THC concentrations in the study of Drummer et al. (2004) may reflect in part the increase in THC content of cannabis over the last 10 years. This in turn may raise the probability of serious impairment compared to the drivers investigated in previous studies. An alternative explanation for the low percentage of drivers with low THC concentrations observed in this study may be the simple fact that drivers with low THC concentrations were rarely involved in crashes. Other factors that affected the classification of users in all studies and that may have confounded results were the use of THC vs. the THC-COOH metabolite as an indicator of cannabis use and the often-significant delay between accident and the time of blood sampling. In conclusion, the results of culpability studies are still inconsistent and statistically too weak to justify selection of a numerical THC limit. Yet these results strongly suggest that THC concentrations in whole blood of less than 5 ng/mL are not associated with an elevated crash risk, whereas higher THC concentrations increasingly are.

Table 3. Distribution of THC and alcohol positive drivers in study by Drummer et al. (2004) (all THC concentrations are for whole blood. To obtain THC concentrations in serum, multiply by 2)

Number of cases	Drug(s) detected	Group	Odds Ratio (OR)
58	THC	all THC concentrations (1–100 ng/mL)	2.7 (1.02–7.0)*
10	THC	less than 5 ng/mL	0.7**
18	THC	5–9.9 ng/mL	2.8**
30	THC	≥10 ng/mL	infinite**
48	THC	more than 5 ng/mL	6.6 (1.5–28)*
43	THC + alcohol		7.8
990	alcohol	all above 0.05%	6.0 (4.0–9.1)*
137**	alcohol	0.1–0.15%	3.7
275**	alcohol	more than 0.2%	25.0

* 95% confidence limits in parentheses

** Personal communication by O. Drummer. At THC concentrations in whole blood of more than 10 ng/mL, all drivers were responsible for the accident (OR = infinite).

Experimental Studies

To date, more than 120 experimental studies have evaluated the impact of cannabis on individual physical, mental and psychological skills that are critical to driving performance and on the performance of complex driving tasks. The vast majority were laboratory studies of single or multiple psychophysical functions such as tracking and reaction time. Some fifteen studies evaluated the influence of cannabis alone or in combination with alcohol on simulator and on-road driving.

Driving Simulator and On-Road Studies

For the present report, Smiley summarized and updated an earlier review of driving simulator and on-road studies, which had evaluated the impact of THC on driving, and compared them with the effects of alcohol (Smiley 1999). The review covers the results of eight driving simulator and seven on-road studies performed between 1969 and 2002. These studies examined a wide range of tasks and dose concentrations of smoked cannabis, alone and in combination with alcohol. Measures of driving performance included the driver's ability to keep the vehicle in the center of the lane, to maintain a specified speed, changes in risk-taking behavior, performance of secondary tasks and response to emergency events. Tests were usually performed during the first hour after smoking, i.e., the period of strongest effects. Several studies also evaluated effects after an extended period. Table 4 summarizes these studies and the parameters tested in each of them.

Table 4. Summary of driving simulator and on-road studies on cannabis and alcohol

Study / Reference	Lane Control	Speed Control	Secondary Tasks	Emergency Response	Risk-Taking	Extended Effects
Driving Simulator Studies						
Crancer et al. 1969			C, A			C, A
Dott 1971				C	C	
Ellingstad et al. 1973					C, A	
Moskowitz et al. 1976			C			
Rafaelsen et al. 1973				C, A		
Smiley et al. 1981	C, A	C, A	C, A	C, A	C	
Stein et al. 1983	C, A	C, A	C, A			
Sexton et al. 2000	C	C		C		
On-Road Studies						
Attwood et al. 1981	C, A	C, A				
Caswell 1977	C, A	C, A	C, A			
Hansteen et al. 1976	C, A	C, A				C, A
Klonoff 1974	C	C				
Peck et al. 1986	C, A	C, A				C, A, C+A
Robbe and O'Hanlon 1993	C	C			C	C
Smiley et al. 1986		C, A	C, A	C, A	C	C, A, C+A

Notes:
C: Effects of cannabis were tested
A: Effects of alcohol were tested
C+A: Effects of combining cannabis and alcohol were tested

Lane Position Control

In the majority of studies, cannabis was associated with poorer lane control (Smiley et al. 1981; Klonoff 1974; Hansteen et al. 1976; Robbe and O'Hanlon 1993; Sexton et al., 2000). Effects started at THC doses as low as 6.3 mg (90 μg THC per kilogram of body weight for a person weighing 70 kg (155 lb.). In those studies in which impaired lane position control was not observed, subjects had slowed down and thus were able to maintain lane position as well as under placebo conditions (Stein et al. 1983; Peck et al. 1986; Caswell 1977). The studies that measured alcohol impacts all found significant impairment of lane control.

Speed Control

In seven of the ten studies in which speed was measured, cannabis was associated with a decrease in driving speed, even though subjects were required to maintain a particular speed. As drivers under alcohol had a tendency to increase speed, this may explain why alcohol also more consistently impaired lane position control (see above) than did cannabis.

Risk-Taking Behavior

Changes in driving speed are one potential indicator of differences in risk-taking behavior between drivers who consumed alcohol and cannabis. Two simulator studies found that subjects on cannabis

treatment were less likely to engage in overtaking maneuvers (Dott 1971; Ellingstad et al. 1973). The second study included an alcohol condition and found that it was associated with the opposite effect, that is, more overtaking. One simulator study and two on-road studies examined car-following behavior and found that drivers adopted longer headways, indicating less risky behavior, under cannabis (Smiley et al. 1981; Smiley et al. 1986; Robbe and O'Hanlon 1993). In summary, cannabis apparently induces more conservative behavior while alcohol appears to induce higher speeds and more overtaking—that is, a riskier behavior.

Driver Instructor and Police Ratings

In a study of urban driving behavior, driving-instructor ratings showed that a dose equivalent to 7 mg THC for a 70-kg person did not impair performance, although subjects rated their driving as being impaired (Robbe and O'Hanlon 1993). In contrast, observer ratings showed that a BAC of 0.04% impaired performance, but subjects did not perceive themselves as being impaired. In a closed-course experimental study, police observed drivers on doses equivalent to 7 and 14 mg THC for a 70 kg person, alone and in combination with a BAC of 0.08% (Peck et al. 1986). Police would have stopped, under suspicion of impaired driving, 15% of the drivers on the placebo, 32% of the drivers on the cannabis treatments, 50% of the drivers on alcohol treatment and 60% of the drivers on combinations of alcohol and cannabis. Thus at the doses used, both driving instructors and police rated those on alcohol treatments as more impaired than those on cannabis treatments.

Emergency Response

The ability to respond in an emergency was tested in one on-road and four simulator studies. Of the latter, one found that cannabis increased decision time for passing, but not when participants had been alerted that they might have to respond quickly (Dott 1971). One simulator study found that both cannabis and alcohol were associated with significantly increased time for braking when a green light in the car suddenly changed to red (Rafaelsen et al. 1973). One study found subjects on the high dose, but not the low dose, crashed into an obstacle that suddenly appeared in the road more frequently than when on placebo (Smiley et al. 1981). One study found no effect of cannabis on detection of hazardous events viewed in a film (e.g., a child running across the street), nor did cannabis affect detection and response when a vehicle suddenly pulled out in front of the driver or slowed ahead (Sexton et al. 2000). In the on-road study, no effects of either cannabis or alcohol were found on an emergency lane-changing task (Smiley et al. 1986). Overall, study results were mixed. Some found effects on emergency decision making at smoked THC doses as low as 14 mg and others found no effect at doses as high as 18 mg.

