Chapter 12

Marijuana and Driving Impairment

Barry K. Logan

1. Effects of Marijuana

After alcohol, marijuana is the most popular recreational drug in North America. Its effects are largely predictable in type, but not in degree, although they do appear in a roughly dose-dependent manner. The effects discussed here make a very convincing case for the potential for marijuana to impair driving, although as noted, the extent to which that potential is realized in a given case will be related to many other factors.

1.1. Getting “High”

People variously use marijuana for its exhilarating, relaxing, hallucinogenic, antinausea, and soporific effects.

Marijuana is most frequently smoked and less frequently eaten in baked goods or drunk as an infusion. Cannabis products, including marijuana, hashish, and hashish oil, can be ingested orally, in tea, or baked into brownies. The effect profile from oral ingestion is much longer, taking longer for the drug to be absorbed and for the active Δ^2-tetrahydrocannabinol (THC) to be distributed. The drug is likely subject to enterohepatic cycling when orally ingested, further complicating its kinetics. Metabolite concentrations are often highly elevated. It is not uncommon for the acute effects to last for 24 hours following oral ingestion. Oral use is also more frequently associated with adverse effects, such as paranoia, panic, depression, and irritability. Currently available tests for blood or urine will not allow discrimination of the route of administration.

Following smoking, marijuana effects appear within 5–10 minutes. The lower-grade effects are remarkably similar to those resulting from alcohol consumption: relaxation, social disinhibition, and talkativeness. This disinhibition leads to users perceiving the drug effects as being mildly stimulatory at low doses. Users report the

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experience as producing a general sense of well-being, which can rise to the level of exhilaration or euphoria. It is described as a blissful state of reverie, fantasy, free-flowing thought, and clarity. The senses are heightened, with colors, smell, touch, taste, and body perception being enhanced. Cravings for food are common. Bouts of uncontrollable spontaneous laughter or giggling are regularly seen, with even common events appearing to be funny or amusing.

The perceptual effects of marijuana use have an association with driving impairment at least in part as a result of their distracting nature. The degree to which someone is absorbed in his or her drug experience will affect his or her inclination to engage fully in other demanding tasks such as driving. The degree of effect will differ from individual to individual and can be significantly affected by the setting.

1.2. Physiological Effects

The physiological effects of marijuana use are more tenuously related to driving; however, they are useful indicators in assessing a person for recent marijuana use. THC is a vasodilator, and within minutes of smoking marijuana, peripheral vasodilation leads to a precipitous drop in blood pressure and a reflex increase in heart rate. Users can feel dizzy or faint until homeostasis is restored. The dilatory effects of the drug on the capillaries in the sclera produce a distinctive reddening of the eyes, giving them a bloodshot appearance. Users usually report a dry throat and mouth. Among the other effects on the eyes are loss of convergence or ability to cross, hippus (an intermittent change in the size of the pupil occurring without external stimuli), and rebound dilation following changing light conditions, in which the pupil size will oscillate before stabilizing. Nystagmus, or the ability of the eye to track smoothly, is affected by marijuana and becomes more prominent under conditions of very high or repeated dosing.

Although these effects are not indicators of impairment per se, this characteristic set of symptoms can be relied on by police officers or medical personnel to make a connection between an individual’s appearance of intoxication and recent marijuana use.

1.3. Cognitive and Psychomotor Effects

Driving is a complex task requiring the integration of various cognitive and psychomotor skills. Cognitive skills are those related to the processes of knowing, thinking, learning, and judging. For driving, these effects include memory, perceptual skills, cognitive processing and task accuracy, reaction time, and sustained and divided attention.

Impairment of short-term memory and learning impairment following marijuana use is probably the most frequently reported and validated behavioral effect of marijuana use, and one for which there is the most consistent evidence. The link between memory impairment and driving impairment is, however, difficult to make convincingly. The strongest argument is the contribution of memory impairment to focus and selective attention. A clear recollection of recent events contributes to organizational and planning ability and promotes goal-directed behavior and action, allowing the subject to devote available cognitive capacity more efficiently to the driving task.

The user’s perception is altered with respect to the passage of time, which appears to pass more quickly relative to real time. Impairment in perception of speed and
distance may be related to the time distortion. Laboratory studies have shown that cannabis users lose the perceptual ability to identify simple geometric figures within more complex patterns when intoxicated. Such perceptual changes can influence a person's normal driving behavior in a potentially unsafe way.

Simple tests of cognitive processing such as measures of associative ability (e.g., digit symbol substitution, Stroop color word test) have been shown to be adversely affected by acute cannabis use resulting in greater numbers of errors. The effect when compared to moderate doses of alcohol, however, is small.

Reaction time effects are also present and are more significant at higher doses, but they are generally small compared with those observed with moderate doses of alcohol. Impairment indicators are more prominent in complex rather than simple reaction time tests, and subjects tend to perform more slowly and make more errors.

