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CANNABIS AND ROAD SAFETY: A REVIEW OF RECENT EPIDEMIOLOGICAL, DRIVER IMPAIRMENT, AND DRUG SCREENING LITERATURE

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Cannabis and Road Safety: A Review of Recent Epidemiological, Driver Impairment, and Drug Screening Literature

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Abstract:

Cannabis is the most commonly used illicit drug in Australia and is used by a wide section of the community, particularly younger people. Contrary to data from the early to mid-1990s, recent Victorian crash data suggest that the use of cannabis is associated with elevated culpability in crashes. It is therefore timely to draw together the international literature in regard to the issues around cannabis use and road safety. This report reviews the key issues concerning cannabis and road safety, including: patterns of cannabis use; the prevalence of cannabis in the driver population, drivers suspected of driving under the influence, and drivers killed or injured; effects on simulator and on-road driving; detection of cannabis in bodily samples; and measurement of impairment using performance tests such as the Standardised Field Sobriety Test. The report highlights the current gaps in knowledge and documents the specific areas of research that need to be pursued in future studies in order to further enhance our understanding of how cannabis influences driving skills.

Key Words:
Cannabis, alcohol, illicit drugs, drug driving, drug testing.

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EXECUTIVE SUMMARY

Cannabis is the most commonly used illicit drug in Australia and is used by a wide section of the community. The 2001 National Drug Strategy Household Survey reported that 33% of Australians over 14 years of age had used cannabis at least once, while 13% had used cannabis recently. While there is much evidence demonstrating that cannabis impairs many aspects of human performance, research is continuing to examine the means by which this impairment manifests in the driving environment. This report reviews the epidemiological, driver performance, and drug screening literature as it relates to cannabis and road safety.

The recent epidemiological studies reviewed show that cannabinoids are present in a significant proportion of drivers killed and injured in road accidents. Recent data for fatally injured drivers in Australia between 1997 and 1999 show that 8.5% of tested drivers were positive for the psychoactive component of cannabis, delta-9-tetrahydrocannabinol (THC). Drivers positive for THC were significantly more culpable than drug free drivers, with culpability increasing further when THC was combined with alcohol.

Case-control studies offer the greatest potential for demonstrating an increased risk of injury associated with drug use, whereby the presence of drugs in injured drivers is compared to the prevalence in a control sample of non-accident involved drivers. While some recent studies of this nature have been published, methodological issues, such as the selection of appropriate treatment and control groups, and sample size, reinforce the need for further epidemiological studies of this type.

There have been numerous studies published in recent decades that have aimed to examine the effects of cannabis on both simulated and on-road driving. Recent on-road and simulator studies have set the benchmark for cannabis and driving research. There is no doubt that recent research is continuing to show that cannabis, both alone and with alcohol, impairs a range of measures of driving performance. The predominant form of impairment observed after smoking cannabis alone is an increase in lane weaving behaviour. This measure of behaviour is also sensitive to impairment associated with fatigue and alcohol consumption. The use of cannabis alone has also been associated with increased variability in headway to a lead vehicle. This is an important finding because it is commonly interpreted as reflecting the ability to perceive changes in the relative velocities of other vehicles and ability to adjust own speed accordingly, and is suggestive of impaired perceptual abilities. Cannabis has also been found to lead to increased reaction time to respond in an emergency decision-making task.

While cannabis has been found to have a number of negative effects on driving performance, it has been suggested that people experiencing the effects of cannabis appear to be aware of their impairment and where possible they compensate by, for example, slowing down, focussing attention and not taking risks (like overtaking). However, drivers are not completely able to compensate for the number of adverse effects on driving behaviour. These alleged compensatory effects come at a cost to the driver, in that increased ratings of perceived effort after smoking cannabis, perhaps by focussing attention, would lead to a reduction in spare capacity. Safety would be compromised, particularly in situations when the driver encounters unexpected events, and/or when the driver is placed in situations requiring increased mental load or continuous attention.

When cannabis is combined with alcohol, variability of headway is again increased, and variability in lane weaving behaviour is increased to a greater extent than for cannabis alone. This is again indicative of impaired performance. Furthermore, drivers with both

cannabis and alcohol take significantly longer to react to changes in the speed of other vehicles, which is suggestive of a decrease in safety. To illustrate, the combination of a moderate dose of alcohol and cannabis is found to produce impairment to a level observed at a Blood Alcohol Concentration of around 0.14%. Furthermore, the frequency of visual search for traffic at intersections has been found to be similar for placebo, alcohol alone, and cannabis alone, but reduced significantly when alcohol & cannabis are combined. In accordance with some previous research, this finding suggests that drivers are less able to respond to peripheral traffic while maintaining performance on the central driving task.

One of the clear messages to emerge from the research reviewed is that there is a need to examine the effects of cannabis in situations where the driver is required to perform several tasks simultaneously or when confronted with a situation that requires a rapid adaptive response. Furthermore, there has been little research examining the effects of cannabis, alone and in combination with alcohol and other drugs, across a range of levels of driving experience.

Literature addressing the detection of drug-impaired drivers is also briefly reviewed. Broadly speaking there are two approaches that are being researched and used world-wide to detect drug use, including cannabis use, at the roadside. The first, and the one that is most actively being researched, is the ability to screen for drugs of abuse in bodily samples. The major samples under investigation are blood, urine, sweat, and saliva. Blood sampling represents the most accurate means for conducting drug analyses, however, it is not a practical means of testing for drug use in the field. While much research is being directed towards researching alternative samples, the majority of effort is being directed towards the development of a saliva-based measure of drug use. Saliva has been identified as the preferred specimen by police forces and experts across the European Union. The second approach is to determine drug-related impairment by measuring performance on standardised tests. Both approaches are being used for law enforcement purposes in Victoria.

1. INTRODUCTION

Cannabis is the most commonly used illicit drug in Australia and is used by a wide section of the community. The most recent National Drug Strategy Household Survey in 2001 was the largest of a series of such surveys conducted since 1985 with a total sample of 27,000 Australians aged 14 years and over (Australian Institute of Health and Welfare, 2001). The survey generates information about current drug consumption patterns, community attitudes toward drugs and drug enforcement, and drug related behaviours and activities.

The 2001 National Drug Strategy Household Survey findings suggest that 33% of Australians over 14 years of age have used cannabis at least once in their lifetime, while 13% have used the drug in the 12 months prior to the survey (recent use). The proportions were higher for the younger males, with 61% of males aged 20-29 years reporting lifetime cannabis use (56% for females), and 35% reporting recent use (compared to 23% for females).

1.2 BASIC PHARMACOLOGY

Cannabis preparations are largely drawn from the plant of *Cannabis sativa* (Hall & Solowij, 1998), of which the major psychoactive component is delta-9-tetrahydrocannabinol (THC)(Adams & Martin, 1996). Cannabis preparations are typically generated from flowering tops and leaves resulting in a THC content between 0.5-5.0%, and is prepared from the dried. Hashish has a THC content between 2-20% and consists of dried cannabis resin and compressed flowers (Hall & Solowij, 1998). Cannabis is usually smoked in a 'joint', approximately the size of a cigarette. Smokers inhale deeply to maximise the absorption of THC into the lungs. While cannabis can be eaten, smoking is the most common form of use because it is the easiest way to achieve the desired drug effects (Hall, Solowij, & Lemon, 1994).

Before discussing the effects of cannabis on performance and mood, it is important to gain an understanding of the pharmacokinetics of cannabis. Ashton (1999) suggests that approximately 50% of the THC and other cannabinoids present in a cannabis cigarette enter the mainstream smoke and are inhaled, while Adams and Martin (1996) suggest that as little as 10 to 25% of available THC may enter the circulation when smoked. Subjective and objective effects are discernible within seconds, and fully apparent within minutes, from the start of smoking. Lower doses of cannabis (i.e., 2.5 mg THC) is enough to produce measurable psychological and physical effects in occasional cannabis users (Ashton, 1999).

On entering the bloodstream, cannabinoids are distributed rapidly throughout the body, reaching first the tissues with the highest blood flow (brain, lungs, liver, etc.). Cannabinoids are highly fat soluble, and accumulate in fatty tissues from which they are very slowly released back into other body compartments, including the brain (Adams & Martin, 1996). The plasma elimination half-life of THC is approximately 56 hours in occasional users and 28 hours in chronic users. However, the tissue half-life is approximately 7 days and complete elimination of a single dose may take up to 30 days (Ashton, 1999). If cannabis is taken orally, the amount of cannabinoids absorbed is 25-30% of that obtained by smoking and the onset of effects is 0.5-2 hours, although duration of action may be prolonged.

The primary psychoactive constituent of cannabis, THC, is metabolised to an active metabolite, 11-hydroxy-delta-9-tetrahydrocannabinol (11-OH-THC), which in turn is

rapidly converted to an inactive metabolite, 11-nor-9-carboxy-delta-tetrahydocannabinol (THC-COOH). In a study of the pharmacokinetic profile of the absorption of THC, Huestis et al. (1992a) showed that THC levels increased rapidly following the smoking of one marijuana cigarette (1.75%, 3.55% THC) and peaked prior to the end of smoking. Peak 11-OH-THC levels occurred immediately after the end of smoking and THCCOOH levels increased slowly and plateaued for an extended period.

High levels of THC are detectable in saliva immediately after smoking, followed by a rapid decline in the first hour (Cone, 1993; Menkes, Howard, Spears, & Cairns, 1991). Cannabis is detectable in saliva for at least four hours post smoking, although this will be dose-dependent (Maseda et al., 1986). The limited evidence with regard to the relationship between saliva THC and the time course of effects of cannabis is equivocal (Cone, 1993). Establishing such a relationship may be challenging as it is clear that THC levels in saliva may result in part from the contamination of the oral cavity during the smoking process (Gross et al., 1985; Kidwell et al., 1998).

Having briefly addressed the pharmacokinetics of cannabis, discussions in the following sections will provide an short overview of the effects of cannabis on mood, performance in general, and driving. After considering the effects of cannabis on driving, the next issue considered is how to detect cannabis-related impairment on the road. The final section of this report discusses the available pharmacological and performance-based measures for defining drug-related impairment.

2. THE EFFECTS OF CANNABIS ON PERFORMANCE AND MOOD

While the effects of cannabis on driving are the focus of this review, it is instructive to briefly consider the effects of cannabis on wider aspects of performance and mood.