Secondary Task Performance

The effects of drugs on secondary task measures are important because those measures indicate how well a driver monitors the road environment for other road users and for hazards, and whether the risk of an accident due to inattention is increased. Two simulator studies found that cannabis use was associated with a significant dose-related increase in mean reaction time to the intermittent appearance of red and green lights (Moskowitz et al. 1976; Smiley et al. 1981). In a third simulator study no effect of cannabis was found on a sign detection task, possibly because subjects knew when signs would appear and were able to prepare to respond (Stein et al. 1983). A fourth study found that cannabis was associated with poorer monitoring of a speedometer (Crancer et al. 1969). In one on-

road study, cannabis was associated with increased time to respond, by pushing a button, to a sound signal (Casswell 1977), while in the other on-road study, there was no effect of cannabis on response to a visual signal (Smiley et al. 1986).

In summary, four out of six studies showed that cannabis impaired secondary monitoring tasks, with the lowest dose that showed a significant effect being 6.25 mg THC and the highest dose not associated with any effects being 14 mg THC.

Extended Effects

Five studies, one simulator and four on-road studies, looked at extended effects of cannabis and alcohol on driving. Only one study showed any effect of cannabis on driving performance after the initial test (Robbe and O'Hanlon 1993). This was an on-road study involving highway driving, and it found effects 1 hour after treatment to be as strong as immediately after treatment. Two studies testing similar doses found no effects on driving 4 hours after dosing. In contrast, three of the studies showed alcohol-alone effects on driving for extended periods (at 3, 4, and 8 hours after dosing).

In summary, simulator and on-road studies show that cannabis may impair some driving skills at smoked THC doses of as low as 6.25 mg. However, results varied considerably between the skills tested and among studies, and some of the skills tested were not impaired at doses as high as 18 mg. Some of the impairment caused by cannabis is mitigated because subjects appear to perceive that they are indeed impaired. Where they can compensate, they do, for example by not overtaking, by slowing down and by focusing their attention when they know a response will be required. Such compensation is not always possible, however, where events are highly unexpected. In blind ratings, police and driving instructors rated a BAC of 0.08% as more impairing than cannabis treatments at moderate to high doses. In all the studies we evaluated, effects on driving performance were found for up to an hour after smoking. These effects did not continue for extended periods.

The above-cited studies focused on observing performance during the *first hour* after smoking cannabis, i.e., during the period of highest impairment. None of the studies measured THC concentrations in blood at the time of the performance testing. Nor do these experimental studies provide a concentration–effect relationship for the later phase of a cannabis high, i.e., 1–4 hours after smoking. This phase is crucial for setting a THC limit, because some drivers may still experience low-level impairment of their driving skills while THC concentrations in serum have already dropped below 15 ng/mL. Higher THC concentrations are clearly indicative of more recent consumption and, according to the results of culpability studies (see above), of elevated accident risk.

Meta-analysis of Experimental Studies

Berghaus et al. (1998a) addressed the need for a systematic evaluation of the impairment corresponding to serum THC concentrations in the 0–20 ng/mL range, through the *meta-analysis* of a large number of experimental studies on THC and driving. Studies considered in this meta-analysis included the simulator and on-road studies reviewed above and numerous laboratory studies of individual driving-related skills. The authors' goal was to develop a basis for a legal THC limit by comparing the impairment caused by THC with that caused by alcohol. The rationale of their approach was as follows.

- **Experimental studies on THC and alcohol use the same methods**
  Experimental studies on the effects of cannabis and other drugs on driving skills use the same methods, equipment and procedures as those for alcohol, i.e., on-road driving, simulator tasks or laboratory experiments. They also use the same statistical methods to process data and report results. Such studies test for the "significance" of changes, i.e., they perform one trial on subjects under the influence of alcohol or a drug, repeat it with the same group of subjects, this time not under the influence, and finally compare the results of the two trials, using statistical procedures. A typical result of such a test would read: a group of drivers who consumed a specific dose of a drug performed "significantly worse" on a particular test than they did under placebo.
- **Meta-analyses allow comparison and synthesis of numerous studies**
  Scientists perform a meta-analysis of published research on a particular subject in order to evaluate and compare the results of a multitude of studies that meet defined quality criteria. For a meta-analysis, one extracts the essential information from the selected studies, codes their results in a standardized form and conducts a computerized evaluation using statistical methods. Provided that a sufficiently large number of studies meet these quality criteria, the meta-analytical approach provides findings of considerably greater significance than those of single studies with particular experimental designs.
- **THC dose can be converted into blood concentrations**
  Most studies on cannabis and driving skills provide information on the dose applied, the mode of application (smoked vs. oral) and time passed between consumption and test. With that knowledge and using a pharmacokinetics model for THC uptake and metabolism, one can estimate the THC concentration in blood at the time at which a test was performed. It must be noted that THC concentrations in blood after oral ingestion or inhalation of a defined dose vary considerably, but that calculations can be performed with the expected mean concentrations.
- **Risk-based alcohol concentrations are well established**
  Jurisdictions now typically use BAC concentrations of between 0.03% and 0.05% as indicators of various degrees of impairment by alcohol.
- **Comparison of meta-analyses for THC and alcohol provides basis for THC limit**
  With the above tools, one can establish equivalent levels of impairment by comparing the results of meta-analyses for alcohol and THC. For example, one may identify the THC concentration in blood at which the same percentage of all test results corresponds to impairment as for a BAC of 0.05% as the THC concentration equivalent to that BAC.

The working group of Krüger (Center of Traffic Sciences, University of Würzburg) and Berghaus (Institute for Forensic Sciences, University of Cologne) performed the necessary evaluation of the literature on cannabis, alcohol and driving. First, Krüger (1990) and Krüger et al. (1990) compiled and evaluated, in a meta-analytical review of the scientific literature, suitable experimental studies on the effects of low doses of alcohol and introduced two classification systems for measuring performance. One system classified according to the type of function, such as tracking or psychomotor performance, while the other classified tests as automatic process, control process or driving/simulator. In 1994, Berghaus employed the same procedure to analyze published experimental studies on THC (Berghaus 1995; Krüger et al.,1995; Berghaus et al.,1998a). This

allowed for a first systematic and quantitative comparison of the results of experimental research on the effects of THC and alcohol.

Studies on Cannabis

In their meta-analysis of experimental studies on cannabis, the authors just named selected, out of more than 120 studies, 66 in which cannabis had been *smoked* and 21 with *oral* intake of cannabis. The selected studies included laboratory tests, driving simulator and on-road studies; they had been published in English or German and met the following minimum quality criteria: testing of at least one driving-relevant skill, a minimum of *five human* subjects tested, and the following core data were provided: THC dose and mode of application; number, age and gender of subjects; time delay between consumption and testing; type of test performed (e.g., tracking, visual function), the tasks themselves (e.g., two-hand coordination, flicker fusion) and the test results, coded as significant improvement or impairment (at least at the 5% level) or as "no significant change." Studies in which THC had been taken together with other drugs or alcohol were excluded.

Since THC concentrations in blood were usually not measured at the time of the tests, the authors estimated them using a pharmacokinetics model developed by Sticht and Käferstein (1998). The model required as input the THC dose, the mode of application (oral vs. smoked) and the time elapsed between intake and test.

This meta-analysis produced the following *general observations* on cannabis and driving:

- The higher the estimated concentration of THC in the blood, the greater the impairment.
- Given the same dose of THC, infrequent or light users of cannabis experience greater negative effects than heavy users. This indicates that regular users develop tolerance to THC and/or that drivers can adapt to the impairment caused by THC.