Driving is a divided-attention task, and as such, laboratory assessments of divided and sustained attention performance have been scrutinized for evidence of effects. These tests show consistently that the greater the demands on cognitive processing ability, the more complex the tasks, and the more tasks to be attended to, the poorer marijuana-dosed subjects performed. This has important implications for marijuana and driving impairment and explains the findings in some of the on-road driving studies discussed later.

Driving demands various levels of attention, cognitive capacity, and psychomotor ability, depending on factors such as weather, road conditions, vehicle condition, other road user behavior, lighting, and city vs highway driving. The threshold demands of driver performance for satisfactory vehicle operation might be within the subject's ability under normal driving conditions, but if the demands change unexpectedly, or emergencies arise, or there is a confluence of demands occurring at once (merging traffic, signal failure, unfamiliar neighborhood, road construction, etc.), the driver's ability is surpassed and errors arise that result in a crash or bring the driver to the attention of the police. Peak cognitive impairment effects are reported to occur roughly 40–60 minutes following smoking and typically last for about 2–3 hours.

1.4. Hallucinations

The effects noted on heightened awareness of colors, smell, touch, and taste can be enhanced to the point where they constitute hallucinations—perceptions of things or sensations that do not exist. Objects can appear to “melt” or to lose or change form. Synesthesias can occur in which, for example, sound or music can trigger visual or olfactory sensations. In most marijuana users who do experience these, they are more correctly characterized as pseudo-hallucinations in that the user is aware that the perception is unreal even while experiencing it. Nevertheless, hallucinations of any kind are distracting and absorbing and, when they occur, will impair attention and focus.

Infrequently, flashbacks are reported where individuals will re-experience or vividly recall the experience of a previous marijuana “trip.” This can be triggered by environmental cues or by readministration of marijuana or some other psychoactive drug.

1.5. Other Adverse Reactions

Although many of the effects discussed above have the potential to be detrimental to driving, the adverse affects considered here are those not sought by the recre-
ational marijuana user (a "bad trip"). They are atypical, but can be related to the user's underlying frame of mind or mood, and are most commonly reported by naïve users. These include dysphoria, fearfulness, extreme anxiety, mild paranoia, and panic. When this occurs, its relationship to impairment of driving is clear. Typically at higher doses or in naïve users, sedation or sleepiness becomes a significant factor, and presumably users already tired would be more susceptible to this effect.

1.6. Discussion

Based on the above considerations, it is clear than in many respects marijuana has the ability to produce side effects—both sought-after and incidental—that can affect the balance of skills and abilities needed to drive safely. These effects can vary in magnitude, but frequently when compared with effects of moderate dosing with alcohol (e.g., the presumptive level for intoxication in many US states of 0.08 g ethanol/100 mL blood), the impairing effects are less severe, even after the use of typical user-preferred doses. Additionally, the consistent observation that the impairing effects of marijuana after moderate use will dissipate in 2–3 hours limits the likelihood of police contact or crash involvement if the driver allows some time to pass between marijuana use and driving. The related ability of marijuana users to recognize the drug effect and take a less risky course of action also contributes positively to harm reduction.

On balance, the empirical evidence suggests that impairment observed following recent marijuana use can very reasonably be ascribed to the drug. This is most likely when the drug use, if moderate, is within 3 hours of driving. Beyond this time frame, however, light to moderate marijuana use under normal demands of driving does not consistently generate impairment in driving skills that would come to the attention of the police or result in increased risk of crash involvement.

2. Evidence of Marijuana Intoxication

2.1. Diagnosis of Marijuana Use:
Physiological and Psychomotor Effects

According to the Drug Recognition Expert evaluation matrix used by police officers, characteristic symptoms of marijuana use include a lack of horizontal or vertical gaze nystagmus, pupil size dilated to normal, lack of pupillary convergence, and pupils normally reactive to light. Pulse is usually elevated within the first few hours following use, and blood pressure is correspondingly elevated. Body temperature will typically be normal. Speech may be slow or slurred, and muscle tone will be normal. Other clues include stale breath; sometimes users will have flakes or residue of marijuana in the mouth or a green discoloration of the tongue. The taste buds may be elevated as a result of irritation from the hot smoke. The user's eyes will typically be bloodshot because of the vasodilatory effects of THC on the capillaries of the sclera. The face may be similarly flushed, and subjects may be diaphoretic. Nystagmus is not typically present, although some studies do suggest an association between acute marijuana use and nystagmus.

Subjects may have short attention spans, express hunger (THC is an appetite stimulant), and giggle or laugh. If acutely intoxicated, users may also seem dazed,
2.1.1 Toxicological Tests

Marijuana use can be demonstrated by chemical or toxicological tests. Toxicological tests for detection of marijuana use currently include hair, urine, blood, sweat, and oral fluid. Hair marijuana tests offer the possibility of looking within hair previously cut and analyzed at a time that marijuana was used. Hair grows at a rate of about 1 cm per month, and most commercial vendors offer testing periods of 3 to 6 months. Hair is a reliable predictor of marijuana use in the past and is not affected by recent use, which can be detected by urine, blood, and oral fluid tests.