2.1 EFFECTS OF CANNABIS ON MOOD

The ability of cannabis to produce a 'high', is no doubt an important single action that sustains its widespread use. The euphoric effect varies greatly with dose, mode of administration, expectation, environment and personality of the user. When small doses are taken in social gatherings, the main effects are a pleasant euphoria, very similar to those of social doses of alcohol (Ashton, 1999). A high can be induced by doses as small as 2.5 mg THC in a cigarette and includes feelings of intoxication and detachment, with decreased anxiety, alertness, depression and tension, in addition to perceptual changes. The intensity of the high is dose-dependent, being increased with higher doses.

In naïve cannabis users, dysphoric reactions to cannabis are not uncommon. Such reactions may include severe anxiety and panic, unpleasant somatic sensations and paranoid feelings (Thomas, 1993). Anxiety-panic reactions are the most common adverse psychological effects of cannabis use. They may include restlessness, depersonalisation, and a sense of loss of control and fear of dying. In some subjects euphoria and dysphoria, laughing and crying, may alternate. After an initial period of excitement following an acute dose, cannabis exerts a central nervous system depressant effect which leads to drowsiness and sleep towards the end of a period of intoxication (Ashton, 1999).

2.2 EFFECT OF CANNABIS ON PERFORMANCE

Perceptual changes induced by cannabis affect all sensory modalities. Temporal and spatial perception is distorted so that judgement of distance and time are impaired. Experimental studies of time perception have found that subjects consistently overestimate the passage of time even after small doses (e.g. four puffs of a cigarette containing 3.6% THC) (Chait & Perry, 1994; Dougherty, Cherek, & Roache, 1994). The effects of cannabis on thought processes are characterised initially by a feeling of increased speed of thought. With higher doses of cannabis, thoughts may become out of control, fragmented, and lead to mental confusion (Ashton, 1999).

The effect of cannabis on memory processes is the single most consistently reported cognitive deficit following the use of cannabis. Cannabis causes a specific deficit in short-term memory, an effect which is apparent even after small doses in experienced cannabis users. Memory impairment induced by cannabis has been investigated in a large variety of tests, including immediate free recall of digits, prose material and word-picture combinations (see Robbe, 1994, Adams & Martin, 1986, for reviews). The deficit appears to be in the acquisition of memory and may result from an attentional deficit combined with an inability to filter out irrelevant information and the intrusion of extraneous thoughts. Memory lapses may account in part for the time distortion and may contribute to poor psychomotor performance in complex tasks (Ashton, 1999).

The effects of cannabis on perception, memory and cognition, motor co-ordination and general arousal level combine to affect various types of psychomotor performance (see Robbe, 1994, for a review). Laboratory investigations show that social doses of cannabis

have minimal effects on performance in simple motor tasks and simple reaction times. However, even small doses (THC 5-15 mg) can cause significant impairment of performance in complex or demanding tasks, such as those involving fine hand-eye co-ordination, complex tracking, divided attention tasks, visual information processing, digit code tests, alternate addition-subtraction tasks and many others. Performance in all of these tasks deteriorates as the dose increases, and can last for two hours or more after a single dose (Ashton, 1999).

While the effects of cannabis on driving skills will be addressed shortly, the effects of cannabis on other complex real-life situations has been investigated. Like driving, piloting an aeroplane is a complex task, and so it is perhaps not surprising that cannabis has been shown to impair the skills of pilots. In double-blind, placebo-controlled studies, gross decrements in performance on flight simulator tasks were found in 10 trainee pilots after smoking cannabis (2.1% THC) (Janowsky, Meacham, Blaine, Schoor, & Bozzetti, 1976a, 1976b). Performance deficits included increased errors, altitude deviations, poor alignment on landing, difficulties in remembering the flight sequence, and time distortion. Significant impairments were noted for more than 24 hours after a single dose of cannabis. Another study examined the effects of cannabis (THC 0, 10 and 20 mg) with two levels of difficulty (calm and turbulent simulated flying) in nine old (aged 30-48 years) and nine young (aged 18-29 years) pilots (Leirer, Yesavage, & Morrow, 1989). It was found that older pilots made more mistakes than younger pilots, and that the effect of cannabis dose, age, and task difficulty were cumulative. At least one aircraft crash in which the pilot was known to have taken cannabis some hours before flying has been reported (Leirer, Yesavage, & Morrow, 1991). The error was a result of a landing misalignment similar to those observed in experimental studies.

2.2.1 The relationship between plasma THC levels and subsequent performance and mood

Numerous studies, using a variety of administration procedures including smoking, intravenous and oral routes of administration, have examined the relationship between plasma THC levels and the time course of subjective, physiological and performance effects of cannabis. While there are some exceptions, the findings of these studies suggest that changes in blood concentration of THC is out of phase with the subjective, physiological and behavioural effects of cannabis (Cone & Huestis, 1993; Kelly, Foltin, Emurian, & Fischman, 1993; Ohlsson et al., 1980). It appears that there is a lag between peak plasma THC levels and peak subjective effects and performance decrements. The failure to observe a direct relationship between plasma THC levels and the effects of cannabis has been attributed to the psychoactive effects of the metabolites and/or the persistence of THC in the CNS (Reeve, Grant, Robertson, Gillespie, & Hollister, 1983). According to this explanation, the subjective, physiological and behavioural effects of cannabis are the result of direct effects of both THC and the metabolite 11-hydroxy-delta-9-tetrahydrocannabinol. The absence of a strong and consistent time-course relationship between plasma THC concentration and performance has important implications for drug detection and the establishing of drug-related impairment.

One important finding is that subjective and physiological effects occur at much lower plasma concentrations following oral administration than are observed following intravenous administration or the smoking of cannabis cigarettes (Ohlsson et al., 1980).

While it is clear that blood THC levels cannot be used to predict the time course or magnitude of the effects of the drug, it appears that they can be used to predict the timing

of cannabis use. Mathematical models have been successfully developed for the prediction of elapsed time since cannabis use on the basis of an analysis of plasma concentrations of THC and THC-COOH (Cone & Huestis, 1993; Huestis, Henningfield, & Cone, 1992b).

3. CANNABIS AND DRIVING

Cannabis use in the driving population and the role of cannabis in accident causation have been examined through epidemiological studies of the prevalence of cannabis metabolites in blood samples of both fatally and non-fatally injured drivers. The effects of cannabis on driving skills have been examined in studies of driver performance after the ingestion of the drug. The discussion here will begin with a consideration of the epidemiological evidence from Australia and overseas, with comment on the culpability studies that have been conducted in Australia. The effects of cannabis on simulated driving and on-road driving performance are then discussed.

A recent MUARC report has presented recent drug driving data for both the general population and drug users (Haworth, Clark, & Lenné, 2004). The following section on drug use surveys is drawn heavily from that report.

3.1 DRUG USE SURVEYS

3.1.1 Estimates of drug driving from general population surveys

Two surveys have recently collected information about drug driving as part of general population surveys of Australians: The National Drug Strategy Household Survey and the AAMI Young Driver Index.

National Drug Strategy Household Survey

In addition to asking about patterns of drug use, the National Drug Strategy Household Survey also asks respondents if they had driven a vehicle under the influence of illegal drugs in the previous 12 months. Overall, 3.9% of the sample had driven under the influence of illicit drugs. Driving was the activity most likely to be undertaken whilst under the influence of illicit drugs. Females were less than half as likely (2.2%) to drive under the influence of drugs than males (5.7%). It is important to note here that the type of drug used is not specified.

AAMI Young Driver Index

In December 2002, AAMI Insurance published their second annual Young Driver Index. The findings were based on the company's insurance claims and a survey of 1,184 licensed drivers of all ages living in New South Wales, the Australian Capital Territory, Victoria, South Australia, Tasmania and Queensland. Overall, 15% of drivers aged 18-24 reported driving after using recreational drugs. Young women were more likely to report having driven after using recreational drugs than to report having driven under the influence of alcohol. Eight percent of young drivers (higher among males) and five per cent of older drivers thought that using a small amount of recreational drugs before driving did not affect their driving ability. Young drivers were more likely than older drivers to consider that driving after using recreational drugs was safer than driving after drinking (15% versus 7%). Support for random drug testing was high among young drivers (84%) but lower than among older drivers (89%). Again however, the type of drug is not specified.

3.1.2 Estimates of drug driving in drug user populations

A number of studies have interviewed drug users about their drug driving behaviour. Lenné, Fry, Dietze and Rumbold (2001), examined the drug driving behaviour patterns of

cannabis users and their attitudes to the (then) proposed introduction of driver impairment testing in Victoria. Their research found a common belief amongst participants that cannabis did not affect their driving ability or increase their accident risk. Over half of the participants said that driving under the influence of cannabis should be legal, were confident that they would not be detected if driving under the influence of cannabis and had no intention of ceasing their drug driving behaviour due to legislative changes. One of the major reasons provided, regarding their confidence in avoiding detection, was a belief that the testing procedures were not sensitive enough to detect their cannabis use. However, the majority of participants did acknowledge that the combination of cannabis and alcohol was detrimental to driving. This was reflected in their driving behaviour, with participants driving only 14% of the time after a combination of cannabis and alcohol use, compared to driving 43% of the time after using cannabis alone.

Due to the sampling criteria, inferences from this research cannot be made to the general population. However, specific findings from this population can provide insights into an area that has little empirical data available. Through exposure to educational information, the drivers in this sample do recognise the correlation between alcohol consumption and driving impairment. They also refrain from driving under the influence of alcohol to avoid being detected. These findings suggest that the introduction of the Road Safety (Drug Driving) Act 2003 Testing Program may successfully deter drug driving in 2 ways. Firstly, via exposure to the public health messages associated with the introduction of Testing Program, regarding the detrimental effects of driving under the influence of cannabis and, secondly, that the testing procedures are now sensitive enough to detect their cannabis consumption.

Darke, Kelly and Ross (2004) reported a Sydney study that examined drug driving and related motor vehicle accidents among intravenous drugs users. The sample consisted of 300 regular intravenous drug users recruited via advertising from the inner, middle and outer geographical regions of Sydney. Information was obtained from participants regarding their drug taking history, drug use locations, psychological functioning and drug driving behaviours.

