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A cannabis reader: global issues and local experiences

Perspectives on cannabis controversies, treatment and regulation in Europe

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Chapter 9
Cannabis use and driving: implications for public health and transport policy

Keywords: cannabis – driving – DUIC – road safety – roadside testing

Setting the context

While cannabis has been a topic of research interest for many years, it has only been recently that the issue of cannabis and road safety has been the subject of a substantial amount of public and government interest. In Europe, the subject has received considerable attention in recent years. An EMCDDA literature review on the effects of drug use on driving, originally published in 1999, was updated in 2007, while a selected issue on drugs and driving formed part of the 2007 *Annual report*. At the European Member State level, numerous initiatives have been carried out on drugs and driving, including specific interventions to reduce driving under the influence of cannabis. For example, in France a major research and prevention campaign ([1]) was launched in 2006, while a supporting study estimated that cannabis accounted for an additional 230 annual road deaths in France, with a significant proportion of these deaths affecting young people under 25 (French national report, 2005). A survey into drug use in recreational settings in the Czech Republic ($n = 1\,010$) found that 56% of respondents reported driving under the influence, a higher rate than for alcohol (41%) (Czech Republic national report, 2005).

From a law enforcement perspective, a number of European countries have tightened drug driving laws in the past decade, for example to stipulate mandatory toxicological tests in the case of fatal accidents or to enable roadside drug testing. Furthermore, increased traffic controls for drug driving have been tested, although approaches vary — controls typically take the form of behavioural 'sobriety' tests and/or device-based 'quick' screening (typically, saliva testing), which are later validated with urine and/or blood analyses (EMCDDA, 2007). Yet, the 'operationalisation' of penalties in a similar

([1]) See www.cannabisetconduite.fr for information on the campaign, together with supporting studies.

way to the blood alcohol concentration (BAC) limits commonly used for drink driving is not as commonplace in Europe for cannabis as in the USA (Grotenhermen et al., 2005). Exceptions exist, however: Belgium and Luxembourg, for example, use a threshold of 2 ng THC/mL blood (Belgian national report, 2006; Luxembourg Ministry of Transport, 2007). Some states in the USA also provide blood THC concentrations to guide judicial practice.

Thus, driving under the influence of cannabis (DUIC) has become an increasingly important issue from a public policy and road safety perspective. Available evidence suggests that while the prevalence of DUIC in the general population is relatively low (Walsh and Mann, 1999), it is substantially higher in important subgroups of the population, in particular young, male drivers (Lenne et al., 2004). Among users of cannabis, and in particular those who seek treatment for cannabis problems, 50% or more may report DUIC at least once in the previous year (Albery et al., 1999; Macdonald et al., 2004a). As well, among young drivers in North America at least, the prevalence of DUIC is similar to or higher than the prevalence of driving after drinking (Adlaf et al., 2003; Asbridge et al., 2005).

While no data on trends in DUIC over time are available, if cannabis use increases in the population DUIC, it is likely that DUIC will increase as well. Thus, there is a clear need to assess the evidence on the impact of cannabis use on collision risk, in order to provide an evidence-based perspective to discussions of the magnitude of the DUIC problem and the need for legislative or programme action. The principal objective of this chapter is to examine critically the findings connecting cannabis and traffic crashes, and a second objective is to consider the problems in developing methods to assess cannabis impairment for legal purposes.

Further reading

Blows, S., Ivers, R., Connor, J., Ameratunga, S., Woodward, M., Norton, R. (2005), 'Marijuana use and car crash injury', *Addiction* 100: 605–611.

Fergusson, D. (2005), 'Marijuana use and driver risks: the role of epidemiology and experimentation', *Addiction* 100: 577–578.

Grotenhermen, F., Leson, G., Berghaus, G., Drummer, O., Krüger, H., Longo, M., Moskowitz, H., Perrine, B., Ramaekers, J., Smiley, A., Tunbridge, R. (2005), 'Developing science-based per se limits for driving under the influence of cannabis (DUIC). Findings and recommendations by an expert panel', International Association for Cannabis as Medicine.

Lenne, M., Triggs, T., Regan, M. (2004), *Cannabis and road safety: a review of recent epidemiological, driver impairment, and drug screening literature*, Monash University Accident Research Centre, Victoria.