It is likely that these tests can be further refined to increase their effectiveness and sensitivity. Overall, when impairment caused by drugs including marijuana is present, it can be detected by the tests currently in widespread use by police officers. The study showed a significant increase in driving impairment in subjects with marijuana levels of 2.5-7.5% in nonconsumed subjects. After 10 minutes, symptoms of impairment were observed in all the subjects except for those taking a placebo, 1.74%, or 2.93% THC content marijuana cigarette. The data are summarized in Table 1.

The study showed dose-dependent increases in rates of impairment in the subjects with marijuana levels of 2.5-7.5% in nonconsumed subjects. After 10 minutes, symptoms of impairment were observed in all the subjects except for those taking a placebo, 1.74%, or 2.93% THC content marijuana cigarette. They applied the three tests—horizontal gaze, standing test, and one-leg stand—to 55 subjects and 105 minutes after smoking a marijuana cigarette, Papadopoulou et al. (1) evaluated the efficacy of the standardized field sobriety tests. The authors also noted a fourth category of impairment, which may not be considered indicators of impairment irrespective of time. A careful validation of the tests for marijuana has recently been performed in 40 subjects. Field sobriety tests are considered with low impairment, that is, if a person is observed in the early stages of field sobriety tests, they may also appear sober or improve their performance and coordination during the first hour or two after use.
Table 1
Relationship Between Time After Smoking, Average Blood THC Concentration (ng/mL), and Percentage of Subjects Considered Impaired Under Standardized Field Sobriety Tests (SFSTs)*

<table>
<thead>
<tr>
<th>Dose</th>
<th>Blood THC</th>
<th>% impaired</th>
<th>Blood THC</th>
<th>% impaired</th>
<th>Blood THC</th>
<th>% impaired</th>
</tr>
</thead>
<tbody>
<tr>
<td>Placebo</td>
<td>0</td>
<td>2.5</td>
<td>0</td>
<td>7.5</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>1.74% THC</td>
<td>55.5</td>
<td>23</td>
<td>6.8</td>
<td>23</td>
<td>3.7</td>
<td>15</td>
</tr>
<tr>
<td>2.93% THC</td>
<td>70.6</td>
<td>46</td>
<td>6.2</td>
<td>41</td>
<td>3.2</td>
<td>28</td>
</tr>
</tbody>
</table>

THC, Δ^4-tetrahydrocannabinol.
*Time 1, 0 min after smoking for blood sampling and 5 min for SFSTs; Time 2, 50 min after smoking for blood sampling and 55 min for SFSTs; Time 3, 100 min after smoking for blood sampling and 105 min for SFSTs.
From ref. 1.

time, however, as would be relevant in an impaired driving investigation. If the subject's prior marijuana use became an issue, this approach could offer some qualitative insight.

2.1.1.1. Toxicological Evidence: Urine

As discussed in Chapters 5 and 9, THC is metabolized to 11-OH-THC and 11-carboxy-THC (THC-COOH). The latter compounds are glucuronidated and excreted in the urine. Substantial variation exists in the excretion patterns of marijuana metabolites in subjects' urine. THC metabolites appear in the urine in detectable amounts within 30–90 minutes following smoking, but they may not reach the levels needed to cause a positive response at typical thresholds used for screening. Many laboratories use the 50 ng/mL screening cutoff mandated for federal workplace urine drug testing, but one study showed that first void urine specimens after smoking a single 3.55% THC marijuana cigarette quantitated below that threshold in five of six subjects, at times ranging from 1 to 4 hours (mean 3.0 hours; ref. 2). In the same subjects, each smoking an identical 3.55% THC cigarette, peak urine concentrations varied considerably (29–355 ng/mL, mean 153 ng/mL), as did the time to peak (5.6–28 hours, mean 13.9 hours). Similarly, urine specimens were confirmed positive by gas chromatography/mass spectrometry at a 15 ng/mL cutoff for 57–122 hours following this single use (mean 89 hours or 3.7 days). The same authors have reported similar results in other subjects (3). Using a lower threshold, for example, 20 ng/mL, was shown to be more effective in identifying use for a longer period of time and presumably for earlier detection of use in urine samples.

Other workers have evaluated the time it took for urine samples to test consistently negative in chronic marijuana users (4). These authors identified an extreme case of a subject who took 77 days to produce 10 consecutive negative urine samples screened at a 20 ng/mL cutoff. Of the 86 subjects evaluated, the mean time to the end of their consecutive positive results at that threshold was 27 days.

There are significant implications following from these and similar studies for the use of urine as the specimen in a driving-under-the-influence-of-drugs (DUID)
setting. A specimen taken up to 3 hours after smoking marijuana may test negative for cannabinoids, depending on the screening threshold used and the potency of the marijuana smoked, even though the subject would have experienced the peak effect within a few minutes and would have been under the influence of marijuana at the time of driving or arrest. Also, following single acute use by naive users, urine concentrations may peak, then drop below detectable levels over the space of a few hours. Conversely, the presence of marijuana metabolites in a subject’s urine may have resulted from drug use several days earlier, considerably after the impairing effects of the drug have passed.