Of the participants who currently drive, 87% reported driving a motor vehicle soon after using drugs within the last 12 months. The drug most commonly involved in drug driving was cannabis (74% ever, 57% during last 12 months). Of the sample, 32% reported having been involved in a motor vehicle accident while drug driving. Heroin was reported as the drug used in accident involvement (53%), followed by cannabis (46%), and then alcohol (42%).

Of the participants, 89% had been a passenger with a drug driver, with 17% being involved in an accident in the last 12 months. Cars were the most common venue for drug taking amongst drug drivers. The report concludes that drug drivers in this sample were most likely to be poly-drug users, who use drugs in their cars and regularly drive while under the influence.

In summary, drug use and drug driving are, not surprisingly, much more common amongst drug user populations. Even among injecting drug users, cannabis remains the drug most likely to be involved in drug driving. Clearly there is a need to conduct further research to establish the drug use and driving behaviours in the wider community.

3.2 EPIDEMIOLOGICAL EVIDENCE

There have been a number of published papers that have reviewed the prevalence of drugs in both the general and crash populations of drivers. The reader is directed to other sources for further information (e.g., Bates & Blakely, 1999; Macdonald et al., 2003).

In order to gain a clear understanding of the extent to which drivers around the world are driving while impaired by drugs, it is critical that substantial data be collected on the prevalence of drug use in the general driving population (i.e., non-accident involved drivers). While such imposing epidemiological studies are yet to be conducted, some data have been collected from roadside surveys that provide some insight into the extent of drug-impaired driving worldwide. Roadside surveys conducted in Germany and the Netherlands suggest that the prevalence of drugs in drivers sampled is as follows: alcohol (6-12%), cannabis (1-5%), amphetamines (0.8-1.4%), opiates (0.7-1.4%), and benzodiazepines (0.3-2.6%) (Maes, Charlier, Grenez, & Verstraete, 1999).

A recent random sample of 1000 drivers in rural Denmark yielded 896 samples and 636 returned questionnaires. The study found that only 1.3% of saliva samples subjected to laboratory analysis were positive for illegal drugs, and 0.7% for benzodiazepines (Behrensdorff & Steentoft, 2003). In this study THC was detected in 21 saliva samples and in only 7 confirmatory tests. Thirty-eight respondents (5.8%) to the survey indicated having used medicinal or illegal drugs in the preceding 24 hours, but only 1 driver admitted to using cannabis during this time. High proportions of the sample supported police enforcement of drugged driving penalties for participants who both did and did not report driving after using drugs in the preceding 24 hours (85 and 935 respectively).

The incidence of alcohol and drugs increases when data from drivers suspected of drugged driving are considered. Table 1 below shows European data on the prevalence of drugs in drivers suspected by police of driving under the influence of alcohol or others drugs. Alcohol is clearly the most common drug found in these studies, followed by benzodiazepines, cannabis, and amphetamines. The data shown in Table 1 are drawn studies conducted in Norway (Cone & Huestis, 1993; Skurtveit, Christophersen, & Morland, 1995), Switzerland (Augsburger & Rivier, 1997), Denmark (Steentoft, Worm, & Toft, 1997), and Finland (Lillsunde et al., 1996).

Table 1: Drivers suspected of driving under the influence (adapted from Maes et al., 1999, page 12).

	Norway	Switzerland	Denmark	Finland
Period	1994	1982-1994	1995	1993
Number of subjects	2529	641 (40 % involved in accident)	221 (46 % involved in accident)	332
Biological sample	Blood	blood, urine		blood
Analytical methods	Immunoassay GC-MS	Emit, RIA, TLC, GC, HPLC		Emit, GC
RESULTS				
Alcohol	89%	35.9%		95.5%
Alcohol only	30%	7.8%		73.2%
Drugs	59% (in 2529 cases With BAC < 1.5 g/l)	85.0%	86.0% (in 221 cases with BAC < 0.5 g/l)	26.8%
Drugs only		56.9%		
Drugs + alcohol		28.1%		24.1%
Amphetamines	21.1%	4.2%	10.0%	2.7%
Antidepressants			< 5.0 %	
Benzodiazepines	30.6%	14.8%	53.0%	22.9%
Cannabinoids	26.1%	57.3%	17.0%	2.4%
Cocaine	0.04%	10.5%	6.0%	1.2%
Methadone	n/a	10.3%	13.0%	
Opiates	7.6% Morphine 4.1% Codeine	36.3%	27.0%	0.0%

As shown in Table 2, data have also been collected on the prevalence of drugs in (European) drivers who were injured or killed in road crashes. The pattern in these studies is similar to that shown in Table 1 with the most prevalent drug being by far alcohol, again followed by benzodiazepines, cannabis, amphetamines, and opiates (Alvarez et al., 1997; Christophersen et al., 1995).

While the prevalence data detailed in Tables 1 and 2 vary markedly between countries, it is not possible to directly compare between studies because of the different methodologies used in each study (driver group, time and location of sampling, potential differences in police procedures, etc). However, these observational studies say little in the absence of knowing the population prevalence. While the prevalence of drug driving appears low, the rate at which these drugs appear in Tables 1 and 2 is higher suggesting increased crash risk. This is followed up in the next section.

Table 2: Drug prevalence in drivers injured or killed in Norway and Spain (adapted from Maes et al., 1999, page 11)

	Norway	**Spain**
Period	1993	1992-1995
Number of subjects	394 (injured drivers)	979 (killed drivers)
Biological sample	Blood	Blood
Analytical methods	GC-MS,HPLC	Immunoassay GC-MS, HPLC
RESULTS		
Alcohol	62.9%	51.2%
Alcohol only	51.8%	44.3%
Drugs	24.1%	14.3%
Drugs only	12.9%	5.9% (2 % illicits+ 3.9 % medicines)
Drugs + alcohol	11.2%	6.9%
Amphetamines	4.1%	0.9%
Benzodiazepines	13.7%	
Cannabinoids	7.6%	1.5%
Cocaine	n/a	5.0%
Opiates	4.3%	3.1%

Data have been collected on the prevalence of drugs in injured drivers in Australia, and are discussed in the following section in the context of the culpability studies.

3.2.1 Culpability studies

Some studies have moved beyond stating the mere prevalence of different types of drugs in bodily samples taken from fatally or seriously injured drivers by using methods for assigning culpability or responsibility for each accident. As shown in Table 2, epidemiological studies suggest that cannabinoids are present in a significant proportion of drivers killed in road accidents. In the first of a series of studies, Drummer (1994) collected data for 1045 drivers killed. Culpability was determined according to the mitigating factors (independent of drug analysis), and drivers were classified as culpable, contributory, or not culpable. The mitigating factors used in the analyses were the condition of the road and vehicle, driving conditions, type of accident, witness observations, road law obedience, difficulty of the task involved, the level of fatigue (Robertson & Drummer, 1994). The proportion of culpable drivers (ratio) was calculated for each drug type condition. The large majority (73%) of drivers in the sample as a whole were culpable, while 18% were not culpable. The relative risks for each drug type are presented below in Table 3.

Table 3: Responsibility analysis for fatal accidents (Drummer, 1994).

Drug group	Prevalence	Relative risk (all cases)	Relative risk (drug alone)	Relative risk (drug + alcohol)
Drug free	51 %	1.0		
Alcohol	27 %		6.0*	
Alcohol + drugs	9 %			9.0*
Drugs	13 %		1.4	
Cannabis	11 %	1.6	0.6	5.6
Stimulants	3.7 %	2.7*	1.6	8.7
Opiates	2.7 %	5.0*	2.3	2.9
Benzodiazepines	3.1 %	5.8*	1.9	9.5
Misc. Drugs	5.6 %	4.0*		8.7

* statistically significant

The first column in Table 3 shows the prevalence of each drug type in fatal crashes found by Drummer (1994). As with the European data, alcohol was the most prevalent drug found in these drivers. The increase in risk (or culpability) associated with each drug type (alone and in combination with alcohol) is shown relative to the drug free drivers. The highest culpability ratio for any drug alone was found for alcohol, then opiates. Culpability ratios were considerably higher for all drugs in combination with alcohol, except opiates. It is interesting to note the ratio for cannabis alone. The analyses for cannabis included THC and the inactive metabolite, THC-COOH, which makes interpretation difficult and suggests that this ratio may not be truly representative of the culpability ratio associated with impairments from THC alone.

A more recent analysis examined the prevalence of drugs in 3398 fatally injured drivers across Victoria, New South Wales, and Western Australia between 1990 and 1999 (Drummer et al., 2003). Due to developments in analytical techniques, Drummer and colleagues were able to determine level of THC as distinct from the longer lasting inactive metabolite only for the latter part of their sample. Between 1997 and 1999, 221 cases (15.6%) were positive for cannabinoids while 121 (8.5%) were positive for THC (the confirmation rate was 52%, which means that THC was detected in just over half of the sample of drivers for whom cannabinoids were detected). Of the THC positive cases, 58 were positive for THC alone, 43 positive for THC and alcohol, and 20 positive for THC and other drugs.

Drummer et al.'s (2003) data were then subjected to culpability analyses in a subsequent publication, and Odds Ratios (ORs) were calculated for various drug combinations (Drummer et al., 2004). Similar to the earlier work, these ORs were the ratio of culpability for those exposed to those unexposed to drug use. The presence of THC was associated with increased culpability for both car drivers (OR 2.7, CI 1.02-7.0) and motorcyclists (OR 2.4, CI 0.5-12.5). Of those drivers positive for THC only (n=58), the majority (84%) had THC levels > 5 ng/ml. Taking only these levels, THC was significantly associated with increased culpability (OR 6.6, CI 1.5-28), which is similar to the OR associated with BAC-positive cases over 0.15%. Drivers positive for THC and who had a BAC over 0.05% were 2.9 times more likely to be culpable than drivers who were BAC positive only, which suggests that THC does enhance impairment associated with alcohol. These data are for THC positive cases only.

It should be noted that the following factors were incorporated into the logistic regression model: gender; age; BAC level; type of drug; type of crash (single versus multi vehicle), State of Crash; and Year of Crash. The age-gender, age-BAC, and age-drug group interactions (amongst others) were not significant. Culpability was higher for 18-25 year olds than 30-39 and 40-59 year olds, and higher for drivers with a drug than controls. Time of day however was not incorporated into the model.