Furthermore, the meta-analysis produced the following specific findings on cannabis and driving skills:

Effects after smoking

The smoked doses ranged from less than 9 mg to more than 18 mg and thus covered the range from a "low" to a "strong social" dose. Of all 761 test results, only 3 showed a significant improvement of functions after cannabis use, while 50% of all results showed impairment, averaged over all doses, functions and times. During the first (acute) phase, typically between 10 and 60 minutes after smoking, test results show significant impairment of overall skills. Maximum impairment occurs at 20–40 minutes after smoking, indicated by impairment in 64% of test results. During the second (post-acute) phase, between 1 and 2.5 hours after smoking, 35–40% of all test results showed impairment. During these first two phases, the smoked dose did not strongly affect the degree of impairment, i.e., higher doses did not necessarily result in greater impairment. The duration of the third (residual) phase and the degree of impairment are dose dependent. At low doses (less than 9 mg) no impairment was observed 2.5 to 7 hours after smoking. At doses between 9 and 18 mg, no impairment was observed between 2.5 and 12 hours. Minor impairment was observed in more demanding flight simulator tests 12 to 24 hours after smoking. At doses of more than 18 mg, several test results indicating impairment were observed more than 5 hours after smoking.

Figure 4 shows the results of the meta-analysis for smoked cannabis by test category (automatic, control, driving) as a function of the time passed since smoking. For each category, the bars represent the percentage of all tests in which subjects on cannabis performed significantly worse than placebo takers. The figure shows that at 20–40 minutes after smoking, commonly smoked THC doses cause strong impairment in all categories. Impairment then subsides with residual impairment of 30–40% of skills at more than 2.5 hours.

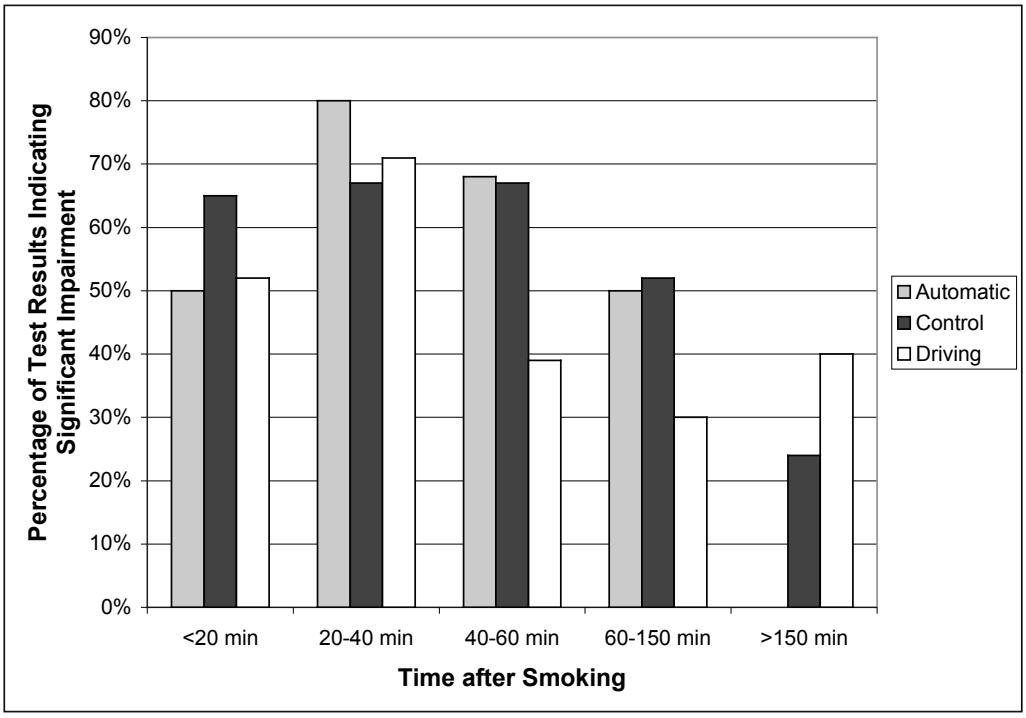

Figure 4. Percentage of test results indicating significant impairment for major test categories at various times after smoking cannabis (Data from Berghaus et al. 1998a).

Figure 5 shows that the total percentage of results indicating significant impairment increases as THC concentration in serum raises above 10 ng/mL. At concentrations below 10 ng/mL, which are characteristic of the post-acute and residual phases of a cannabis high, 40% of all test results still showed some impairment. At concentrations above 10 ng/mL, more than 50% of all test results showed impairment.

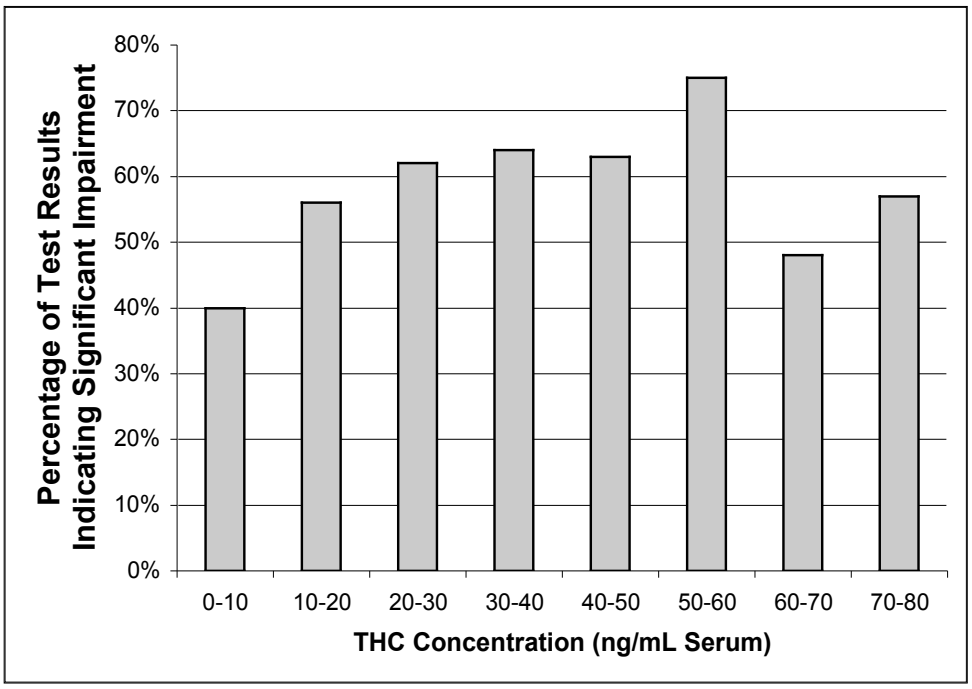

Figure 5. Percentage of test results indicating significant impairment for all test categories vs. THC concentration in serum (data from Berghaus et al. 1998a).

Effects after Oral Use

In the 21 studies evaluated, oral doses of THC ranged from 2 to 39 mg, covering the range from a very low to a strong social dose. Typical oral doses in social settings are in the 10–20 mg range. Of all 354 test results, only one showed improvement, while 28% of all results showed significant impairment. Maximum impairment occurs 60–90 minutes after ingestion, i.e., 40–50 minutes later than with smoking. At that time, 50% of all test results indicate impairment relative to placebo treatment. The impairment rate falls off to typically 20% during the fourth hour after ingestion. Tests at 15 hours after ingesting cannabis showed no residual impairment.

Figure 6 (Berghaus 2001, p. 246, Figure 11.4) shows that the total percentage of results indicating significant impairment after oral cannabis intake increases with increasing THC concentration in serum, albeit more gradually than after smoking. At serum concentrations between 5 and 7 ng/mL, the overall percentage of test results indicating impairment is somewhat lower than if the same THC concentration was produced by smoking.