Cannabis use and driving: implications for public health and transport policy

Robert E. Mann, Gina Stoduto, Scott Macdonald and Bruna Brands

Impairment: effects of cannabis on performance

A substantial amount of information has accumulated on the effects of cannabis on human performance. Of particular interest here are those studies most relevant to the possible effects of the drug on driving behaviour. According to Maes et al. (1999), research measures can be grouped in the following categories: attention tests (simple and divided attention); vigilance tests (ability to sustain attention); auditory and visual tests (visual acuity, accommodation to darkness/light); reaction time (simple and choice reaction time); cognitive tests (e.g. digit/symbol substitution test, Stroop word/colour test, letter cancellation test); memory tests; mental arithmetic; flicker fusion test; visual–motor coordination tests; body sway; physiological measurements (EEG, eye movements, pulse, blood pressure); and self-awareness measures. Additionally, studies may involve simulated or actual driving tasks.

Several comprehensive reviews of this literature have emerged, and the results appear to be very consistent. A consistent conclusion is that the acute effect of moderate or higher doses [2] of cannabis impairs the skills related to safe driving and injury risk. Moskowitz (1985) concluded that marijuana use impairs driver performance under a variety of experimental conditions. Berghaus and Guo (1995) conducted a meta-analysis of 60 studies and concluded that marijuana causes impairment of every performance area connected with safe driving of a vehicle, such as tracking, psychomotor skills, reaction time, visual functions, and attention. Of these performance criteria, the most deterioration from marijuana use was found for measures of attention (e.g. the continuous performance task), tracking (e.g. the pursuit rotor task) and psychomotor skills (e.g. simple reaction time) (Coambs and McAndrews, 1994; Berghaus and Guo, 1995). Similar conclusions have been reached by other reviews (Hollister, 1981; Maes et al., 1999; Smiley, 1999; Ashton, 2001; O'Kane et al., 2002; Ramaekers et al., 2004; Lenne et al., 2004). Some authors have postulated that the various cognitive impairments mentioned previously are related to duration of drug use (Hall and Solowij, 1998). Johns (2001) notes that cannabis use can occasionally result in short-term

[2] See Corrigan, this monograph, for a discussion of dosage and the pharmacology and pharmacodynamics of cannabis.

psychiatric distress and even psychotic states, and that cannabis may provoke relapse and aggravate existing symptoms in people with major mental illnesses such as schizophrenia. In addition, potential withdrawal effects of heavy, long-term cannabis use, such as restlessness, insomnia, and anxiety, could also influence injury risk (Ashton, 2001).

Smiley (1999) concluded that marijuana impairs skills and ability. She speculated that drivers are aware of this impairment, which may prompt them to slow down and drive more cautiously, suggesting that experienced cannabis users can compensate for the deleterious effects of cannabis on driving skills. This compensation for the effects of the drug is a form of tolerance to its effects. Tolerance is defined as a reduction in response to a particular dose of a drug with repeated administration, or the requirement that larger amounts are needed to obtain the same drug effect (Kalant et al., 1971). Tolerance to cannabis over repeated administrations is observed in animal studies with cannabis (Ashton, 2001), but little systematic research on cannabis tolerance in humans is available. When considering the extent to which tolerance to cannabis might influence drivers, it is useful to consider possible parallels between tolerance to cannabis and tolerance to alcohol. Tolerance is observed for both drugs, and substantial research has addressed the issue of alcohol tolerance in humans (e.g. Vogel-Sprott, 1992). The impairing effect of alcohol on psychomotor tasks is readily observed. However, under conditions where reinforcement is provided for non-impaired performance, tolerance will develop over a series of drinking sessions (Mann and Vogel-Sprott, 1981; Beirness and Vogel-Sprott, 1984), and the extent of tolerance development is related to awareness of impairment and efforts to compensate (Mann et al., 1983). Nevertheless, impairment returns when reinforcement contingencies are withdrawn (Mann and Vogel-Sprott, 1981; Zack and Vogel-Sprott, 1993). This return of impairment indicates that even tolerant or experienced users will display impairment of psychomotor performance. Thus, the same process that Smiley (1999) suggested may alleviate performance deficits in experienced cannabis users has been extensively studied with human subjects in laboratory research with alcohol. These studies indicate that even in those who learn to compensate for a drug's impairing effects, substantial impairment in performance can still be observed under conditions of general task performance (i.e. when no contingencies are present to maintain compensated performance).