Data have also been reported on the prevalence rates for various drugs in non-fatal accidents in Australia. Longo and colleagues collected blood samples from 2500 non-fatally injured drivers in South Australia in 1995-1996 (Longo, Hunter, Lokan, White, & White, 2000a, 2000b). Alcohol was the most prevalent drug in these samples, being present in 8.6% of cases. The next most prevalent drugs were cannabis (THC) only (7.1%), cannabis and alcohol (3.0%), benzodiazepines only (1.8%), and stimulants only (0.8%). Just over 75% of drivers tested were negative for alcohol and other drugs. Alcohol and cannabis were more prevalent in single vehicle accidents than multiple vehicle accidents. Culpability analyses were conducted and the results appear below (Table 4). Over half (59%) of those cases positive for THC had levels <2 ng/ml, and there was no relationship between culpability and level of THC for these cases. It should be noted that the concentrations of THC were quite low, which contrasts starkly with the THC levels reported by Drummer et al (2004) where most samples (84%) were above 5 ng/ml.

The trend continues in that alcohol was the most dangerous drug in terms of the percentage of drivers found culpable with one drug alone. Culpability was again much higher for drugs in combination with alcohol, particularly cannabis and benzodiazepines.

Table 4: Percentage of drivers culpable for each drug type in an analysis of 2500 non-fatally injured drivers in South Australia (Longo et al., 2000b).

Drug combination	Percentage culpable
Drug free	52.8
Alcohol only	90*
THC only	47.7
Alcohol + THC	85.7*
Benzodiazepines only	69.6*
Stimulants only	68.8
Benzodiazepines + alcohol	93.8*

Note: Data have not been included here for stimulants + THC, benzodiazepines + THC, and other combinations. While all classes were 100% culpable, only 1-3 cases were found in these classes (of 2500) which was deemed too low to include here.
* significantly different from drug free group.

Culpability analyses certainly provide valuable information concerning the role of drugs in injury crashes. However, while culpable cases may be positive for a drug, this does not represent conclusive evidence for a causal relationship because these studies only examine crash-involved drivers. So, while culpability analyses indicate that, for example, cannabis is associated with higher culpability, further research is needed to examine the link between the presence of cannabis in the blood and subsequent impairment.

Other types of observational studies offer the greatest potential for demonstrating any changed risk of injury associated with drug use. One such design involves the use of the case-control design, whereby drug exposures measured through samples taken from

injured drivers (cases) is compared to drug exposures in samples collected from drivers who have not been involved in crashes (controls) (see Bates & Blakely, 1999, for a discussion on the methodologies in this context). A recent case-control study in the Netherlands attempted to implement this study design by sampling 110 motorists admitted to a hospital emergency room (cases) and 1029 randomly selected drivers from moving traffic (controls) (Movig et al., 2004). Control drivers were asked to participate in the study on a voluntary basis. After consenting participants were asked some questions about their drug use, and to provide a urine sample for analysis (a blood sample was taken if a urine sample could or would not be provided). Forty percent of cases were positive for one or more drugs compared to 14% for controls. While increased odds ratios were found for the use of benzodiazepines and alcohol, there was not a significant increase in risk associated with the use of cannabis.

Movig et al. 2004 discuss two major potential confounding factors in their study. Firstly, participation in the control group was high (79%), but voluntary, hence it is possible that those drivers with a drug(s) other than alcohol in their system may have refused to participate. Although Movig et al. (2004) suggest no differences in the demographics for those control drivers who did and did not participate, this potential confound remains. Secondly, drivers in the control sample were asked firstly to provide a urine sample, and blood samples were only taken when a urine sample either could or would not be provided. While those authors state that there are advantages in urine sampling (e.g., the longer presence of drugs in samples and in higher concentrations compared to blood), such sampling is problematic in the case of cannabis because presence in the urine is by no means associated with impairment (see later sections of this report). While the authors state that 6.3% of urine and 7.3% of blood samples were positive for cannabis, the potential for an underestimation of the risks of cannabis use remain.

While there are some concerns from the conclusions about the risks associated with cannabis use derived from this study, it has reinforced, with a case-controlled design, the significantly elevated risks associated with driving under the influence of multiple drugs and alcohol-drug combinations.

In a larger case-control study of different design to Movig et al., Mura and colleagues compared drug exposures between 900 injured drivers (cases) and 900 non-driver controls (Mura et al., 2003). Car drivers were recruited from six hospital emergency departments in France after admission resulting from non-fatal accidents. Controls were patients attending these emergency departments, who had a driver's licence, but were admitted for any non-traumatic reason (matched for age and gender). Cannabis (THC) was measured from blood samples, with the mean time between the crash and sample collection being 1.8 hrs. Higher proportions of the drivers aged 18-22 and 23-26 years had THC detected (> 1 ng/ml) compared to controls. Across all age groups 10% of drivers and 5% of controls were positive for THC. The prevalence of cannabis was higher in the drivers compared to controls for both those drivers with THC < 2 ng/ml (OR 2.5) and > 2 ng/ml (OR 2.7). The only conclusions that can be drawn from this study are that more young people are involved in crashes, and that cannabis is present in a higher proportion of cases than controls. The age result could, however, be biased by the time of day.

3.2.2 Summary

The studies reviewed here clearly show that alcohol is still a major drug of concern for road safety. It is the most commonly detected drug in roadside and injured driver samples, and it is associated with a very high degree of accident culpability. The combination of

other drugs, particularly cannabis and benzodiazepines, with alcohol is also of great concern and associated with high culpability.

It is interesting to note that after reviewing all of the available experimental and epidemiological evidence, Tunbridge et al. (2000) classified alcohol and benzodiazepines as the two drugs that should be regarded as being the highest priority in terms of the nature of their impairing effects and the frequency of their incidence in the driving population, and, thereby, representing the greatest risk to road safety. Amphetamines, cocaine, opiates, and cannabis were classified as medium priority.

It has been suggested that methodological concerns with epidemiological studies, such as misclassification of drug use, confounding by treatment duration and concentration, and statistical power, may contribute to the underestimation of crash risk (Ramaekers, 2003). However, recent Australian data suggest that the presence of cannabis in blood significantly increases culpability in fatal crashes, and that THC further enhances impairment resulting from the use of alcohol.

As discussed, case-control studies offer the greatest potential for demonstrating an increased risk of injury associated with drug use, whereby the presence of drugs in injured drivers is compared to the prevalence in a control sample of non-accident involved drivers. While some recent studies of this nature have been published, methodological issues, such as the selection of appropriate treatment and control groups, reinforce the need for further epidemiological studies of this type.

3.3 DRIVER PERFORMANCE STUDIES

While much research has shown that cannabis impairs performance on simple tasks in the laboratory (Berghaus, Scheer, & Schmidt, 1995; Chesher, Bird, Jackson, Perrignon, & Starmer, 1990), there is comparatively little research on driving. There have been a number of studies examining the effects of cannabis using driving simulators and real-life driving situations. Although there are some inconsistencies, in general these studies suggest that cannabis does appear to impair driving performance as measured in these settings. However, unlike alcohol, the relationship between this impairment and crash risk is not well-understood.

There have been several reviews of the effects of cannabis on the performance of complex tasks, including driving (e.g., Newman, 2004; O'Kane, Tutt, & Bauer, 2002; Ramaekers et al., 2004; Robbe, 1994; Smiley, 1986; Victorian Parliamentary Road Safety Committee, 1996; Ward & Dye, 1999). The earlier studies will therefore be reviewed briefly, with more attention focussed on the studies conducted after 1990.

3.3.1 Simulator studies

Early studies such as those by Rafaelsen and colleagues used driver training simulators to examine the effects of 8, 12, and 16 mg of ingested THC (Rafaelsen, Christrup, Bech, & Rafaelsen, 1973; Rafaelsen et al., 1973). The 12 and 16 mg doses significantly increased braking time and start time (in response to traffic lights) over 10 minutes of driving, 105 minutes after cannabis consumption. However, there was no effect on mean speed.

Moskowitz, Hulbert, & McGlothlin (1976) tested subjects on a driving simulator with filmed (rather than computer generated) vision. Four doses of cannabis were used: 0, 50, 100, and 200 ug THC/kg. Twenty-three subjects completed all four sessions. Cannabis did

not significantly affect car control measures such as speed, steering wheel position, and lateral position across 45 to 70 minutes of driving (approximately 30 minutes after cannabis consumption). However, performance on a subsidiary search-and-recognition task was significantly impaired. This suggests that some of the ancillary perceptual processes necessary for safe driving may be adversely affected by the drug.

The first reported study that used a fully interactive simulator was conducted by Smiley and colleagues (Smiley, Moskowitz, & Ziedman, 1981). Participants received placebo, 100, and 200 μg/kg cannabis, and drove for 45 minutes commencing 15 minutes after cannabis consumption. Both doses of cannabis increased the standard deviation of lateral position (SDLP), and the higher dose also increased speed variability on curves. After smoking cannabis participants displayed increased secondary reaction time and, in an emergency decision-making task, crashed into the obstacle on the road significantly more often after the high dose. While cannabis also increased headway variability, it also seemed to induce some caution in that participants increased headways and refused more opportunities to overtake. With the exception of SDLP and headway variability, impairments were only associated with the high dose of cannabis.

Stein (1987) examined the effects of cannabis and alcohol using a similar simulator to Smiley et al (1981) (Stein, 1987). The doses of THC were the same as in the Smiley et al. (1981) study (i.e., placebo, 100, and 200 μg/kg). Cannabis was combined with placebo alcohol and alcohol to the 0.10% BAC level. In addition to basic measures of driving performance, Stein and colleagues measured steering gusts and examining how the drivers compensated for the gusts. Reactions to anticipated and unexpected obstacles were also recorded. Alcohol, alone and in combination with cannabis, did significantly increase the number of accidents, while cannabis alone did not. Alcohol also increased SDLP, speed variability and response time. Cannabis was only associated with a drop in mean speed, and an increase in speed variability during the divided attention task. The combination of cannabis (high dose only) with alcohol produced significantly more impairment than alcohol alone.