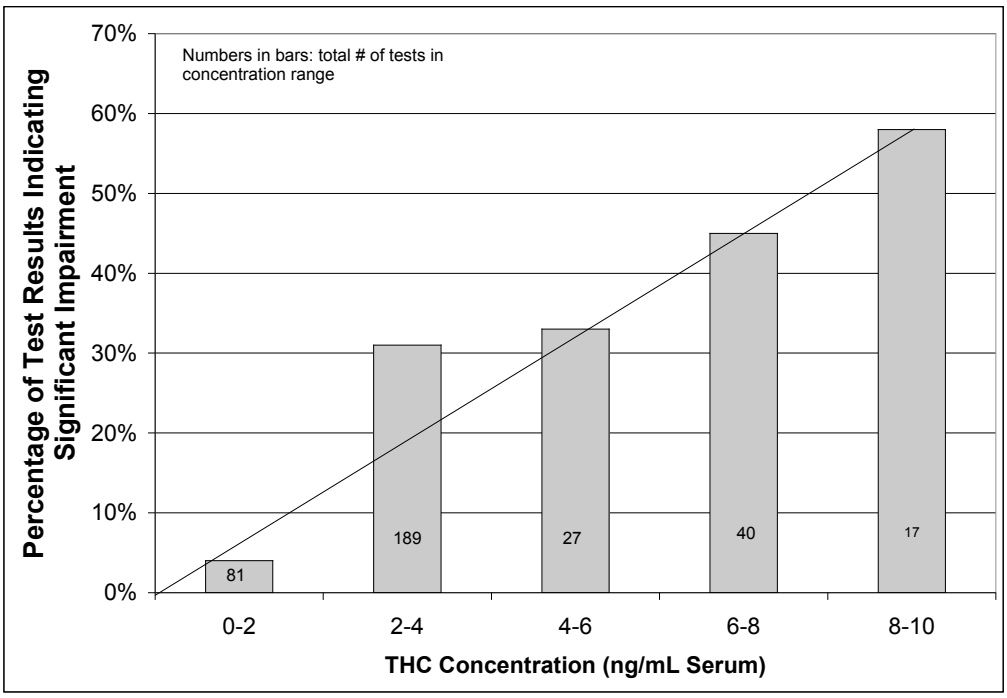

Figure 6. Correlation between THC concentration in serum and percentage of test results indicating impairment after oral cannabis use (cited from Berghaus et al., 1998a).

Comparison with Alcohol

The authors compared the findings of their meta-analysis on THC, described above, with those of a previous meta-analysis on impairment by alcohol (Berghaus et al., 1998b). These results of this latter study are in general agreement with the findings of a similar meta-analysis performed by Moskowitz et al. (2000). Figure 7 compares the survival functions (or percentage of significantly impaired test performance) for the total of tests in all categories under the influence of alcohol and cannabis. It suggests that THC serum concentrations of about 4 ng/mL from smoking cannabis produce the same overall percentage of test results indicating impairment as BAC concentrations of 0.04%. At these concentrations, about 30% of all test results show impaired performance for both alcohol and THC. For oral cannabis, a THC concentration in whole blood of 4–5 ng/mL produces the same level of impairment as a BAC of 0.04%.

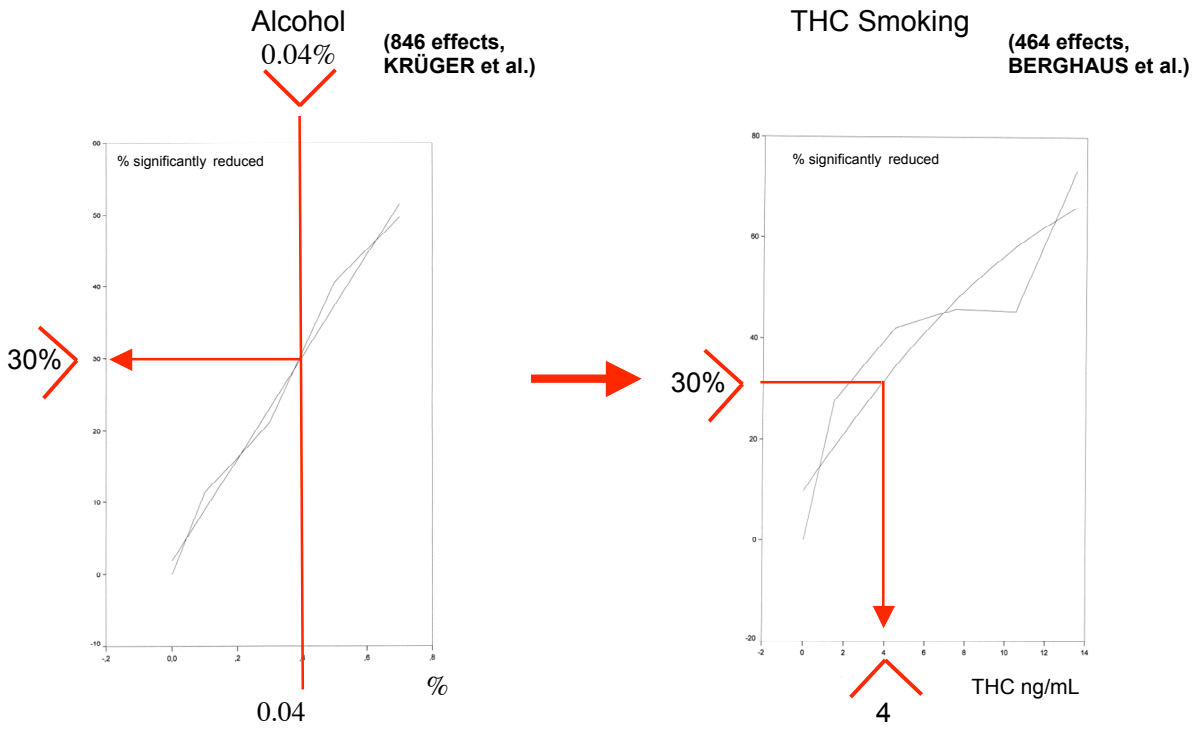

Figure 7. Comparison of survival functions for THC and alcohol and establishment of points of equal impairment.

The two meta-analyses (Berghaus et al.1998a, 1998b) and their comparison represent a systematic evaluation of the impact of cannabis on driving skills and allow correlating the effects of alcohol and cannabis on driving performance. The authors point out the following limitations of their meta-analysis. These must be considered when selecting a numerical value for a legal THC limit.

- The doses administered in most of the studies evaluated cover the range from low to "strong social" doses. However, the impairment caused by very strong THC doses was underrepresented in the tests. Consequently, the correlation obtained between THC concentration and impairment may be less accurate during the later phases of a strong cannabis high.
- The methodology of comparative meta-analyses assumes implicitly that if a set of THC and alcohol concentrations produces the same impairment ratio in experimental studies, it also produces the same actual accident risk under real traffic conditions. This assumption will not be valid if drivers under traffic conditions compensate differently for the impairment caused by THC and alcohol.

Furthermore, recent proficiency trials in German forensic laboratories show a high variability between different laboratories in the reported THC concentrations for a blood samples spiked with the same amount of THC. For a spiked concentration of 10 ng/mL, laboratories reported values of 2–16 ng/mL, which reflects a variability considerably higher than that for alcohol samples (Schmitt et al. 2003). This variability, which is likely to be encountered in the United States as well, must also be considered when selecting an enforceable numerical THC limit, i.e., a margin of safety needs to be added to a numerical limit to account for the expected variability in test results. That issue is addressed in the Recommendations section (Section 5).