Other researchers have investigated the effects of cannabis combined with alcohol on laboratory performance measures. These studies have been stimulated in part by the apparent frequency with which both drugs are used together (Cimbura et al., 1990; Jonah, 1990; Stoduto et al., 1993; Walsh and Mann, 1999). In general, these studies typically, but not always, reveal that the effects of cannabis plus alcohol are greater than the effects of cannabis alone (Liguori et al., 2002; Chait and Perry, 1994). The research suggests that the effects of combining cannabis with alcohol on skills necessary for safe driving such as visual search and road tracking are either additive, in which the effects of both drugs together are roughly equivalent to adding the effects of the

two together, or multiplicative, in which the effects of the two drugs together are greater than the effects of the two individually (e.g. Robbe, 1998; Laemers and Ramaekers, 2001). In reviewing this literature, O'Kane et al. (2002) observed that alcohol's effects are strongest on integrative tasks while the effects of cannabis are strongest on tasks requiring attention and psychomotor skills.

Epidemiological studies on collision risk associated with cannabis use

Epidemiological studies are necessary to assess the impact of cannabis use on collision risk. In the past two decades, several studies have been published on the involvement of cannabis in collisions. In this review of the literature, conclusions from three types of studies will be drawn: (i) descriptive and analytical epidemiological studies on the prevalence of cannabis use through drug testing in injured drivers; (ii) studies of collision risk of clinical samples of cannabis users; and (iii) studies of collision risk among general populations of drivers. The purpose of this section is to review the available empirical research in order to assess the risks that cannabis may pose for traffic collisions. This assessment of risk is central to our understanding of the role of cannabis in traffic safety.

Studies using drug tests of injured drivers to detect cannabis metabolites

Studies that obtained drug tests of urine, blood or saliva from injured drivers are included in this section. Also included are studies of special populations where drug tests were taken of drivers suspected of driving under the influence or of reckless driving. A large number of descriptive studies have been conducted where the blood or urine of injured drivers has been analysed for the presence of cannabis metabolites. Thirty-two studies were found. The research methodologies and results in terms of the proportion testing positive for cannabis metabolites are described in Table 1.

There have been many epidemiological studies that have reported drug tests of fatally and non-fatally injured drivers. The percentage of fatally injured drivers testing positive for cannabis ranged from 1.4 to 27.5% (mean = 10.7%); while for non-fatally injured drivers the percentage ranged from 5 to 15.7% (mean = 11.5%) (Macdonald et al., 2003). The prevalence rates for cannabis are highest for the special driver populations, that is, those suspected of drug or alcohol impairment or reckless driving. The percentage of impaired or reckless drivers testing positive for cannabis ranged from 7.4 to 65.9% (mean = 34.6%).

Although many studies have been conducted on the prevalence of positive drug tests among injured drivers, few studies incorporated control groups so that assessments

Table 1: Summary of study results on the percentage of injured drivers testing positive for cannabis

Reference	Jurisdiction	Consent required	% positive cannabis	Comparison group
Brookoff et al. (1994)	Memphis, Tennessee, USA	No	33%	No
Budd et al. (1989)	Los Angeles, California, USA	No	19.6% (preliminary), 18.5% (follow-up)	No
Christopherson et al. (1990)	Norway	No	31.5%	No
Cimbura et al. (1990)	Ontario, Canada	No	10.9% — drivers; 7.6% — pedestrians	No
Crouch et al. (1993)	Salt Lake City, Utah, USA	No	13%	No
Drummer (1995)	Melbourne, Australia	No	11%	Yes; drivers not responsible
Drummer et al. (2003)	Australian states: Victoria, New South Wales and Western Australia	No	13.5% fatally injured drivers	No
Dussault et al. (2002)	Quebec, Canada	No for fatal drivers; yes for controls	19.5% for fatal drivers; 6.7% for controls	Yes
Everest and Tunbridge (1990)	England and Wales	No	2.6%	No
Fortenberry et al. (1986)	Alabama, USA	No	11% — drivers; 5% — passengers; 1% — pedestrians	No
Holmgren et al. (2005)	Sweden	No	33 cases positive for THC	No
Kintz et al. (2000)	Strasbourg, France	No	9.6%	No
Laumon et al. (2005)	France	No	At-fault drivers — 8.8%; control drivers — 2.8%	Yes; 3006 not-at-fault fatally injured drivers