A significant study in the area of cannabis and driving was completed very recently (Sexton et al., 2000). This UK study examined issues such as the effects of cannabis on driving, mood, and hazard perception, the link between saliva and blood levels of THC, and the link between sobriety test performance and driving simulator performance. For this reason it is pertinent to discuss the methodology and findings from this study in some detail.

Participants were 15 males with a mean age of 27 years. All smoked cannabis at least once a week, all drank alcohol at least once a week, and 46% used other drugs – with ecstasy being the most frequently used other drug (72%). The entire sample reported having used cannabis in combination with alcohol at some time, and the majority of the sample (73%) reported using cannabis in combination with alcohol at least once per week.

Four doses of cannabis were used in this study, and they were:

1. Placebo: 0.005% ± 0.002 of THC
2. Low dose: 1.70% ± 0.14 THC
3. High dose: 2.67% ± 0.04 THC
4. Cannabis resin (about 1.7% THC)

Blood, urine, and saliva samples were taken upon arrival, and 10, 25-35, and 95-100 minutes post-smoking.

Individual smoking techniques during ad-lib smoking vary to such an extent that differences in the THC delivered to the lungs, and absorbed into the lungs, are inevitable (see Robbe, 1994). To control for inter and intra-individual variations, some studies have used a standardised smoking procedure. Sexton et al. (2000) developed a procedure that was based on a literature review and pilot testing. The final smoking procedures adopted is shown in Table 5.

Table 5. Smoking procedures adopted by Sexton et al. (2000)

Variable	Time (seconds)
Draw-time	5
Breath hold duration	5
Inter-draw interval	30
Number of draws	Various

Sexton et al. (2000) measured performance using a driving simulator, a hazard perception task, and a compensatory tracking task. The driving simulator used was a Silicon Graphics powered computer system that seems similar to the Mid Range Driving Simulator at MUARC. There were three components to the simulator drive. The first was a motorway drive which consisted of a 3-lane road. Other vehicles on the road were programmed in a way that their actions were linked to the speed of the participants' car. However, other vehicles were programmed to place the driver in two situations that required an immediate response (a car pulling out in front, and a car in front braking suddenly).

The second component of the drive involved driving a 'figure of eight' loop. Participants were asked to drive between 30 and 40 mph through two large loops with constantly changing curve radii. The participants were therefore required to make continuous steering corrections in order to stay in the middle of the lane. The third and final component of the drive was a dual-carriageway with four intersections with traffic lights. The signals changed colour as the driver approached and the reaction time to these changes was measured.

The hazard perception task employed by Sexton et al. (2000) involved viewing video recordings of situations that would require the driver to take immediate action such as swerving or braking suddenly. The reaction time to detect hazards and the proportion of hazards detected were the dependent measures. Finally, the compensatory tracking task involved tracking a moving circle on a computer screen with the mouse while concurrently responding to the changing colour of symbols in the four corners of the screen. Visual Analogue Scales were used to assess mood.

Sobriety testing was also conducted. The impairment testing included pupil size, as measured by a Pupilometer; presence of lateral and vertical nystagmus and convergence; the walk and turn test; one leg stand; finger-nose test; and Romberg's test with internal clock. A physical examination documented general demeanour and behaviour, examination of speech, pulse, temperature, ears, eyes, heart, lungs, blood pressure and reflexes. Results from the impairment testing and physical examination were used by the expert to

determine whether the individual was impaired, and whether that impairment might be due to the presence of a drug. The results from the driving simulator test are summarised in Table 6.

Further analyses were conducted using simulator and subjective mood data to compare the performance of those participants who were judged by the forensic medical expert to be impaired with the performance of those participants who were not impaired. For only three of the eight simulator measures was there a difference between those participants who were and were not judged to be impaired (mean speed, and SDLP on the figure of eight for both left and right curves). For only one of the eight driving measures (SDLP for right curves) was there a difference between those participants whose condition was due to a drug compared to those whose condition was not due to a drug, as judged by the forensic medical expert.

There was however strong agreement between the subjective estimates of the levels of impairment and intoxication with the forensic medical expert's determinations of impairment and whether a drug was likely to have caused that impairment. This suggest that the participants were acutely aware of their impairment under the influence of cannabis. This result also brings into question the effectiveness of the placebo condition.

The mean maximum levels of cannabis across the conditions were 11.5 mg for the low dose, 17.9 mg for the high dose, and 4.7 mg for the resin condition. The blood levels of THC (in ng/ml) at 10 and 30 minutes after smoking for the high dose were 478 and 105, for the low dose were 370 and 102, and for the resin condition were 116 and 58. The 10 minute time point was selected because it has been suggested as the time that THC concentrations are at their peak. While the blood levels for the high dose were considerably greater at 10 minutes post-smoking than for the low dose, the blood levels are almost identical for the high and low dose conditions at 30 minutes post-smoking. There was not a strong relationship between blood and saliva levels of THC at 10 and 30 minutes post-smoking (which is not surprising).

In summary, cannabis did not have a dramatic influence on driving performance. Cannabis reduced mean speed, which was interpreted as the participants being aware of their impairment, and adjusting their performance to make the task easier and thereby compensating for the effects of cannabis. The primary effects of cannabis were on tracking ability, as seen by impaired performance on the figure of eight task. This is consistent with previous research which shows that the initial effects of cannabis are on psycho-motor performance as opposed to higher-order cognitive processes.

Table 6: Results from Sexton et al. (2000)

Variable	Differences between placebo, low THC, high THC, and resin groups
Driving simulator measures	
Speed – minimum	No significant difference (trend towards lower speeds in all 3 cannabis groups)
Speed – maximum	No significant difference
Speed – mean	Lower for low and high THC than placebo*
RT to pulling out event	No significant difference*
RT to braking event	No significant difference*
Figure of Eight loop	SDLP: High THC > Low THC > Placebo = Resin
Traffic light tasks	RT: High THC faster than Low THC faster than Placebo
Hazard Perception	
RT to detect the hazard	No significant difference
Proportion of hazards detected	No significant difference
Tracking task	
Mean tracking accuracy	Worse for High THC
Proportion correct	Worse for High THC
Mean RT	No significant difference
Sobriety Tests	
Indicative of Impairment?	Yes (Chi-square)
Related to drug consumption?	Yes (Chi-square)

* A different analysis was conducted using placebo performance as baseline, and then comparing performance in the three other conditions to baseline. Reductions in average speed (between 5 – 6 mph) and RT were observed using this method for low and high THC conditions but not the resin condition.

3.3.2 On road studies

An on-road study by Klonoff (1974) found that cannabis (up to 8.4 mg) did have detrimental effects on driving skills and performance in a restricted driving area and even more so under normal conditions of driving on city streets. There were, however, marked individual differences even with a similar dose and this seemed to depend on whether the subject could compensate for the drug effects. It should be noted however that the city drive performance was rated by a professional observer and not by traditional measures of driving performance.

Hansteen, Miller, Lonero, & Marx (1976) examined driving ability after placebo, 21, and 88 μg/kg THC, and alcohol (0.07%). Participants drove laps marked by cones on a closed course. The higher dose of cannabis resulted in a greater number of cones being hit, and increased time to complete each lap. Alcohol however resulted in more cones being hit, reduced lap times, and 'rough handling' of the car as judged by one of the study investigators. The particularly low dose of cannabis (about 6 mg THC) used in this study should be noted.

In another study participants were given combinations of alcohol (placebo, 0.05%, & 0.10%) and cannabis (placebo, 3.12 mg, & 6.12 mg) (Casswell, 1979). The driving task included overtaking, hairpin bends, responding to traffic signals and performing an auditory secondary task. Alcohol alone and in combination with cannabis resulted in greater SDLP, higher speed, and more course steering corrections. Cannabis with alcohol increased secondary reaction time. Cannabis alone also increased reaction time but was also associated with reduced driving speed. Casswell (1979) again concluded that drivers compensated for the effects of cannabis by reducing the information processing load (by reducing speed) while alcohol induced riskier behaviours. Again, it is important to note the low doses of cannabis used.

The reader is directed to other reports for more detail on these and other cannabis and driving studies conducted before1990 (Robbe, 1994; Smiley, 1986).

3.3.2.1 Cannabis studies in The Netherlands

The most comprehensive series of on-road experiments were conducted by Robbe (1994; 1998), in the Netherlands. Because his research contributes significantly to cannabis and driving research it will be discussed in some detail. Before discussing the four driving studies, it is interesting to comment on a preliminary experiment that was conducted by Robbe (1994) to establish the doses of cannabis that would be used in the driving studies. It is particularly pertinent to mention this study in some detail because the findings of this study are often used to highlight the belief that the doses of cannabis used in experimental research are not realistic and are substantially lower than the levels of cannabis consumed by users outside the laboratory. This issue is one of the major criticisms of experimentally-based cannabis research.

As mentioned, the aim of Robbe's (1994) preliminary study was to determine the appropriate doses of cannabis to be used in the driving studies for recreational cannabis users. Twenty-four participants were given the opportunity to smoke a maximum of three cannabis cigarettes ad lib for up to 15 mins or until they had achieved the maximum psychological effect. The cigarettes contained on average 20 mg THC. Of the 23 participants, six consumed one cigarette, 13 smoked two, and four smoked all three cigarettes. The amounts of THC smoked are shown in Table 7.

Table 7. Mean, median, and range of amounts of THC consumed (adapted from Robbe (1994), p. 81).

	Absolute amount (mg)			Relative to body weight (µg/kg)		
	Mean	median	range	mean	median	Range
Males (n=11)	22.3	18.6	14.7-35.2	324	292	203-524
Females (n=12)	19.4	18.9	11.3-28.2	293	292	194-440
All (n=23)	20.8	18.8	11.3-35.2	308	292	194-524

The amount of THC smoked did not differ for those people who smoked more than once per week versus those who smoked more than once a month but less than once a week. Participants reported their peak feelings of being 'high' to be on average 70% of the greatest ever experienced. The mean amount of cannabis smoked ad-lib (by body weight) was 308 μg/kg, and hence on the basis of these findings the maximum THC dose for the following experiments was set at 300 (μg/kg). While there are undoubtedly differences in the smoking experiences associated with smoking in normal social settings compared to smoking in the laboratory, the dose of cannabis used here represents the mean amount that was used by recreational users in a 15 min period.