In summary, a positive urine test for THC-COOH cannot be used to infer either intoxication or marijuana use within any forensically useful time frame. At best, if coupled with objective observations of physiological signs and symptoms of marijuana use and documentation of psychomotor impairment, it can substantiate an opinion that observed impairment was a result of marijuana use.

2.1.1.2. Toxicological Evidence: Blood

Blood or plasma* analysis of THC provides the most direct toxicological evidence of recent marijuana use and, consequently, of intoxication. There are several approaches to the interpretation of blood toxicological data.

2.1.1.2.1. THC and THC-COOH Concentrations

Because the effects of marijuana use have a relatively rapid onset when smoked, users can titrate the effects against the rate of administration to maximize the desirable drug effects while minimizing the adverse effects. Various studies have attempted to identify a “user-preferred” dose of marijuana. These have established a typical user-preferred dose of about 300 μg/kg, or about 21 mg in a 70 kg (154 lb) individual (7). In terms of what this translates to in marijuana cigarettes, that will depend on the THC content of the marijuana and the individual’s smoking technique, with more efficient absorption achieved with deeper inhalation and breath holding.

For context, a standard National Institute on Drug Abuse marijuana cigarette (weight 558 mg) having 3.58% THC content would deliver 20 mg of THC, although not all of that may be bioavailable, depending on the subject’s smoking technique. Plasma concentrations of THC and THC-COOH from one study with different levels of dosing are shown in Table 2.

Current street marijuana strength can vary considerably, from essentially zero to 20% THC content or more; consequently, predicting THC concentration or impairment based on a history of how many “joints” were smoked is inadvisable.

Peak blood or plasma THC concentrations occur within a few minutes of the end of smoking and begin a rapid decline as the drug distributes from the central compartment into tissues. There is widespread agreement that the peak effects of the drug occur after the blood concentration has peaked and begun to decline. Plasma THC concentrations of 2–3 ng/mL (equivalent to whole blood concentrations of 1–1.5 ng/mL)...

*Most pharmacokinetic studies have made measurements of THC and its metabolites in plasma, whereas in a forensic context whole blood is the most commonly analyzed specimen. The plasma-to-whole blood ratio for cannabinoids is approx 2:1 (5,6); therefore, when comparing whole blood concentrations to plasma concentrations, the plasma concentrations should be divided by 2.
Table 2
Mean, Median, and Range of THC and THC-COOH Concentrations in Plasma of 14 Subjects Under Various Dosing Conditions

<table>
<thead>
<tr>
<th></th>
<th>100 µg/kg</th>
<th>200 µg/kg</th>
<th>300 µg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t = 35</td>
<td>t = 190</td>
<td>t = 35</td>
</tr>
<tr>
<td>THC</td>
<td>Mean</td>
<td>7.9</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>6.5</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>0.8–17.2</td>
<td>0.0–1.3</td>
</tr>
<tr>
<td>THC-COOH (ng/mL)</td>
<td>Mean</td>
<td>8.2</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>7.4</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>1.4–19.4</td>
<td>0.0–12.0</td>
</tr>
</tbody>
</table>

THC, Δ⁴-tetrahydrocannabinol; THC-COOH, 11-carboxy-THC.

From ref. 7.

mL) were linked by several authors to recent use (within 6–8 hours) and consequently potential impairment of some psychomotor functions (8–10). Other authors have suggested that whole blood concentrations of 1.6 ng/mL or greater may cause psychomotor effects.

Detection of THC-COOH in the absence of any detectable parent drug is a not infrequent finding in DUID cases. This emphasizes the importance of using appropriate cutoffs for confirmatory testing, which should be of the order of 1 ng/mL or less for both THC and THC-COOH. Assuming that these thresholds are observed, data such as those in Table 2 and in other work suggest that even following acute impairing doses of marijuana, concentrations of THC are likely to become undetectable within 3 hours following use, whereas THC-COOH may persist longer. In chronic users, THC concentrations of 2 ng/mL have been shown to persist for more than 12 hours.

These limitations highlight the importance of obtaining a timely blood sample when investigating cases of impaired driving attributed to marijuana use.

2.1.1.2.2. THC:THC-COOH Ratio

As noted previously, peak psychomotor and cognitive effects following marijuana use occur within the first hour after smoking, a time interval during which the THC concentration is falling rapidly and THC-COOH is beginning to appear as a result of oxidative metabolism. Several studies (2,6,10) suggest that following single acute administration, THC-COOH concentrations will surpass THC concentrations within 30–45 minutes following initiation of use (see, e.g., the patterns in Table 2). Consequently, THC/THC-COOH ratios of greater than 1 suggest use within the prior hour, the period during which effects are likely to be greatest.

In practice, in a DUI setting, the likelihood of obtaining a specimen during the hour following initiation of smoking is small because of the time taken to investigate, assess, and obtain a sample from a subject.