Study group	Comments
150 drivers stopped for reckless driving	12% positive for both cocaine and cannabis. 18.7% positive for alcohol (0.03–0.21 mg/dL)
Preliminary study: 102 fatally injured drivers. Follow-up study: 492 fatally injured drivers	18.6% positive for alcohol + cocaine/cannabis/ both (preliminary). 16.2% positive for alcohol + cocaine/cannabis/both (follow-up)
3159 drivers suspected of driving under the influence of alcohol and drugs	One or more drugs present in 67%
1169 fatally injured drivers, 225 fatally injured pedestrians (aged 14 or over)	9.2% positive for cannabis + alcohol (drivers). 5.8% positive for cannabis + alcohol (pedestrians)
168 fatally injured truck drivers	Impairment due to cannabis use in all cases where THC level exceeded 1.0 ng/mL 2.3% positive cannabis + alcohol. 20% of accidents positive for drugs had driver fatigue
1045 fatally injured drivers, 1990–93	Responsibility analysis conducted. No statistical significance for cannabis
3398 fatally injured drivers, 1990–99	11.8% positive for car drivers; 22.2% positive for motorcycle drivers; 6.5% positive for truck drivers; 15.9% positive for single vehicle crash; 11.1% positive for multiple vehicle crash; 10.9% positive for 1990–93; 13.5% positive for 1994–6; 15.6% positive for 1997–9
354 fatally injured drivers; 11952 roadside controls	Fatalities were significantly associated with positive tests for cannabis in the case–control study. No significant relationship was found for the responsibility analysis. Selection bias due to the 49.6% response rate of providing a urine sample for the control group could have inflated the odds ratios
1273 fatalities (drivers, passengers, motorcycle drivers, pedestrians)	8.3% of those positive for drugs were also positive for alcohol (> 0.08 mg/100 mL)
510 fatally injured drivers, passengers, and pedestrians with urine samples	8.8% positive for both cannabis + alcohol
855 fatally injured drivers	
198 injured drivers (car, motorcycle, truck, bicycle) aged 13–57	
6766 at-fault fatally injured drivers	Cannabis increased fatal collision risk in a dose-related manner after controlling for alcohol, age, type of vehicle and time of crash

Table 1: Summary of study results on the percentage of injured drivers testing positive for cannabis (continued)

Reference	Jurisdiction	Consent required	% positive cannabis	Comparison group
Logan and Schwilke (1996)	Washington State, USA	No	11%	No
Longo et al. (2000a,b)	Australia	No	10.8%	Yes; non-culpable drivers
McBay (1986)	Los Angeles, California, USA	No	13.4%	No
McLean et al. (1987)	Tasmania, Australia	No	6% of total sample	Yes; 387 blood donors
Marquet et al. (1998)	France	No	drivers — 13.9%; patients — 7.6%	Yes; 278 non-injured patients, aged 18–35
Mason and McBay (1984)	North Carolina, USA	No	7.8%	No
Mercer and Jeffery (1995)	British Columbia, Canada	No	13%	No
Movig et al. (2004)	The Netherlands	Yes	12% hospitalised drivers; 6% controls	Yes; 816 roadside survey controls
Mura et al. (2003)	France		10% of drivers, 5% of controls	Yes; 900 controls admitted to emergency room of six hospitals
Orsay et al. (1994)	Chicago, Illinois, USA	No	7.4% of total sample	Yes; 300 non-impaired, injured drivers
Peel and Jeffrey (1990)	Canada	No	20% of impaired drivers	No
Poklis et al. (1987)	St Louis, Missouri, USA	No	47%	No
del Rio and Alvarez (2000)	Northern Spain	No	1.4%	No
Risser et al. (1998)	Vienna, Austria	Yes	47% of 19 samples in 1993; 72% of 99 samples in 1996	No
Seymour and Oliver (1999)	Strathclyde, Scotland	No	39% of impaired drivers	Yes; 151 fatally injured drivers