Robbe's first driving experiment examined the effects of cannabis on restricted highway driving. The same 24 people participated, all who used cannabis more than once a month but less than weekly, and all who attended four sessions with THC doses of 0 (placebo), 100, 200, and 300 μg/kg. The average amount consumed for the three cannabis conditions was 6.8, 13.6, and 20.4 mg THC, which is equivalent to 94, 186, and 282 μg/kg. The participants drove along an 11 km stretch of highway that was closed to traffic, which was referred to as the road tracking task, and were required to maintain a constant speed of 90 km/h and a steady lateral position. This was done for 20 min periods at 40 and 110 minutes after smoking. Blood samples were taken immediately before the driving tests.

Females displayed higher SDLP than males, although this effect was not related to cannabis dose. There was a significant dose effect, and all three doses of cannabis increased SDLP compared to placebo, but there were no differences in SDLP across cannabis dose. There was no difference in SDLP for the two driving tests. Changes in mean speed and standard deviation of speed and steering angle were not affected by cannabis. Perceived driving quality was lower for all three cannabis doses than placebo, and perceived effort increased with increasing doses. Cannabis decreased alertness, particularly for the first driving test. The mean plasma concentrations of THC at 30 and 90 min post-smoking for each condition were: 100 μg/kg (9.5 & 3.5 ng/ml); 200 μg/kg (15.9 & 4.8 ng/ml); 300 μg/kg (20.7 & 6.2 ng/ml). Blood THC was clearly related to dose and time of blood sampling.

SDLP was not correlated with plasma levels of THC, or the participants' frequency of cannabis use. Excessive SDLP occurred in four subjects for each of the two highest cannabis conditions, but occurred in the second drive, when plasma levels were lower. This illustrates the difficulty in estimating SDLP from single measures of THC (Robbe, 1994). Finally, the decrements in SDLP after high dose THC were estimated to be equivalent to impairments at a BAC of around 0.07%, when compared to previous data by Louwerens, Gloerich, d Vries, Brookhuis, & O'Hanlon (1987).

Following on from restricted highway driving, Robbe's second experiment was conducted in normal highway traffic. The doses of cannabis used were the same as in the first study, and the mean amounts of cannabis consumed in the three cannabis conditions by the 16 participants were 6.9, 13.8, and 20.7 mg. A car following task was performed 45 min after smoking and lasted for about 15 min. Participants then drove for 64 km completing the road tracking task which lasted about 50 min, and the performed the car following task again. This required the participants to respond to changes in the behaviour of a lead (experimental) car, which varied in speed between 80 km/h and 100 km/h, while maintaining a headway of 50 m. Blood samples were taken at 35 and 110 min after smoking.

Similar to the first study, SDLP was impaired in a dose related manner, being significantly higher after the two highest cannabis doses. Mean speed, and standard deviations of speed and steering wheel angle were not significantly affected by cannabis. In the car following task, mean headway was significantly greater in the low THC dose condition but the two higher doses had no effect. It should be noted that participants always had the low dose of THC first, which had a headway of 8 m, through to the highest THC dose, which had a headway of 2 m. Thus, it initially appears that drivers were more cautious the first time they had cannabis, which was always the lowest dose. When adjusted for headway, cannabis did not affect the reaction time to respond to changes in the speed of the lead car.

Robbe's third experiment examined the effects of alcohol and cannabis in city driving, which was deemed to be more complex than highway driving. Cannabis (100 μg/kg) and placebo were administered to 16 participants, while another 16 received alcohol (0.43 g/kg) and placebo. The average amount of THC consumed was 6.9 mg, while the mean BAC was 0.35% 35 min after drinking. Participants were required to drive for 17.5 km in urban traffic, commencing 30 min post smoking. Their performance was assessed on-line by a trained observer and again after the drive by a driving instructor who viewed video of the drive. Over one hundred dichotomous variables covering car control, judgement, and handling of the vehicle were scored. On-line ratings by the trained observer indicated that neither alcohol nor cannabis affected driving. Retrospective ratings, however, indicated that while cannabis did not affect driving, alcohol did. Interestingly, ratings of driving quality were significantly lower following cannabis use but did not change following alcohol use. Ratings of perceived effort were also significantly higher after smoking cannabis. It is important to note the low dose of cannabis used in this study.

The fourth study reported by Robbe (1998) examined the combined effects of cannabis and alcohol. It involved highway driving with both road tracking and car following tasks. Participants attended six sessions with combinations of alcohol (placebo, dose to 0.07% and top ups to sustain at 0.04%) and THC (0, 100, & 200 μg/kg). Smoking commenced 60 min after drinking, and driving commenced 30 min after smoking. Significant effects of THC and alcohol were found, but no interaction. Greatest impairments were evident for both THC doses combined with alcohol, and only minor and moderate after 100 and 200 μg/kg THC respectively. The impairment observed with alcohol and THC (200 μg/kg) was equivalent to that associated with a BAC of 0.14% (Robbe, 1998). Drivers took significantly longer to react to changes in the speed of the lead car (in car following) after the highest THC dose was combined with alcohol.

To summarise this work, Robbe (1994) himself concludes that his findings corroborate the findings from other simulator and on-road studies in that "THC in single inhaled doses up to 300 μg/kg has significant, yet not dramatic, dose-related impairing effects on driving performance." (p. 170). The effects of cannabis are indeed small because the participants attempt to compensate for the adverse effects of cannabis (Robbe, 1994). The participants were aware of the effects of cannabis as shown by the lower ratings of driving quality and higher ratings of perceived effort after smoking cannabis. However, despite compensating by increasing headway and slightly reducing mean speed, the participants were not completely able to compensate for the adverse effect on SDLP. Robbe (1994) suggests that this is because SDLP is primarily controlled by an automatic information processing system that operates beyond conscious control.

Finally, Robbe (1994) suggests that the compensatory effects of cannabis come at a cost to the driver. The increased ratings of perceived effort after smoking cannabis, perhaps by focussing attention, would lead to a reduction in spare capacity. So while drivers were able

to maintain some basic levels of driving skill (with the exception of increased SDLP) after using cannabis, they may not be equally able to perform in situations of higher mental load (Robbe, 1994). One of the clear messages to come from this research is that there is a need to research the effects of cannabis in situations where the driver is required to perform several tasks simultaneously or when confronted with a situation that requires a rapid adaptive response. This is one of the recommendations that Robbe makes in relation to future research.

In subsequent research in The Netherlands, Ramaekers et al. (2000) present the findings from a study that used a very similar methodology to that reported in the final study by Robbe (1998). Again, 18 participants attended six sessions across with the same two doses of alcohol and three of THC, and the same road tracking and car following tasks. Every drug combination increased SDLP from double placebo. While alcohol increased SDLP by 2.2 cm, THC doses of 100 and 200 μg/kg increased SDLP by 2.7 and 3.5 cm, and by 5.3 and 8.5 cm when taken with alcohol. While both alcohol and THC increased the time spent out of the lane (TOL), only alcohol with THC 100 and 200 μg/kg significantly increased TOL compared to placebo. Alcohol and THC 200 μg/kg significantly increased RT in the car following task, however mean headway remained stable across conditions. While alcohol increased standard deviation of headway (SDH), THC doses of 100 and 200 μg/kg increased SDH by 2.9 and 3.8 m without alcohol, and by a statistically significant (although smaller) amount with alcohol. Note, SDH reflects ability to perceive changes in the relative velocities of other vehicles and ability to adjust own speed accordingly. While alcohol and THC both significantly increased ratings of intoxication, the highest ratings were found for the two alcohol-THC combinations.

In summary, the Ramaekers et al. (2000) study shows that while alcohol and THC both impaired performance on the road tracking task, the combination of alcohol and THC impaired performance to a greater extent, equivalent to the impairment associated with alcohol to the 0.09-0.14% level. Drivers all seemed well aware of their impairment.

In the most recent study from the research group based in the Netherlands, Lamers & Ramaekers' (2001) final study, 16 participants drove in city traffic over four sessions with combinations of alcohol placebo or 0.05% BAC, and THC placebo or 100 μg/kg, administered in a double-blind crossover design (Lamers & Ramaekers, 2001). In a similar methodology to that described by Robbe (1998), participants smoked 70 min and consumed alcohol 25 min prior to a 40 min city driving task (deemed to more demanding that highway driving). The 15 km route covered turns at intersections, lane changes, and responses to traffic signals. Eye movements were recorded, and a driving instructor in the front seat rated the drivers' performance in accordance with a modified version of the Dutch Driving Proficiency Test. Performance on the driving test was not affected by drug condition. The frequency of visual search for traffic at intersections was similar for placebo, alcohol alone, and THC alone conditions, but reduced significantly for alcohol & THC. In accordance with some previous research, this finding was interpreted as corresponding to the drivers being less able to respond to peripheral traffic while maintaining performance on the central driving task. The very low dose of THC administered in this study should be noted.

3.3.3 Summary

In her comprehensive review of the effects of cannabis on simulator and on-road performance, Smiley (1986) concluded that people experiencing the effects of cannabis appear to be aware of their impairment and where possible they compensate by, for

example, slowing down, focussing attention and not taking risks (like overtaking). However, this compensation is not possible when the driver encounters unexpected events and/or when the driver is placed in situations requiring increased mental load or continuous attention (Robbe, 1994; Smiley, 1986).

Discussions of compensation aside, recent research is continuing to show that cannabis, both alone and with alcohol, impairs aspects of driving performance. The predominant form of impairment observed after smoking cannabis alone is an increase in lane weaving behaviour. Use of cannabis alone has also been associated with increased variability in headway to a lead vehicle. This is an important finding because it is commonly interpreted as reflecting the ability to perceive changes in the relative velocities of other vehicles and the ability to adjust one's own speed accordingly, which is suggestive of impaired perceptual abilities. Cannabis has also been found to lead to increased reaction time to respond in an emergency decision-making task.

When cannabis is combined with alcohol, variability of headway is again increased, and variability in lane weaving behaviour is increased to a greater extent than for cannabis alone, which is again indicative of impaired performance. Furthermore, drivers with both cannabis and alcohol take significantly longer to react to changes in the speed of the lead car (in car following), which is suggestive of a decrease in safety. To illustrate, the combination of a moderate dose of alcohol and cannabis is found to produce impairment to a level observed at a BAC of 0.14%. Finally, the frequency of visual search for traffic at intersections has been found to be similar for placebo, alcohol alone, and cannabis alone, but reduced significantly for alcohol & cannabis. In accordance with some previous research, this finding suggests that drivers are less able to respond to peripheral traffic while maintaining performance on the central driving task.