Concurrent Use of Cannabis and Alcohol

A particular concern to traffic safety is that cannabis is frequently consumed together with alcohol. Several experimental studies have evaluated the impact of cannabis and alcohol on driving skills, alone and in combination. Ramaekers et al. (2000) studied the effect of THC doses of 7 and 14 mg in a road-tracking and car-following test in normal traffic, with and without concurrent alcohol doses resulting in a BAC of 0.04%. The main outcome measures were standard deviation of lateral position (SDLP), time driven out of lane (TOL), reaction time (RT) and standard deviation of headway (SDH). THC doses alone and alcohol alone both significantly impaired the subjects' performances in both driving tests. Performance deficits were minor after alcohol and moderate after both THC doses. Combining THC with alcohol additively impaired driving performance. Alcohol combined with THC doses of 7 and 14 mg produced rises in SDLP equivalent to those associated with a BAC of 0.09% and 0.14%, respectively. Mean TOL rose exponentially with SDLP. Changes in SDH ranged between 0.9 and 3.8 m. Relative to placebo, mean RT increased by 1.6 s under the combined influence of alcohol and 14 mg of THC. The authors concluded that low doses of THC moderately impair driving performance when given alone but severely impair driving performance in combination with a low dose of alcohol.

Sexton et al. (2000, 2002) of the British Transport Research Laboratory (TRL) tested the effect of smoked cannabis doses of 12 and 19 mg, respectively, alone and in combination with alcohol producing a BAC of 0.05%. Combining the low THC and alcohol doses significantly increased impairment in lane-position and computerized tracking tests with respect to the impairment resulting from consumption of THC or alcohol alone. In particular, on a right-hand curve, the SDLP was found to increase in the following order: placebo / alcohol / low cannabis dose / low cannabis dose + alcohol / high cannabis dose. TRL tests with the adaptive tracking task (a laboratory task which measures ability to track a moving object on a computer screen) also showed that tracking performance deteriorated with increased dose, in the order placebo / low cannabis dose / low alcohol dose / low cannabis + low alcohol dose.

Overall, the results of these recent studies consistently show that combining low doses of THC and alcohol impairs driving skills much more than does either of the drugs alone. There are not much data available so far, and the effects may vary depending on the time each drug was taken.

4. Summary and Discussion of Findings

Scientific evidence on cannabis and driving is not yet sufficient to permit the selection of a numerical enforceable THC limit with the same level of confidence as for alcohol. In particular, data from epidemiological studies suffer from a low number of cases with THC concentrations of 5–20 ng/mL serum (about 2.5–10 ng/mL blood). However, the combined findings and conclusions from epidemiological and experimental studies on cannabis and driving offer an initial science-based foundation for a legal limit.

<u>Epidemiological Studies</u>

Epidemiological studies on DUI examine the association between relatively rare events, such as traffic crashes, injury or death, and a risk factor, such as the consumption of alcohol or a drug. The

results of some 20 studies on cannabis and driving are somewhat inconsistent. The most meaningful recent culpability studies indicate that drivers with THC concentrations in whole blood of less than 5 ng/mL have a crash risk no higher than that of drug-free (sober) drivers. The crash risk apparently begins to exceed that of sober drivers as THC concentrations in whole blood reach 5–10 ng/mL (corresponding to about 10–20 ng/mL in serum or plasma). Because recent studies found only few drivers with THC concentrations in that critical range, a reliable assessment of the associated crash risk is still lacking.

Even frequent users of cannabis do not seem to have a higher accident risk than nonusers as long as they are not under the acute influence of the drug, i.e., there appear to be no effects of prolonged cannabis use on traffic safety. Any long-term impairment by cannabis would be reflected in an overall higher crash risk of drivers testing positive for THC-COOH. However, no such increase was found in culpability studies.

Experimental Studies

Altogether, the more than 120 laboratory tests and driving studies conducted to date have demonstrated that cannabis use may acutely impair several driving skills, including cognition and psychomotor performance. As is the case with alcohol, impairment generally increases with dose. For cannabis, the effect of a certain dose varies considerably between individuals, more so than is the case for alcohol. The main causes of that variability are the development of tolerance with regular use, differences in smoking technique and differences in absorption of THC.

Smoking cannabis impairs driving skills most severely during an acute phase, which typically lasts up to 60 minutes after smoking. A post-acute phase (60–150 minutes after smoking) and a residual phase (>150 minutes after smoking) during which impairment subsides rapidly, follow. The duration of the post-acute phase and the intensity of impairment during the residual phase both increase strongly with dose. After smoking “typical doses” of about 20 mg THC, the residual phase lasts about 2 hours. Several studies have compared the impairment caused by cannabis and alcohol. The results of a meta-analysis of about 90 experimental studies of the impact of smoked and oral cannabis on driving suggest that THC concentrations in serum correlate with impairment in performance during the post-acute and residual phases. Comparison with the results of a meta-analysis on alcohol and driving suggests that a THC concentration in serum of about 4 ng/mL (about 2 ng/mL in blood), caused by smoking or oral use of cannabis, is associated with the same overall performance impairment as a BAC of 0.04%. A BAC of 0.08% corresponds approximately to a THC concentration in serum of 9 to 10 ng/mL.

Even such “equivalent” blood alcohol and THC concentrations affect driving skills in different ways. The detrimental effects of THC are more prominent in highly automatic driving functions such as tracking performance, while more complex driving tasks that require conscious control (e.g., overtaking, time to speed adaptation, interpretation and anticipation of traffic, and navigation) are severely affected only at higher THC doses. This may explain why subjects under the influence of cannabis appear to be able to make the correct response if given a warning, yet exhibit impaired performance when a response is called for unexpectedly. In comparison, alcohol severely affects more complex driving and divided attention tasks, while simple attention tasks are not so much affected and psychomotor skills, especially tracking and simple reaction time tasks, are only affected at higher BAC.

Depending on the dose consumed, most acute effects on driving skills subside within 3 to 4 hours after smoking a cannabis cigarette, i.e., during the residual phase. Larger doses extend the period of impairment. Most studies found no effect of cannabis on psychomotor functions after 4 hours. The studies that did find some impairment for up to 24 hours after the last consumption involved highly demanding flight simulator tests in which subjects had to orient themselves in three dimensions. An alternative explanation for the impairment observed in these tests may be persisting memory deficits caused by cannabis. This suggests that a waiting period of about three hours after smoking a medium to strong social dose will be sufficient to reduce a driver's impairment to that comparable to a BAC of less than 0.03%.

Cannabis is often consumed together with alcohol. The combined use of low doses of THC and alcohol impairs driving skills much more than consuming each of the respective doses individually and must be considered when setting limits for THC in blood.

Testing for Cannabis

Blood concentration of THC correlates with impairment of driving skills during the post-acute and residual phases of a cannabis high, which typically extend from 1 to 4 hours after consuming cannabis. In contrast, the presence of the slowly excreted THC metabolite THC-COOH in blood and particularly in urine does not indicate acute impairment, but rather only the use of cannabis in the preceding few days. Saliva screening for THC is an emerging technique for estimating the time and severity of the most recent use of cannabis. Ongoing trials suggest that the technology is still too immature to offer *reliable* noninvasive roadside testing, and it should not be used as sole evidence for determining impairment by cannabis. While saliva screening may be suitable for roadside screening of suspect drivers, blood THC concentrations are currently the most meaningful indicator of and testing parameter for impairment by cannabis.