Study group	Comments
347 fatally injured drivers	10% positive for alcohol + drugs; 15% positive for drugs alone; 63% of cannabis users positive for alcohol
2500 injured drivers admitted to an ER	7.1% tested positive for cannabis-only. Blood tests taken — most drivers who tested positive for THC acid, the inactive metabolite
2610 fatally injured drivers	2.8% of drivers were positive for cannabis without any other drug; 28% positive for drugs + alcohol
194 road users (42 fatally injured, 37 accident survivors, 115 breath-tested drivers/riders)	8% of those positive for alcohol (> 0.5 g/L) had also used cannabis. Non-significant differences in drug use between groups
296 injured drivers, aged 18–35	Prevalence of cannabis among female drivers was significantly higher than for female patients ($P < 0.05$)
600 fatally injured drivers	11% positive for alcohol + drugs; 2.8% positive for drugs alone
227 fatally injured drivers	11% positive for alcohol + drugs
110 injured drivers admitted to hospital	Urine/blood test determined drug positivity. 39% of injured drivers had urine test versus 85% of controls had urine test. Effect of cannabis on risk of injury accident not significant
900 injured (non-fatal) drivers	10% injured drivers positive for THC, 5% of controls positive for THC. Among under-27-year-olds, cannabis increased collision risk significantly
285 alcohol or drug-impaired, injured motorists and motorcyclists	Impaired drivers had higher injury severity scores than control drivers ($P < 0.001$). Impaired drivers more frequently involved in collisions, cited for moving violations; found to be at fault
492 cases: 94 injured; 172 impaired and 226 fatally injured drivers	Of 53 impaired drivers, 4% positive for cannabis
137 drug positive DUI drivers, Jan. 1983 to May 1986	32 different drugs detected
285 fatally injured drivers	Of all positive for drugs, 19.6% were also positive for alcohol
205 reckless drivers from 1993 to 1996, aged 17–24 years. 199 car drivers; six motorcycle drivers	Increase in cannabis use increased significantly over time ($P < 0.05$)
752 drivers suspected of being impaired	Drugs were present in 19% of fatally injured drivers; polydrug use was prevalent; alcohol detected in 33%

Table 1: Summary of study results on the percentage of injured drivers testing positive for cannabis (continued)

Reference	Jurisdiction	Consent required	% positive cannabis	Comparison group
Soderstrom et al. (1995)	Baltimore, Maryland, USA	No	12%	No
Stoduto et al. (1993)	Toronto, Ontario, Canada	No	13.9%	No
Sugrue et al. (1995)	Sydney, Australia	No	15.2% drivers (> 100 ng/dL); 8% cyclists (> 200 ng/dL); 13% passengers (> 200 ng/dL); 14% pedestrians (> 200 ng/dL)	No
Terhune and Fell (1982)	Washington DC, USA	No	10%	No
Williams et al. (1985)	California, USA	No	37%	No

of relative risks could be estimated. The best methodological studies are analytic epidemiological studies that utilise the case–control method (Meulemans et al., 1996; Marquet et al., 1998; Dussault et al., 2002; Mura et al., 2003). However, these studies are very difficult to conduct, and other investigators have used methods based on analysis of crash responsibility (e.g. Drummer, 1995; Longo et al., 2000a,b; Dussault et al., 2002; Drummer et al., 2004) (see Table 1). The logic of these studies is that if a drug increases collision risk, drivers under the influence of the drug are more likely to be considered responsible for the collision based on police reports (Terhune and Fell, 1982).

In a case–control study conducted in France, 296 injured drivers at emergency room departments and 278 non-injured control patients matched by age were urine tested for the presence of cannabis (Marquet et al., 1998). Methodologically, this study is unique among case–control studies in the field because consent was not required for urine tests of either cases or controls and, therefore, the results are free of selection biases. Results indicated that drivers testing positive for cannabis were not significantly more likely than controls to be involved in collisions. However, when the analyses were restricted to women only, the relationship became significant (Marquet et al., 1998).