It is important to note that there are methodological concerns that continue to manifest in some studies of the effects of cannabis on driving. For several years there has been concern that the levels of cannabis used in experimental research are much lower than those used by moderate to heavy recreational users. Furthermore, different measures of driving performance show different effects. For example, while use of cannabis has been found to impair vehicle control (lane weaving) and headway (Ramaekers et al., 2000; Robbe, 1998), no effect has been found on brake reaction time (Liguori, Gatto, & Jarrett, 2002; Liguori, Gatto, Jarrett, & Vaughn McCall, 2003). However, because in this later study, as in many others, THC levels in bodily samples were not measured, it is difficult to reach a firm conclusion about the extent of cannabis-related impairments to performance.

4. MEASURING CANNABIS USE AT THE ROADSIDE

The literature reviewed in previous sections has demonstrated that cannabis is present to different degrees in samples of drivers who are suspected of driving under the influence of drugs and/or alcohol or who are injured, and that cannabis does impair many aspects of simulator and on-road driving performance. From an enforcement viewpoint, it is important to examine how to detect drivers who are driving under the influence of drugs such as cannabis.

Broadly speaking there are two approaches that are being researched and used world-wide to detect drug use, including cannabis use, at the roadside. The first, and the one that is very actively being researched, is the ability to screen for drugs in different samples. The major samples under investigation are blood, urine, sweat, and saliva. The second approach is to determine drug-related impairment by measuring performance on standardised tests. Both of these approaches are being used for law enforcement in Victoria (see Swann, Boorman, & Potter, 2004).

4.1 MEASURING CANNABIS USE IN BODILY SPECIMENS

Much research world wide is being directed toward the development of a reliable measure of drug use that can be used in the field, and the majority of this research is taking place in Europe. The samples that can potentially be used to conduct drug analyses are blood, urine, sweat, saliva, and hair (Dolan, Rouen, & Kimber, 2004: Samyn, Viaene, Vandevenne, & Verstraete, 1999). Blood sampling represents the most accurate means for conducting drug analyses, however it is not a practical means of testing for drug use in the field such as at mining sites or on the roadside. Aside from the practical issues of mass screening drivers and taking blood in the field, it takes at least 24 hours to obtain a blood drug screen, which is not suitable for roadside screening purposes. Furthermore, there is still much that remains unclear about the relationship between blood levels of a drug such as cannabis and subsequent performance levels. Even less is known about the relationships between levels of drugs in other specimens and performance levels. It is known however that recent cannabis use is indicative of performance impairment. The majority of effort is being directed towards evaluating saliva-based measures of drug use. Saliva has also been identified as the preferred specimen by police forces and experts across the European Union (Moeller et al., 1999).

One of the issues that complicates the measurement of drug use in alternative samples is the pharmacokinetics of each individual drug. Each drug is metabolised in different ways and is present in different proportions in different specimens (Kidwell, Holland, & Athanaselis, 1998). For example, THC is present in high levels in blood but only in very low levels in saliva (Kintz, Cirimele, Mairot, Muhlmann, & Ludes, 2000; Samyn & van Haeren, 2000). As a consequence, a specimen that may be a good measure of recent drug use for one drug may not necessarily also be a good measure of recent drug use for other drugs. The following discussions focus on the detection of cannabis in alternative samples.

4.1.1 Urine analysis

While urine drug screening is an effective means for detecting recent use of drugs such as heroin (Cone, Welch, Mitchell, & Paul, 1991), it is not a good measure of recent cannabis use. Although many other metabolites are excreted in urine, it is the inactive carboxy-metabolite (THC-COOH) that serves as a target for urine drug testing. The presence of THC-COOH in urine is useful as a marker for previous cannabis use, but not as an

indicator of recent use and impairment (Crouch, Frank, Farrell, Karsch, & Klaunig, 1998; Rebekah, Crouch, & Cook, 2000; Samyn, 2000; Towt et al., 1995; Wennig et al., 1998). For example, chronic use of cannabis can be detectable for more than 30 days post-use (Cone, 1993). There is also substantial variation in urine THC-COOH levels between subjects and between doses (Huestis, Mitchell, & Cone, 1996). Several urine tests are now available that provide results within minutes, and a full inventory of available devices, accompanied with evaluation data, has been published (Samyn et al., 1999). These devices still cannot detect *recent* cannabis use reliably, and it is probable that this will not be possible through analysis of urine.

4.1.2 Hair analysis

Many studies have examined the efficacy of hair analysis as a means of measuring drug use (Cooper et al., 2000; Montagna, Stramesi, Vignali, Groppi, & Polettini, 2000; Quintela et al., 2000; Ricossa, Bernini, & Ferrari, 2000; Tagliaro et al., 2000). While it may be useful for forensic testing post-mortem, hair testing is unlikely to be a very useful means of measuring drug use at the roadside. Aside from the practical issues of hair analysis being conducted at the roadside, analysis of drug use in hair samples will only indicate the long term exposure or use of drugs (Spiehler, 2000). For example, in an Outreach Program in the United States, hair analysis confirmed that a much higher proportion of the client group had used cocaine than did urine analysis (which is more indicative of recent cocaine use)(Martinez et al., 1993). It is also difficult to determine details of the time of use and the dose used (Wennig, 2000). The presence of a drug in a hair sample is therefore not necessarily going to be indicative of any drug-related impairment. Furthermore there is a six to eight hour time lag between use of a drug and the appearance of traces of that drug in hair. The majority of the drug detectable in hair does not appear until one to two weeks after drug use, after the hair shaft containing the drug grows beyond the surface of the skin (Spiehler, 2000). It is also not known how age, gender, ethnicity, and various hair treatments affect drug levels in hair (Wennig, 2000). A combination of these factors means that hair analysis of drugs is not likely to be a practical and valid measure of drug use in the field.

4.1.3 Sweat analysis

While drugs detectable on the skin surface can be excreted from sweat glands, they can also be excreted via sebaceous glands or transdermal liquid transport (Sachs, 2000). There are two general sweat testing procedures. In the first, sweat was typically collected by sweat patches that remained in contact with the skin for 1-7 days, and then the sweat was extracted for toxicological analysis. The second form of testing involves analysis of samples within minutes through the use of on-site devices such as Drugwipe which can screen for drugs in sweat within minutes.

A review of the applications of the Drugwipe screening device for sweat testing has been published (Mura et al., 2000). Drugwipe has been used to collect sweat from the forehead, the palm, the armpit, and the neck or back. A lack of sensitivity was reported for all four drug classes examined (opiates, cannabis, amphetamines, cocaine). The proportion of false negatives was 27% for opiates, 75% for cannabinoids, 37% for amphetamines, and 24% for cocaine. To a smaller extent, false positives have also been found for cannabinoids (11%) and cocaine (10%), but this was associated with collection of sweat from the armpit. As was the case for saliva, Mura et al. (2000) suggested that, until new antibodies with a higher sensitivity for THC or opiates are developed, the Drugwipe should not be considered as a good tool for on-site detection of drugs of abuse in sweat.

Drugs may remain present for up to three weeks in sweat, and so it is not possible to pinpoint the time of drug consumption and there the period of impairment. It has been suggested that while sweat testing may be an appropriate means drug screening for prisoners on weekend leave, it is likely to be of little use for roadside testing (Sachs, 2000).

4.1.4 Analysis of oral fluid

Oral fluid was identified as the preferred specimen for roadside drug screening in the European Union several years ago (Moeller et al., 1999), and it remains the preferred medium (Verstraete, 2004). Preferably, devices should provide clear and unambiguous test results within five minutes. The five drug types identified in Europe, in order of decreasing priority, were cannabis, benzodiazepines, amphetamines, cocaine, and opiates. A device was preferred that could screen for these five drug types as part of the one test (Moeller et al., 1999).

As noted previously by other authors, there have been few published evaluation studies of oral fluid screening devices (e.g., Walsh, de Gier, Christopherson, & Verstraete, 2004; Verstraete, 2004). An early model of the RapiScan device was evaluated in Melbourne by comparing three mechanisms of examining drug use by injecting drug users, who are known to be consumers of a variety of drugs (Lenné et al., 2000). The three methods examined were: (1) self-report; (2) blood drug screens; and (3) saliva screening through the use of a saliva sampling device. The Rapiscan device produced by Cozart Bioscience Limited was used to test saliva samples with 5-drug panels (Catalogue No. CZR500, Lot Number 19471, Exp 07/2000). These drug panels allowed screening for the following five drug types as part of the one test; opiates, benzodiazepines, cannabis (THC), cocaine, and amphetamines. While THC was found in the blood of 10 of the 13 participants who reported recent use of cannabis (six hours prior), there were no positive saliva results using the RapiScan device. At the time of conducting this study the device cut-off for THC was 600 ng/ml. It was recommended that further work be done refining the device to improve the sensitivity to THC. European data also suggested that early models of this device lacked the sensitivity to reliably detect THC in oral fluid (Verstraete & Puddu, 2000). It should be noted that the sensitivity of these devices is constantly improving.

The early models of the Drugwipe screening test have also been evaluated in several studies conducted in the late 1990's. While very few false positives or negatives were found when testing for cocaine and amphetamines, a high rate of false positives was found for opiates (35%). The results for cannabinoids were the poorest with high proportions of false negatives (40%) and a false positive rate as high as 28% in one study (see Mura et al., 2000). The detection limits of the device for THC were however not specified. Again using an early model Drugwipe device, a study by Samyn and van Haeren (2000) sampled 27 participants who displayed signs of intoxication, of whom 15 reported recent use of cannabis. The stated surface sensitivity of the device was 50 ng/ml for THC. Samyn and van Haeren (2000) reported three false positives and nine false negatives from the 15 who reported recent cannabis use. It was suggested at that time that new antibodies with a higher sensitivity for THC were required to improve the Drugwipe test for cannabis (Mura et al., 2000; Samyn & van Haeren, 2000).