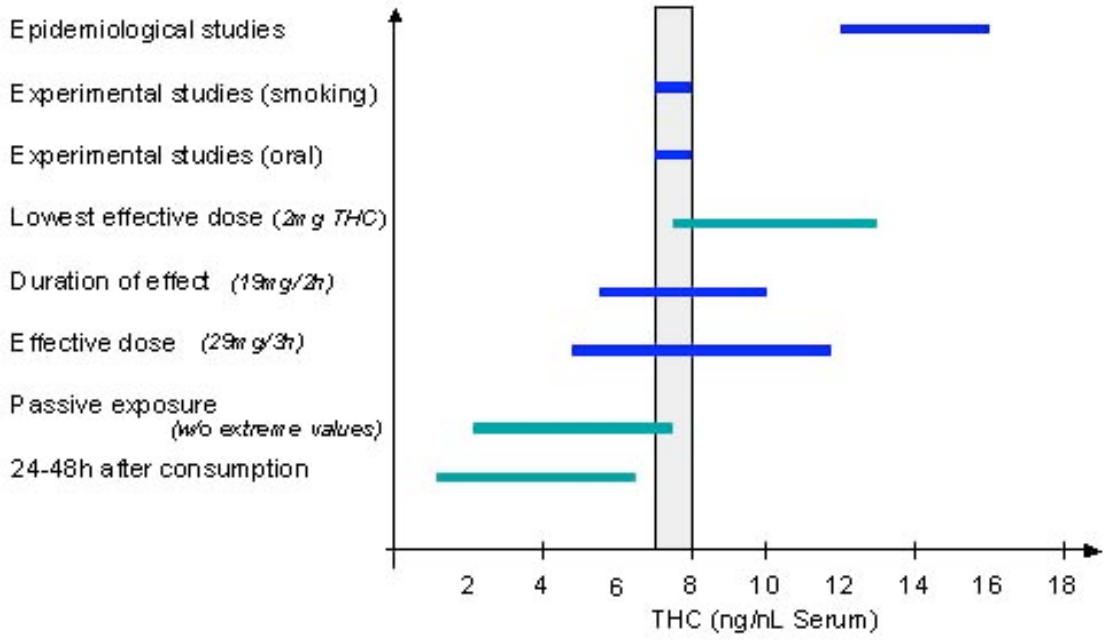

Figure 8. Correlation between THC concentrations in blood serum and relevant effects (from Berghaus et al., Cannabis and Traffic Safety, Presentation at the 33d Conference of the German Society for Traffic Medicine (Deutsche Gesellschaft für Verkehrsmedizin) on March 10, 2005).

Figure 8 summarizes the above findings. It shows the characteristic range of blood THC concentrations for each effect and motivates the recommended choice of a THC limit for DUIC of 7–10 ng/mL. Specifically, the figure indicates that epidemiological studies have found a significant increase in the odds ratios only at THC serum concentrations above 12 ng/mL. Experimental studies suggest that a THC serum concentration of 7–8 ng/mL from a single smoked or oral cannabis dose causes impairment similar to a BAC of 0.05%. Serum THC concentrations as high as 12–13 ng/mL can be produced by the lowest effective THC dose of 2 mg and by higher doses even 2–3 hours after smoking, i.e., when impairment has subsided. Finally, serum THC concentrations as high as 7 ng/mL can result from passive exposure to cannabis smoke or from consumption by regular cannabis users as much as 24–48 hours prior to a test. Figure 8 confirms the notion that a THC concentration in serum below 7–10 ng/mL (about 3.5–5 ng/mL whole blood) is too low to indicate an elevated accident risk. THC concentrations as high as 7 ng/mL are found in persons who smoked more than 3–4 hours ago and are not associated with impairment of driving-related skills. Such concentrations are also found in persons who were exposed to second hand cannabis smoke.

5. Recommendations

On the basis of the panel's findings, its participants suggest the following principles and elements of a DUIC control system, including a target range for a per se limit, an approach to testing for cannabis use and suggestions for further research.

Principles of DUIC Control

Traffic safety laws regulating driving under the influence of alcohol and other drugs should deter irresponsible drug use and driving. At the same time, such laws should encourage drivers to consider responsible alternatives to DUI. The panel suggests that a DUIC control system based on the following guiding principles will be effective in achieving these goals.

1. *DUIC laws and regulations should be rationally derived from the best available scientific evidence on the impairment and traffic risk caused by the use of cannabis.*
   While current empirical evidence on "cannabis and driving" is still much less conclusive than for alcohol, it allows setting boundaries for a rational and enforceable legal limit.
2. *Regulations should be clear and transparent to drivers and enforceable by police and the courts.*
   Per se laws using numerical limits to define "impairment" are clear and transparent to the driver, as long as authorities effectively communicate penalties and precautionary measures for avoiding "impaired driving." Per se laws are also readily enforceable if law enforcement is provided with a consistent method for determining THC concentrations in blood.
3. *DUIC control laws should give drivers an incentive to separate cannabis use and driving.*
   Laws that punish the exceeding of a numerical per se limit for THC motivate drivers to separate cannabis use and driving, as long as the limits can be complied with through practical measures, such as restricting consumption and abstinence for a reasonable period before driving. Extended or complete abstinence, as implicitly stipulated by a zero THC limit in blood, is not a realistic option, particularly for many younger drivers, who are the primary target for DUIC control. A zero limit also interferes with the concept of using designated drivers. A driver who used cannabis more than 12 hours before an event may still present with measurable THC

concentrations, and would therefore be in violation of a zero limit whether he or she abstained from use at the event or not.

4. *DUIC control should focus on improving traffic safety and not on achieving other societal goals.* Completely eliminating the (illegal) use of cannabis through a zero-tolerance law for DUIC seems unrealistic and counterproductive, as it may not increase the motivation for casual cannabis users to abstain for long enough to avoid exceeding a per se limit.

Suggested Provisions of DUIC Control Laws

- Based on the results of meta-analyses of experimental studies and from culpability studies, per se laws for DUIC should specify a science-based legal limit for THC in blood serum of between 7 and 10 ng/mL as a reasonable choice for determining relative impairment by cannabis. This corresponds to THC concentrations in whole blood—the parameter commonly used in U.S. jurisdictions—of 3.5 to 5 ng/mL. A limit in that range will clearly separate unimpaired drivers with residual THC concentrations of 0–2 ng/mL (serum) from drivers who consumed cannabis within the last hour or so. These latter drivers are likely impaired and typically present with THC concentrations greater than 20 ng/mL serum (10 ng/mL blood).
- When selecting a numerical value, the risks of false positives and negatives must be balanced. A higher limit will result in a high proportion of false negatives, especially if the time lag between roadside detention and collection of a blood sample is long. A lower limit will increase the number of false positives, e.g., in drivers who consumed cannabis within the last 48 hours, still have THC serum concentrations of several nanograms per milliliter but are no longer impaired, and drivers who were exposed to secondhand cannabis smoke. Background THC concentrations of regular users are also an uncertainty factor when estimating impairment based on THC blood concentrations.
- When adopting a numerical enforceable THC limit, legislators must also consider the variability in THC concentrations measured by forensic laboratories in identical blood samples. The authors suggest that a safety margin equal to the standard deviation observed in a comparative proficiency test of forensic laboratories be added to any impairment-based limit. The results of a recent proficiency test in Germany suggest that this safety margin may be 3–4 ng/mL (serum) at a concentration of 10 ng/mL. Effective validation of procedures by certified forensic laboratories will be crucial to minimizing the variability in measured THC concentrations,
- The concurrent use of alcohol and cannabis impairs driving skills more than each drug individually. Setting a lower THC limit may be appropriate if a BAC of more than 0.03% is also detected in the blood sample of a suspect driver.
- Recently commercialized techniques for detecting THC and other drugs in saliva could be used by law enforcement as a roadside screening tool, in addition to or in lieu of field sobriety tests for suspect drivers. However, ultimate determination of impairment by cannabis should be based only on blood THC concentrations measured by properly certified forensic laboratories.
- Government agencies should effectively communicate to drivers how a legal THC limit will affect their risk of being detected and how they should adjust consumption to avoid impairment and detection, as they now do for alcohol. Recommending to drivers a waiting period of at least

three hours after the last consumption is a practical tool for avoiding residual impairment by cannabis, provided that the driver did not consume alcohol at the same time.