Algorithms for predicting time of marijuana use based on both THC concentrations and the THC/THC-COOH ratio have been described (9,11). Although preliminary data suggest that these models are accurate in predicting a likely time interval for
last use following single acute moderate doses, they have not been extensively evaluated in chronic users and have not been evaluated with THC concentrations of less than 2 ng/mL, precluding their use in many DUID cases. Although these models may be informative for evaluation of cases, readers are urged to exercise caution in their application in a forensic setting because their limitations are still debated (12). More extensive evaluation of this approach in chronic users is promising and warrants further study.

In a report of a gas chromatography/mass spectrometry method for the simultaneous determination of THC and THC-COOH in serum (13), this method was applied to serial samples from subjects smoking 300 µg of THC/kg body weight and to 212 forensic serum specimens, including driving cases. The samples from the smoking study showed that THC concentrations in serum had fallen below 5 ng/mL (equivalent of 2.5 ng/mL in blood) in 33% of subjects within 100 minutes, and in 92% of subjects within 160 minutes following smoking. The distribution of concentrations of THC and THC-COOH in the forensic cases is shown in Table 3 and illustrates that delays between the time of driving and the time of sample collection can result in undetectable THC concentrations. Of these cases, 87% have blood equivalent THC concentrations of less than 1.5 ng/mL.

2.1.1.3. Toxicological Evidence: Oral Fluid (Saliva)

Oral fluid (saliva) is receiving a lot of scrutiny for its efficacy in detecting marijuana usage at the time of driving. Oral fluid is a plasma ultrafiltrate produced through the parotid and other glands in the mouth. Many water-soluble drugs appear in this ultrafiltrate and can be detected by on-site immunoassays. Because of its lipophilicity, THC does not readily transfer from the blood to the oral fluid, but contamination of the oral cavity during smoking, from the smoke and possibly from marijuana debris from the cigarette, can result in a positive test within 30–90 minutes of use.

Oral fluid testing is still somewhat controversial. Many of the devices currently being sold are not consistently reliable, are subject to operator error, and are not comprehensive in terms of the drugs they test for. Additionally, the role of roadside testing is still a subject of debate. Because the tests are not comprehensive, drivers who appear impaired should be arrested regardless of the results of the roadside test, making it somewhat superfluous. The presence of the drug must still be confirmed by forensically acceptable techniques, requiring resampling or preservation of the roadside sample and subsequent laboratory tests.
2.1.1.4. SUMMARY

Blood concentrations of both THC and THC-COOH drop precipitously in the first few hours following smoking, because these substances partition into fatty compartments. It is recommended that blood or plasma concentrations of THC and THC-COOH be interpreted with caution. Under most circumstances, detection of parent THC will reflect recent use, meaning within the last few hours, making the likelihood of impairment within that time frame that much greater. More distant, higher-intensity marijuana use cannot be ruled out, however, when THC is detected, and under that pattern of use impairment may persist longer than the 2–3 hours typical of the low- to moderate-dose administration. Detection of THC-COOH in the absence of the parent drug (i.e., <2 ng/mL) tends to suggest more distant use (>2 hours). It should go without saying that the screening threshold and confirmatory test sensitivity of the analytical laboratory must be taken into consideration when evaluating these results.

3. EPIDEMIOLOGY OF MARIJUANA AND DRIVING

A thorough review of epidemiological studies related to marijuana in various driving populations was done recently by Huestis (14), and we will not attempt to replicate that in this chapter. The focus of this discussion is on studies that have attempted to relate marijuana use to risk of accident involvement or accident culpability.

A survey of many of the studies cited by Huestis shows various rates of marijuana positivity in impaired drivers, fatally injured drivers, drivers injured in motor vehicle accidents, and commercial vehicle operators. The rates of positivity vary depending on whether blood or urine was tested, whether the parent or metabolite was tested for, whether the samples were provided voluntarily or following arrest, the sensitivity of the testing method, and whether the study group was selected out (e.g., only subjects without alcohol tested). In spite of these variables, in the fatally injured driving population overall, 10–20% of drivers test positive for cannabinoids, whereas in the arrest population rates are between 15 and 60%, suggesting a significant role for marijuana use.

None of these studies has control data, however, that would show the rate of marijuana use in the local driving population not killed or injured in a collision, such that a comparative rate or odds ratio for fatal accident involvement could be calculated. Another limiting factor was that in some studies urine was tested, and, as noted above, urine can test positive for marijuana use for a few days following use, while the impairing effects last only for a few hours.

These studies do uniformly find evidence, however, that there is widespread use of marijuana in all these driving populations. In nonselected populations (e.g., all fatally injured drivers, trauma patients), the incidence of cannabinoid positives was typically between 5 and 20%. In selected populations (e.g., young males, fatally injured drivers) the rate was as high as between 15 and 60%.