Findings of another case–control study have recently been reported for 354 fatally injured drivers and 5931 roadside controls in Quebec (Dussault et al., 2002). The odds ratio was statistically significant and indicated that fatally injured drivers were 2.2 times

Study group	Comments
1338 injured (1077 car drivers; 261 motorcyclists)	
339 injured drivers admitted to trauma unit (291 car drivers; 48 motorcyclists)	16.5% positive for alcohol + drugs
Total 262 (164 injured drivers, 12 pedal cyclists, 31 pedestrians, 55 passengers)	16% positive alcohol + drugs
500 injured drivers	25% positive for alcohol
440 fatally injured male drivers aged 15–34	Percentage of crash responsibility increased significantly from zero drugs to two or more detected drugs ($P > 0.001$); 81% of cannabis users positive alcohol

more likely to test positive for cannabis than controls. However, this result should be treated cautiously owing to the possibility of systematic bias in the study. Little bias is likely for the proportion testing positive among the fatal drivers (19.5%); however, for the control group, consent was required by participants to provide a urine test. Only 49.6% of controls agreed to provide a urine sample. The authors used saliva samples to assess the degree of possible bias, with the rationale that the reason drivers refused both urine samples and saliva sample would be the same (fear of detection). The participation rate for saliva tests was 84.6%, which suggests that a large proportion of people found urine tests more invasive. The high rate of refusal to provide a saliva test indicates that the results should be interpreted with caution.

Meulemans et al. (1996) conducted a study where urine tests were taken from injured drivers at emergency rooms in Belgium. The authors examined injury severity of those in crashes. Being positive for cannabis metabolites was not significantly related to injury severity.

Mura et al. (2003) conducted toxicological tests on blood samples from 900 drivers involved in a non-fatal collision and 900 controls attending emergency rooms for non-traumatic reasons in France. Younger drivers (under 27) with cannabis alone in their blood were significantly more likely to be involved in collisions (OR = 2.5). This was somewhat less than the OR associated with alcohol alone (3.8), and when alcohol and cannabis were combined the OR for collision involvement increased to 4.6.

Several Australian studies have used responsibility analysis techniques and also had access to blood samples. Blood samples permit analyses of both the active and inactive ingredients of tetrahydrocannabinol (THC) and are the best approach for determining likely cannabis impairment. Longo et al. (2000a,b) obtained drug tests from 2 500 injured drivers. Their analysis found no significant differences in the degree of culpability associated with cannabis-positive compared with cannabis-negative drivers. Drummer (1995) examined the blood samples of driver fatalities linked with traffic reports in an Australian study. Similarly, he found no significant elevation of collision risk associated with cannabis use. More recently, Drummer et al. (2003, 2004) reported a responsibility analysis of 3 398 drivers killed in collisions in the Australian states of Victoria, New South Wales and Western Australia. Cannabis alone increased the likelihood of involvement in a fatal collision in a dose-related manner. The odds ratio (OR) for fatal collision involvement for those positive for cannabis only was 2.7; however, when analyses were restricted to those with concentrations greater than 5 ng/mL, the OR rose to 6.6.

A recent study from France employed responsibility analysis methods with a large sample of fatally injured drivers for whom blood samples were available. Laumon et al. (2005) reported on 10 748 drivers killed in France between October 2001 and September 2003. Blood levels of Δ^9-tetrahydrocannabinol were compared in 6 766 drivers considered to be at fault for their collisions and 3 006 drivers, selected from the 3 982 other drivers, not considered to be at fault. These authors found that cannabis increased risk of involvement in a fatal collision in a dose-related manner, after controlling for presence of alcohol, age, type of vehicle and time of crash. The adjusted odds ratio for fatal collision involvement associated with blood levels of 5 ng/mL or over was 2.12. As well, these authors estimated that 2.5 % of fatal crashes in France could be attributable to cannabis.

Studies using clinical samples of cannabis abusers in treatment

The characteristics of studies using clinical samples of cannabis users in treatment are summarised in Table 2. We know from existing studies that clinical substance abuse populations are likely to drive after using cannabis. In one study, of a sample of 210 users in treatment for heroin dependency, 58 reported driving after drug use, and 62 % of these reported driving at least once after using cannabis (Albery et al., 1999). In a study of those in treatment for alcohol, cannabis or cocaine abuse, 63 % reported driving after use of cannabis (Macdonald et al., 2004a).