Research Needs

To strengthen the scientific basis for a per se limit for THC, stronger empirical evidence is needed in the following areas:

- Additional culpability studies with a higher number of cases in the THC concentration range of 5–15 ng/mL (serum),
- Simulator and on-road studies on driver performance after consuming higher doses of THC and during the later phases of a cannabis high, i.e., 2–5 hours after smoking or ingesting cannabis, preferably with study designs that include measurements of THC concentrations in blood and saliva..

Acknowledgments

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Appendix A:

Overview of State DUID Laws in the United States

Prepared by
Dale Gieringer, Berkeley, CA
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Each of the 50 states of the United States has adopted legislation outlawing "driving under the influence of drugs" (DUID), including marijuana or other forms of cannabis. However, specific legal standards for what constitutes DUID vary considerably from state to state. The great majority of states have "effects-based" laws defining "under the influence" to require proof that the driver was actually impaired by the drug. They do not employ concentration-based "per se" standards of impairment like those used for drunk driving, where intoxication is automatically defined to occur at a fixed threshold (usually 0.08%) of the blood alcohol content (BAC). Instead, defendants are judged to be "under the influence" if the totality of evidence indicates that their driving was adversely impacted by the drug. This evidence may include results of drug tests as well as actual driving behavior, field sobriety tests, expert testimony, etc.

It should be noted that all but five states (AL, AK, MA, NJ and WV) have "implied consent" laws authorizing police to require drug tests from DUID suspects [Walsh, "Driving Under the Influence of Drugs (DUID) Legislation in the United States," The Walsh Group, November 2002]. In addition, two states, Alabama and Alaska, authorize police to require drug tests in case of serious accidents. Elsewhere, as in Massachusetts, drug tests that may have been incidentally taken in the course of hospital treatment are also admissible as criminal evidence.

The precise definition of "under the influence" varies somewhat from state to state. Some states set the standard as "incapacity" to drive; others as being "impaired," others as "not having the normal use of mental or physical facilities." Some states use the term "driving while intoxicated." In all cases, the prosecution must prove that the driver was adversely impacted by marijuana.

With the advancement of drug testing techniques, a few states have moved to adopt "per se" standards for DUI laws for marijuana based on concentrations of THC or metabolites detected through drug tests. Nine states have "zero-tolerance" laws for marijuana, in which any detectable amount of the drug is considered legal proof of DUID. However, the definition of detectable amounts of marijuana differs considerably in different states.

The table summarizes per se laws for DUID in the United States and their main provisions re. the presence of indicators for cannabis use.

Summary of States with Per Se DUID Laws
(Updated March 2005)

State	Zero-tolerance standard, incl. metabolite in urine	Zero THC in blood
Arizona	Y	Y
Georgia	Y	Y
Illinois	Y	Y
Indiana	Y	Y
Iowa	N	Y
Michigan	N	Y
Minnesota	N	Cannabis exempt Other CS banned
Nevada	10–15 ng/mL in urine	2–5 ng/mL in blood
North Carolina	N	For minors only
Pennsylvania	(Cannabis metabolites not prosecuted)	5 ng/mL in blood
Rhode Island	N	Y
Utah	Y	Y
Virginia	N	Cannabis exempt; specified levels of other CS
Wisconsin	N	Y

Per se laws fall into three basic categories, in order of increasing selectivity.

(1) The *strictest zero-tolerance laws* prohibit the presence not only of THC but also its metabolites in bodily tissues and fluids. Under these laws, drivers can be judged guilty of DUID if they show positive urine test results for THC metabolites, even though these may be present for days after consumption of cannabis. Drivers may also be convicted if they show THC metabolites in the blood or (in some states) other bodily fluids.

(2) Some states have a *milder version of zero tolerance*, in which only THC, not its metabolites, is considered. In practice, this generally requires a blood test, since THC is not normally measured in urine, and other forms of testing—e.g., saliva—are not currently used. (In Iowa and Rhode Island, the law specifically stipulates that THC be present in the blood; other states specify blood or urine; while still others anywhere in the body.) Since THC can persist in blood at detectable levels for 24 hours or more after last use, marijuana-using drivers can be found guilty of DUID well after adverse effects on driving, which typically last 2–4 hours, have faded.

(3) Two states have enacted *nonzero per se standards for marijuana impairment*. Nevada sets limits for THC at 2 ng/mL in blood or 10 ng/mL in urine (sic), and for metabolite 5 ng/mL and 15 ng/mL respectively. These numbers were taken from the NIDA/SAMHSA standards for workplace testing, which are not specifically applicable to impairment. The cutoff for THC in urine is difficult to

understand, since THC is not measured in standard urine tests. The second state, Pennsylvania, sets a standard of 5 ng/mL in blood, around the level where adverse effects of marijuana on driving have been demonstrated.

Because few legislators understand the complexities of the relation between impairment and drug test results, considerable legislative confusion is apparent in the state laws regarding DUID. In Michigan, courts have given different interpretations of the state's "zero-tolerance" law, which forbids "any amount of a [Schedule 1] controlled substance." Some courts have ruled that this includes marijuana metabolites, while others have held it means THC only. In Pennsylvania, the legislature enacted a theoretical "zero-tolerance" standard, defining DUID to occur when the "individual's blood [shows] any amount of a: Schedule 1 controlled substance." However, the state Department of Health, which was authorized to issue regulations interpreting the law, raised the minimum level for THC to 5 ng/mL in blood.

Several states, including California, have adopted provisions, which make it unlawful for a person "who is addicted to the use of any drug to drive a vehicle." However, the statutes do generally not clarify whether habitual cannabis users can be judged as "addicts."

Recent years have seen a surge of interest in per se DUID legislation. Michigan enacted a new zero-tolerance law in 2004. The number of DUID arrests tripled from 289 to 840 during the first five months of the new law. (AP report, "Michigan Law on Drugs and Driving Creates Backlog," Jun 21, 2004). In Ohio and Hawaii, zero-tolerance bills were introduced but fell short of passage in 2004. The Ohio legislature is debating another per se DUID bill this session (2005).

Under the Bush administration, federal officials have begun to push for stricter DUID legislation. In 2004, three bills were introduced in Congress, intended to develop new federal standards for DUID. Two of them specifically envisaged imposing "zero-tolerance" laws on the states. In 2005, the House of Representatives adopted a more moderate measure as an amendment to the federal transportation-funding bill. The proposed "Drug Impaired Driving Research and Prevention Act" would have the National Institutes of Health and the National Institute on Drug Abuse "assess the status of drug impaired driving laws in the United States" and "determine per se unlawful impairment levels for controlled substances." The Department of Transportation would then be authorized to "develop a model statute for states relating to drug impaired driving." It appears likely that this or other federal legislation will be adopted in the near future. It remains to be seen what standards for cannabis impairment will ultimately be developed.