A recent voluntary test of commercial vehicle operators in Washington and Oregon (15) showed a marijuana-positive rate of 5%, in spite of a 19% refusal rate in what is a highly regulated industry with mandatory random testing. A similar survey done in 1988 showed 15% of tractor trailer drivers positive for cannabinoids, suggesting some improvement following the introduction of testing (16).
3.1. Assessment of Relative Crash Risk Following Marijuana Use

Studies that have assessed crash responsibility offer more insight into the quantitative relationship between marijuana usage and crash involvement. An excellent review of culpability studies has recently been published (17). The general design of these studies is to compare rates of drug use in at-fault drivers vs no-fault drivers and compute the ratio, with values greater than 1.0 indicating increased rates of risk. The 95% confidence interval is also computed, and when the range includes 1.0, the difference in responsibility rates is not significant at the $p = 0.05$ level.

In most of these studies, authors validate their data set and methodology by assessing odds ratios for alcohol. The relationship between alcohol and risk of crash involvement has been well established, most famously in the 1960 Grand Rapids Study. In each case the method showed the expected significant relationship at the $p = 0.05$ (95% confidence interval) level between alcohol positivity and greater odds of crash involvement.

The data from studies that made odds ratio assessments based on the presence of the inactive THC-COOH metabolite uniformly failed to show significant differences at the $p = 0.05$ level in rates of accident involvement for the drug-positive drivers. This can be rationalized in terms of the fact that the metabolite is inactive and that in most cases urine was being tested. Bearing this in mind, together with the fact that urine can test positive for the metabolite for many hours or even days after the effect has passed, its detection in urine is not a good surrogate for impairment, and the negative findings are not surprising.

Studies assessing crash risk based on parent THC in blood are more informative. One study of 2500 injured drivers (18,19) showed a trend towards increasing odds ratio with increasing THC concentration (although not significant at $p = 0.05$) and found that culpable drivers had a higher mean THC concentration ($p = 0.057$). This suggests a dose-dependent increase in risk, with the threshold for significance being somewhere above 2 ng/mL THC. One limitation of the Hunter study is the lack of control of the interval between driving and when the sample was collected. Intervals of an hour or less between the driving and the time the sample was collected would cause appreciable decreases in THC concentration.

In a cohort of 3398 fatally injured drivers (20), the authors avoid this limitation because absorption of THC will stop at the time of death. Those data showed an odds ratio of 2.7 in cases in which THC was detected and 6.6 when the THC concentration was greater than 5 ng/mL.

Several studies have evaluated crash risk in drivers positive for both alcohol and marijuana (THC or THC-COOH). Table 4 shows that irrespective of whether the parent drug or metabolite was measured, when combined with alcohol the odds ratio for crash involvement was between 3.5 and 11.5 (significant in all cases, $p = 0.05$) and compared to alcohol positive cases was still significant, with an odds ratio of 2.9.

Taken together, these data represent strong evidence for a concentration-dependent (and consequently dose-dependent) relationship between THC and risk of crash involvement and enhanced risk for any use of marijuana when combined with alcohol.
Table 4
Summary of Odds Ratio of Becoming Involved in Fatal or Injurious Traffic Accidents Under the Influence of Cannabis, Alcohol, or Their Combination as Reported in Culpability Studies

<table>
<thead>
<tr>
<th>Substance</th>
<th>Authors</th>
<th>Odds ratio</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drug-free cases</td>
<td></td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Alcohol</td>
<td>Terhune and Fell (21)</td>
<td>5.4*</td>
<td>2.8–10.5</td>
</tr>
<tr>
<td></td>
<td>Williams et al. (22)</td>
<td>5.0*</td>
<td>2.1–12.2</td>
</tr>
<tr>
<td></td>
<td>Terhune et al. (23)</td>
<td>5.7*</td>
<td>5.1–10.7</td>
</tr>
<tr>
<td></td>
<td>Drummer (24)</td>
<td>5.5*</td>
<td>3.2–9.6</td>
</tr>
<tr>
<td></td>
<td>Hunter et al. (18)</td>
<td>6.8*</td>
<td>4.3–11.1</td>
</tr>
<tr>
<td></td>
<td>Lowenstein and Koziol-Melain (25)</td>
<td>3.2*</td>
<td>1.1–9.4</td>
</tr>
<tr>
<td></td>
<td>Drummer et al. (20)</td>
<td>6.0*</td>
<td>4.0–9.1</td>
</tr>
<tr>
<td>THC-COOH</td>
<td>Terhune and Fell (21)</td>
<td>2.1</td>
<td>0.7–6.6</td>
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<tr>
<td></td>
<td>Williams et al. (22)</td>
<td>0.2</td>
<td>0.2–1.5</td>
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<td></td>
<td>Terhune et al. (23)</td>
<td>0.7</td>
<td>0.2–0.8</td>
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<td>Drummer (24)</td>
<td>0.7</td>
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<td></td>
<td>Hunter et al. (18)</td>
<td>0.9</td>
<td>0.6–1.4</td>
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<td></td>
<td>Lowenstein and Koziol-Melain (25)</td>
<td>1.1</td>
<td>0.5–2.4</td>
</tr>
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<td>TCH (range: ng/mL)</td>
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<tr>
<td>&lt;1.0</td>
<td>Hunter et al. (18)</td>
<td>0.35</td>
<td>0.02–2.1</td>
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<tr>
<td>1.10–2.0</td>
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<td>0.51</td>
<td>0.2–1.4</td>
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<td>&gt;2.0</td>
<td></td>
<td>1.74</td>
<td>0.6–5.7</td>
</tr>
<tr>
<td>1–100</td>
<td>Drummer et al. (26)</td>
<td>2.7*</td>
<td>1.02–7.0</td>
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<tr>
<td>5–100</td>
<td></td>
<td>6.6*</td>
<td>1.5–28.0</td>
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<tr>
<td>Alcohol/THC or THC-COOH</td>
<td>Williams et al. (22)</td>
<td>8.6*</td>
<td>3.1–26.9</td>
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<tr>
<td></td>
<td>Terhune et al. (23)</td>
<td>8.4*</td>
<td>2.1–72.1</td>
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<tr>
<td></td>
<td>Drummer (24)</td>
<td>5.3*</td>
<td>1.9–20.3</td>
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<td>Hunter et al. (18)</td>
<td>11.5*</td>
<td>4.6–36.7</td>
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<tr>
<td></td>
<td>Lowenstein and Koziol-Melain (25)</td>
<td>3.5*</td>
<td>1.2–11.4</td>
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</table>