The majority of research has been conducted in Europe as part of a large research program that focussed on roadside drug testing. This work, part of the ROSITA project, examined the relationship between levels of drugs in blood, urine, and saliva, using a range of drug screening devices, in nearly 3,000 samples (Verstraete, 2000; Verstraete & Puddu, 2000). This research confirmed that oral fluid testing is the most promising alternative to blood

screening for drugs, but concluded that tests available at that time were not satisfactory. There is much effort is being directed towards the development of drug screening tests, and advances in technology are improving the detection limits of the devices. It is timely therefore that a new program of evaluation has commenced under the ROSITA-2 project (Verstraete, 2004). Newer on-site oral fluid tests are being evaluated across six countries in Europe and five states in the United States through a series of laboratory and field-based evaluations. Preliminary data from some laboratory evaluations in the United States are published. The experimental protocol involved challenging each device with a low, medium, and high concentration of the target drug, as well as a drug-free control. Known levels of drugs were added to samples of oral fluid in this laboratory-based study (for further details on experimental protocol see Walsh, Flegel, Crouch, Cangianelli, & Baudys, 2003). The results showed that three of the six oral fluid tests evaluated (Uplink, cut-off 25 ng/ml; Drugwipe, cut-off 30 ng/ml; RapiScan, cut-off 150 ng/ml) could reliably detect THC at the high level (50 ng/ml), and importantly no false positives were reported (Walsh, Flegel, Crouch, & Cangianellil, 2004). The results from the field-based evaluations from ROSITA-2 are yet to be published. A laboratory-based testing program of oral fluid screening devices for THC and methamphetamine has recently been undertaken in Victoria (Swann et al., 2004). The authors of the present report are unaware of any published data from this program.

Other authors have noted the requirement for published evaluations of oral fluid screening devices, and the need to improve the sensitivity for detection of THC (Walsh, de Gier, et al., 2004; Verstraete, 2004). Ongoing research and development in the area of drug detection will lead to continued rapid improvements in the sensitivity of these devices in the near future.

4.2 MEASURING DRUG IMPAIRMENT USING PERFORMANCE TESTING

As discussed in the preceding section, developing an accurate and validated test to screen for drugs at the roadside has been challenging. Law enforcement has therefore had to seek alternative means for establishing driving impairment in the field. In Victoria, the Standardised Field Sobriety Tests (SFST) were introduced. Performance on these tests, accompanied by blood drug screens and roadside assessments, is used to determine whether a person had been driving while impaired by a drug (see Wylie & Swann, 2000). The implementation of such legislation was recommended in a 1996 Parliamentary Road Safety Committee report (Victorian Parliamentary Road Safety Committee, 1996). Data from 2002 suggest that 96% of the drivers (n=100) who failed the SFST were positive for one or more drugs, while 30% were positive for THC (Gerostamoulos, McCaffrey, Drummer, & Odell, 2002).

The SFST battery was developed by the National Highway Traffic Safety Administration (NHTSA) in the United States. It was introduced in 1981 to help determine whether drivers who were suspected of driving while intoxicated had BACs greater than 0.10%. The SFST is now used in all 50 states in the United States. It includes the horizontal gaze nystagmus test, the one leg stand test, and the walk and turn test (Stuster & Burns, 1998).

Using the SFST battery, recent research has also shown that police officers can estimate whether a driver has a BAC above 0.08% with as high as 94% accuracy. Furthermore, the officers could estimate whether a drivers' BAC was above 0.04% but below 0.08% in 94% of the decisions to arrest (Stuster & Burns, 1998). It was suggested by Stuster and Burns (1998) that the SFST battery was clearly valid to discriminate above or below 0.08%, and

that results strongly indicated that that SFST could also accurately discriminate above or below 0.04%.

While the SFST battery has been used in the US to test for alcohol impairment, it has been expanded to the Drug Recognition Expert (DRE) Program. This program encompasses a greater number and range of tests than the SFST, and enables police officers to determine whether or not a driver is impaired by drugs (other than alcohol), and then to determine the type of drug causing the observable impairment (Burns, 1986; Burns & Adler, 1995; Kosnoski, Yolton, Citek, Hayes, & Evans, 1998; Page, 2000).

The DRE Program is a 12 step process that, in the year 2000, was used across 34 states in the US (see Page, (2000) for further details). The first step is conducted by a police officer (a breath test), however the remaining 11 stages are performed by an expert. Based upon interview, physical tests, performance tests, and toxicology results, the DRE forms an opinion of whether the driver is impaired by drugs other than alcohol. The DRE can then attribute the observable impairment to the consumption of one of seven drug categories: CNS depressants (including alcohol), inhalants, phencyclidine (PCP), cannabis, CNS stimulants, hallucinogens, and narcotics.

The DRE program has been evaluated in two experimental studies (Heishman, Singleton, & Crouch, 1996, 1998). In the first study, 28 DREs were required to assess 18 participants who were given alcohol (0, 0.28. & 0.52 g/kg), cocaine (4, 48, & 96 mg/70kg), and cannabis (0, 1.75, & 3.55% THC). When the DRE's concluded that the participants were impaired by drugs other than alcohol, their conclusions were consistent with the toxicology results in only 44% of cases (Heishman et al., 1996). However, individual measures in the test were used to accurately predict the administration of alcohol, cocaine, and cannabis. While predictive validity was optimal when 17-28 of the 100 variables were considered, high accuracy (80 to 92%) was achieved when using a five variable model. This suggests that predictions of impairment may be improved if the DREs focussed on a subset of variables associated with each drug class (Heishman et al., 1996).

In the second study 48 participants were given three doses of alprazolam, d-amphetamine, codeine, or cannabis (n=12 for each drug group). When DREs concluded that a participant was impaired, their decisions were consistent with the administration of any active drug class in 76% of cases, but consistent with toxicology in 32% of cases. Consistency with toxicology was highest for cannabis (45.2%). Hence, while the DREs were able to detect drug-induced impairment, they experienced difficulty discriminating between the drug classes. It was suggested that accuracy might be improved if the DRE program focussed on key variables identified by mathematical models. It must be noted however that fewer cues indicative of drug use were available to the DREs in these experimental settings compared to in the field (such as the observation of impaired driving, the presence of drugs or drug-related equipment in car, or the smell of a drug such as cannabis). The DREs in the study were also not allowed to interview the participants as they would have in the field (drivers will often admit drug use when interviewed). Accuracy in these experimental settings is therefore likely to be reduced compared to accuracy in the field. Nonetheless, the DRE program is hailed as a great success in the United States (Heishman et al., 1998). While there is certainly room for improved accuracy with these testing procedures, it should be acknowledged that finding a series of tests that are sensitive to such a diverse range of drug effects is a challenging task.

5. CONCLUSION

There are a significant number of Australians, and particularly young Australians, who are using cannabis. Recent surveys suggest that over half of all young males in Australia report ever having used cannabis, and just under half report using recently. Cannabis is also prevalent in meaningful proportions of drivers randomly screened at the roadside, in drivers suspected of driving under the influence of drugs, and in injured drivers. While it remains unclear to what extent members of the community and recreational cannabis users drive while impaired by cannabis, there is some evidence that regular cannabis users drive very frequently at times in which they are highly likely to be impaired, that is, immediately after using or while using cannabis. Furthermore, there is evidence that heavy drug users are not aware of the potentially impairing effects of drugs, alone, and in combination, on driving skills, and that they would not change their drug use and driving behaviour if tougher drug-driving legislation were introduced. Clearly there is a need for the development of a long-term educational program targeted towards attitudinal change amongst drug users who drive. Further research is also required to understand the extent of drug driving in the wider community.

Recent advances in analytical methods of drug detection have been able to differentiate between cannabinoids and THC, which has enabled researchers to demonstrate increased crash culpability associated with the recent use of cannabis. Nevertheless, there remains a need to conduct large epidemiological studies to further understand the prevalence of drugs such as cannabis in both the general driving community and crash involved drivers.

The review of the effects of cannabis on simulated and on-road driving highlights the complex effects that cannabis exerts on driving skills. Taken in isolation, some changes in behaviour, such as a reduction in average speed, have been linked to the notion that drivers are able to compensate, to an extent, for the effects of cannabis. It is important however to focus on a wider range of performance measures. Cannabis typically impairs lateral placement, resulting in a greater degree of lane weaving, and produces greater variability in headway. This latter finding is important because it is commonly interpreted as reflecting the ability to perceive changes in the relative velocities of other vehicles and the ability to adjust speed accordingly, and is suggestive of impaired perceptual abilities. The effects of cannabis alone on other variables such as reaction time and decision time, in the context of driving, are less clearly defined. This review, and others (e.g., Ramaekers et al., 2004) have concluded that cannabis does impair aspects of driving performance. When cannabis is combined with alcohol, driving ability is impaired to a greater extent than for cannabis alone, as indicated through measures of vehicle control and responses to other vehicles. The combination of a moderate dose of alcohol and cannabis has been reported to produce impairment similar to that observed at a BAC of 0.14%.

As previous researchers have suggested, it is critical to examine the effects of cannabis when the driver in placed in situations involving increased mental load. This represents a shift in the experimental research away from looking simply at the effects of cannabis on traditional measures of driving performance such as lateral placement and speed, and a move towards supplementing traditional measures with investigation of the effects of cannabis when a driver is placed in an unexpected high accident risk situation that requires an immediate decision and response. Furthermore, it is not known how cannabis affects inexperienced and experienced drivers in these situations. These issues are being further addressed in a simulator study that is being conducted by the Department of Psychology and MUARC.

Many different methods of drug detection are actively being researched. Saliva screening is the most favoured approach to detecting cannabis use in the field. Saliva drug screening for field use offers practical advantages over other forms of drug screening such as blood, urine, hair, and sweat testing. Furthermore, a critical advantage is that the psychoactive component of cannabis and the indicator or recent cannabis use, THC, can be detected in saliva. While preliminary published data suggest that some devices can detect THC at accepted levels (50 ng/ml or less), a recent European report has noted, at the time of publication, the need for further published evaluations of oral fluid screening devices, particularly to improve the sensitivity for detection of THC (Verstraete, 2004). Ongoing research and development in the area of drug detection will lead to continued rapid improvements in the sensitivity of these devices.

In light of the extent of cannabis use, the prevalence of cannabis in various driver samples, the evidence of the impairing effects on driving, and the emphasis worldwide on establishing enforcement regimes for driving while impaired, it is important that further research continues to enhance the understanding of the road-safety implications of drug use.

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