Attachment 1:

Excerpts from State "Per se" DUID laws

Arizona: ZT = zero tolerance for MJ & metabolite

Driving under the influence is presumed "While there is any drug … or its metabolite in the person's body."
(Revised Statutes 28-1381(A) 3)

Georgia: ZT

DUI presumed if (6) Subject to the provisions of subsection (b) of this Code section, there is any amount of marijuana or a controlled substance, as defined in Code Section 16-13-21, present in the person's blood or urine, or both, including the metabolites and derivatives of each or both without regard to whether or not any alcohol is present in the person's breath or blood.

Subsection (b) specifies: (b) The fact that any person charged with violating this Code section is or has been legally entitled to use a drug shall not constitute a defense against any charge of violating this Code section; provided, however, that such person shall not be in violation of this Code section unless such person is rendered incapable of driving safely as a result of using a drug other than alcohol which such person is legally entitled to use.

(Georgia General Assembly Code 40-6-391)

Illinois: ZT

DUI if "(6) there is any amount of a drug, substance, or compound in the person's breath, blood, or urine resulting from the unlawful use or consumption of cannabis listed in the Cannabis Control Act, a controlled substance listed in the Illinois Controlled Substances Act, or an intoxicating compound listed in the Use of Intoxicating Compounds Act."

(625 ILCS 5/11_501) (from Ch. 95 1/2, par. 11_501)

Indiana: ZT

… (c) A person who operates a vehicle with a controlled substance listed in schedule I or II of IC 35-48-2 or its metabolite in the person's body commits a Class C misdemeanor.

(IC 9-30-5-1)

Iowa: THC only

A person commits the offense of operating while intoxicated if the person operates a motor vehicle in this state … *(c)*. While any amount of a controlled substance is present in the person, as measured in the person's blood or urine."

(321J.2 2)

Michigan: THC only

Vehicle Code 257.625 Sec.(8) A person, whether licensed or not, shall not operate a vehicle upon a highway or other place open to the general public or generally accessible to motor vehicles, including an area designated for the parking of vehicles, within this state if the person has in his or her body any amount of a controlled substance listed in schedule 1 under section 7212 of the public health code, 1978 PA 368, MCL 333.7212, or a rule promulgated under that section, or of a controlled substance described in section 7214(a)(iv) of the public health code, (1978 PA 368, MCL 333.7214.)

Minnesota: marijuana excluded, ZT for other CS

DUI "when the person's body contains any amount of a controlled substance listed in schedule I or II other than marijuana or tetrahydrocannabinols."

(169A.20 Driving while impaired.)

Nevada: Nonzero standards for THC & metabolite

Nevada is the only state to legislate nonzero DUID standards for all drugs.

(NRS 484.379 Driving under the influence of intoxicating liquor or controlled or prohibited substance)

… 3. It is unlawful for any person to drive or be in actual physical control of a vehicle on a highway or on premises to which the public has access with an amount of a prohibited substance in his blood or urine that is equal to or greater than:

Prohibited Substance	Urine (ng/ml)	Blood (ng/ml)
(a) Amphetamine	500	100
(b) Cocaine	150	50
(c) Cocaine metabolite	150	50
(d) Heroin	2,000	40
(e) Heroin metabolites		
(1) Morphine	2,000	50
(2)6-monoacetyl morphine	10	10
(f) Lysergic acid diethylamide	25	10
(g) Marijuana (THC)	10	2
(h) Marijuana metabolite	15	5
(i) Methamphetamine	500	100
(j) Phencyclidine	25	10

North Carolina: minors only zero THC

N.C. is the only state with a per se DUID standard for minors only:

§ 20-138.3. Driving by person less than 21 years old after consuming alcohol or drugs.

(a) Offense.—It is unlawful for a person less than 21 years old to drive a motor vehicle on a highway or public vehicular area while consuming alcohol or at any time while he has remaining in his body any alcohol or controlled substance previously consumed, but a person less than 21 years old does not violate this section if he drives with a controlled substance in his body which was lawfully obtained and taken in therapeutically appropriate amounts.

The general N.C. statute regarding impaired driving states:

§ 20-138.1. Impaired driving.

(a)Offense.—A person commits the offense of impaired driving if he drives any vehicle upon any highway, any street, or any public vehicular area within this State:

(1) While under the influence of an impairing substance; or

After having consumed sufficient alcohol that he has, at any relevant time after the driving, an alcohol concentration of 0.08 or more.

Pennsylvania: 5 ng/mL THC in blood

As written, the state law appears to mandate a zero-tolerance standard. However, by a directive of the Department of Health the standards for marijuana have been legally redefined to be 5 ng/mL THC in blood. Metabolites are ignored in the case of marijuana, but not for cocaine and other drugs.

75 Pa.C.S.A. 3802(d)

An individual may not drive, operate or be in actual physical control of the movement of a vehicle under any of the following circumstance:

(1) There is in the individual's blood any amount of a:

(i) Schedule 1 controlled substance;

(ii) Schedule 2 or 3 controlled substance that has not been medically prescribed for the individual; or

(iii) metabolite of a substance under subparagraph (i) or (ii)

Rhode Island: THC only

§ 31-27-2 Driving under influence of alcohol or drugs

(2) Whoever drives or otherwise operates any vehicle in the state with a blood presence of any scheduled controlled substance as defined within chapter 28 of title 21, as shown by analysis of a blood or urine sample, shall be guilty of a misdemeanor and shall be punished as provided in subsection (d) of this section.

Utah: ZT

(2) In cases not amounting to a violation of Section 41-6-44, a person may not operate or be in actual physical control of a motor vehicle within this state if the person has any measurable controlled substance or metabolite of a controlled substance in the person's body.

(3) It is an affirmative defense to prosecution under this section that the controlled substance was involuntarily ingested by the accused or prescribed by a practitioner for use by the accused. (Statutes 41-6-44.6)

Virginia: Marijuana excluded, specified blood cutoffs for certain CS

§ 18.2-266. Driving motor vehicle, engine, etc., while intoxicated, etc. It shall be unlawful for any person to drive or operate any motor vehicle, engine or train… (v) while such person has a blood concentration of any of the following substances at a level that is equal to or greater than:

(a) 0.02 milligrams of cocaine per liter of blood,

(b) 0.1 milligrams of methamphetamine per liter of blood,

(c) 0.01 milligrams of phencyclidine per liter of blood, or

(d) 0.1 milligrams of 3,4-methylenedioxymethamphetamine per liter of blood.

Wisconsin: THC in blood

346.63 Operating under influence of intoxicant or other drug.

(1) No person may drive or operate a motor vehicle while:

(a) Under the influence of an intoxicant, a controlled substance, a controlled substance analog or any combination of an intoxicant, a controlled substance and a controlled substance analog, under the influence of any other drug to a degree which renders him or her incapable of safely driving, or under the combined influence of an intoxicant and any other drug to a degree which renders him or her incapable of safely driving; or

(am) The person has a detectable amount of a restricted controlled substance in his or her blood"

Attachment 2:

Example of Effect-Based DUID Law

California is typical of the majority of states which currently have "effects-based" DUID laws rather than per se standards. The California law reads as follows:

Vehicle Code 23152 (a): It is unlawful for any person who is under the influence of any alcoholic beverage or drug, or under the combined influence of any alcoholic beverage and drug, to drive a vehicle.

Note that the law is not limited to drugs, which are controlled substances. Elsewhere, Vehicle Code 23630 stipulates that "the fact that any person charged with driving under the influence of any drug...has been entitled to use the drug under the laws of this state shall not constitute a defense."

California is one of five states to include a separate law for addicts, as set forth in VC 23152 (d): "It is unlawful for any person who is addicted to the use of any drug to drive a vehicle." Similar laws apply in CO, ID, KS, and WV. It is unclear whether habitual cannabis users can be judged as "addicts."