Significant changes in OR indicated as follows: *<0.05.

THC-COOH, 11-carboxy-THC; THC, Δ9-tetrahydrocannabinol.
From ref. 11.

4. MARIJUANA AND ON-ROAD DRIVING STUDIES

The above considerations suggest that in addition to the empirical intoxicating properties of marijuana, there is epidemiological and behavioral evidence that it can cause impairment in the first few hours following use. Assessments of psychomotor performance following marijuana use have been performed, and these have been reviewed recently by Ramaekers et al. (17). These studies support the idea that dose-dependent impairments in psychomotor performance and cognition appear immediately following marijuana administration, peak after the blood concentration peaks, and persist for 3–4 hours. Although there is a relationship between many of these tasks and the driving task, the clearest means of assessing the actual effects of mari-
Marijuana on drivers is to measure their performance in actual on-road driving following marijuana administration. A number of such studies have been done.

4.1. Study of Klonoff et al. (27)

Conducted in Vancouver, British Columbia, in the early 1970s, drivers were dosed with 4.9 or 8.4 mg of THC by smoking. This represents 70 and 120 μg/kg, respectively, in a 70-kg person, compared with the 300 μg/kg described by Robbe and O’Hanlon (7) as the user-preferred dose, so both should be considered relatively low-dose conditions compared to normal patterns of use. Following drug administration, drivers drove both on a closed traffic free course and on the streets of downtown Vancouver during peak traffic hours. Driving performance was rated subjectively by a professional driving examiner. Researchers found subtle differences between the marijuana and placebo conditions and noted some bidirectional changes in performance. Sixty-four volunteers drove the driving course. There was a trend towards a greater number of subjects, demonstrating poorer performance going from placebo to low dose to high dose, with 73% of the high-dose subjects demonstrating a decline in performance. However, 23% of subjects demonstrated an increase in performance in the high-dose condition, with 14% showing significant improvement.

Thirty-eight subjects participated in the on-street driving. Similarly, although 79% of subjects demonstrated a decline in driving performance, 16% demonstrated improved performance even in the high-dose condition.

The components of driving that were most affected by marijuana following the high dose were judgment, care while driving, and concentration. Minimally affected were factors such as general driving ability, speed, confidence, and aggression, and cooperation and attitude were unaffected. Unusual behaviors documented in drivers after marijuana use included missing traffic lights or stop signs, passing without sufficient caution, poor anticipation or handling of the vehicle with respect to traffic flow, inappropriate awareness of pedestrians or stationary vehicles, and preoccupation and lack of response at green lights.

Although the tendency was toward deterioration in driving performance with increasing dose of marijuana, the trend was not uniform. The authors struggled to explain the bidirectional changes in performance and hypothesize that interindividual differences in response can outweigh dose-related effects, and that subjects can recognize impairment and compensate, and in some cases overcompensate, resulting in improvement.

Caution should be exercised in applying the results of this study to users engaging in more demanding driving and also to drivers using higher doses and more potent marijuana.

4.2. Study of Robbe and O’Hanlon (7)

The most comprehensive work on marijuana in actual on-road driving has been done at the University of Maastricht in the Netherlands, beginning with this report. The authors first made an assessment of the dose of marijuana preferred by users, so that appropriate doses could be assessed for their effects on driving. Twenty-four subjects who used the drug more than once a month and less than daily and who had driven within an hour of marijuana use within the last year were assessed. Their aver-
age preferred dose to achieve the desired psychological effect was 20.8 mg, which after adjustment for body weight was 308 μg/kg, with no significant difference for males and females.

Subjects were tested on a closed driving course with doses of 0, 100, 200, and 300 μg/kg THC. Interestingly, 40–60% of the subjects indicated that they would have been willing to drive for unimportant reasons shortly after smoking the two highest doses. Driver performance was assessed by measurement of standard deviation of lateral position (SDLP), an index of weaving that has been validated for alcohol and other drugs as a measurement of deterioration of driving performance.

There was dose-dependent deterioration in SDLP. Driving performance decrement persisted undiminished for 2 hours following drug administration, even after perceived “high” and heart rate had declined. It also persisted even as measured plasma THC concentrations fell, but SDLP was not quantitatively related to plasma THC or THC-COOH concentrations. Drivers accurately assessed their performance as being poorer than normal under the two highest-dose conditions. Quantitatively, the decrement in SDLP was equivalent to blood alcohol concentrations (BACs) of 0.03–0.07 g/100 mL.

Having determined the scale of the performance decrement, the researchers decided it was safe to evaluate driving performance on open highways around other vehicles under the same dosing conditions. Subjects were again dosed with 0, 100, 200, and 300 μg/kg THC. SDLP as an index of weaving and a car-following test where the subjects had to maintain headway with a lead vehicle were conducted. This phase confirmed the dose-dependent deterioration in SDLP, with the lower doses producing impairment less than 0.05 g/100 mL and the highest dose producing impairment marginally above that. The subjects rated their performance as worse than normal at the two highest doses, but still expressed a willingness to drive.

The final phase of the study involved more demanding urban city driving, and consequently only the placebo and lowest dose were administered because the prior two phases had shown significant impairment in the two highest-dose conditions. In this phase the driver’s performance was compared against other drivers dosed to a 0.05 g/100 mL BAC. The alcohol condition produced the expected deterioration in driving performance, but the 100 μg/kg THC dose produced no measurable decline in urban city driving performance. Interestingly, the alcohol-impaired drivers reported no perceived deterioration in performance even while it was evident to the observers, whereas the subjects receiving the low-dose THC reported feeling impaired even while no impairment could be measured. This echoes the experience of Klonoff’s study that users were compensating and often overcompensating for their perceived impairment.

Most importantly, this careful work demonstrates that although marijuana has the ability to impair under certain conditions, and does so in a dose-dependent manner, the degree of impairment associated with a user-pref erred dose of 300 μg/kg produced impairment equivalent to BACs of 0.03–0.07 g/100 mL. Additionally, it confirmed the lack of correlation between plasma THC concentrations and the level of impairment.

4.3. Study of Lamers and Ramaekers (28)

In this study, performed at the same institute and using the same methodology, researchers assessed the combined effects of alcohol and marijuana using 0.04 g/100
mL BAC and 100 μg/kg THC on urban city driving. Additionally, using a head-mounted eye movement-recording system, the subjects’ visual search or side glances were assessed.

This study confirmed that low doses of marijuana, or alcohol at the 0.04 g/100 mL concentration, when taken alone, did not impair city driving or performance or interfere with visual search frequency at intersections. When alcohol and THC were taken in combination, however, visual search frequency decreased by about 3%. The study also confirmed the finding of previous work that subjects did not feel impaired when using alcohol, even when impairment was present, but did feel impaired after marijuana use even when no impairment was measurable. The subjects’ ability to recognize their impairment from marijuana was abolished, however, when it was consumed in conjunction with alcohol.

5. CONCLUSIONS

The material reviewed in this chapter highlights the challenges of assessing driving impairment caused by marijuana. Epidemiologically, there is evidence for dose-dependent increases in crash risk with increasing blood THC concentration. There is good evidence that the prevalence of cannabinoids in the system of injured, killed, and arrested drivers is higher than the incidence in the population at large. Empirically, the drug produces effects on cognition and psychomotor performance, which have the potential to impair driving ability, and users recognize the presence of that impairment and can even compensate accordingly. There is good evidence that there is a significant dose–response relationship between marijuana use and the degree of impairing effects. On the other hand, the passage of time between driving or involvement in a crash limits our ability to get an accurate measurement of the THC concentration at the time of driving. More complex tasks are more sensitive to the effects of marijuana and increase the likelihood that that the impairment will become significant and observable.

Studies of driving behavior have been conducted with typical user-preferred doses and show that the effects, at least on the alcohol-impairment scale, are mild to moderate and are affected by the dose, the time since use, the users’ perception of the effect, and their degree of compensation or overcompensation for those effects.

In short, the assessment of the role of marijuana use in a crash or impaired driving case must be made with caution and will be most defensible when all available information is considered, including the pattern of driving, recent drug use history or admission to marijuana use, an appearance of impairment, performance in field sobriety tests, the presence of physiological signs and symptoms of marijuana use, and toxicological test results of blood or serum samples.

6. GENERAL READINGS

REFERENCES


Marijuana and Driving Impairment