Few studies exist that examine collision risks experienced by clinical samples of individuals receiving treatment for cannabis. In the first of these studies, Smart et al. (1969) observed elevated collision rates in abusers of one or more drugs other than

Table 2: Studies of self-reported drug use and injuries in clinical samples

Reference	Jurisdiction	Comparison group	Research objective	Study group	Comments
Albery et al. (1999)	London, England	No	Examine collision rates among 210 out-of-treatment drug users	210 out-of-treatment drug users	62.1% of cannabis users drove at least once after using the drug; frequency of driving after using drugs was not significantly related to collisions
Macdonald et al. (2004b)	Toronto, Canada	Yes	What is the collision risk of cannabis abuse clients in treatment compared with population controls?	Treatment clients with a primary drug problem of cannabis, matched population controls	The cannabis clients had significantly more collisions before and after treatment
Mann et al. (1993)	Toronto, Canada	No	Examine the contribution of drug use to accident rates	144 male substance users, aged 21–40	50% of the accidents that occurred in the past 5 years occurred under the influence of alcohol and/or drugs
Mann et al. (1995)	Toronto, Canada	Yes	Evaluate the effects of substance abuse treatment on accident rates	137 males, aged 21–40, who were in treatment for substance use.	There were significant declines in number of accidents ($P < 0.05$), drinking–driving convictions ($P < 0.001$) and moving violations ($P < 0.001$) after treatment
Smart et al. (1969)	Toronto, Canada	Yes	Investigate accident rates of abusers of one or more drugs other than alcohol	30 psychiatric patients	Patients had an overall accident rate 1.9 times larger than the expected rates

alcohol, but the sample was very small ($n = 30$). In another study of 144 male substance abusers aged 21–40, Mann et al. (1993) examined collision rates in the year before entry into treatment and compared these rates to collision rates in the general male population of the same age. The subjects estimated that about 50% of their collisions in the preceding year occurred while they were under the influence of alcohol and/or drugs. As well, results suggested that the frequency of any substance use, as opposed to the use of specific substances, predicted collision involvement and significant post-treatment reductions were found in moving violations, DWI convictions, and total collisions (Mann et al., 1995).

A recent study examined the driving records of a large sample of cannabis abuse clients in treatment (Macdonald et al., 2004b). This study utilised blind linkage procedures a note to explain this method to avoid non-respondent bias, and compared the clinical sample to a randomly selected, frequency-matched (age, gender, location) control group of drivers. Significant elevations in collisions were found for abusers of cannabis compared with population controls, both prior and after treatment (Macdonald et al., 2004b). While this study demonstrates an association between cannabis abuse and elevated collision risk, alternative explanations for this relationship cannot yet be ruled out.

Studies using general populations of drivers

Recently, Asbridge et al. examined the impact of self-reported DUIC on collision risk among high-school students in the four Atlantic provinces of Canada. These authors observed a significant elevation of collision risk (OR = 1.84) among students who reported DUIC, after controlling for demographic factors, driver experience, and self-reported driving after drinking. Similarly, Mann et al. (2005) examined the association of collision risk with DUIC among a representative sample of adults surveyed in Ontario. Reporting DUIC in the past year increased significantly the odds of reporting a collision, after controlling for age, gender and other demographic variables (OR = 2.61).

General discussion of cannabis and collision risk

Early reviews of the literature on the association of cannabis use with collision risk concluded that conclusive demonstrations of cannabis use as risk factor for collisions did not exist (Robbe and O'Hanlon, 1993; Ferrara et al., 1994; Chesher, 1995; Christopherson and Morland, 1997; Hunter et al., 1998; Bates and Blakely, 1999; de Gier, 2000; Morland, 2000; Vingilis and Macdonald, 2002; Macdonald et al., 2003). However, more recent studies clearly suggest that cannabis use increases collision risk (e.g. Dussault et al., 2002; Mura et al., 2003; Drummer et al., 2004; Laumon et al., 2005;). Recent reviews of this literature are reflecting this growing body of studies finding a collision-enhancing effect of recent cannabis use (e.g. Kalant, 2004).

Numerous epidemiological studies have been found where drug tests were conducted of injured drivers. Early analytical epidemiological studies that used responsibility analysis or case–control methods did not provide clear proof that cannabis use is related to increased injury risk from collisions (Bates and Blakely, 1999). These studies often have poor statistical power because the presence of drug metabolites is relatively rare and large sample sizes are required to detect significant effects. To demonstrate that a relationship exists, much larger sample sizes are likely required with methodological approaches free of biases that could inflate odds ratios.

Several methodological issues complicate the use of some types of drug tests. For example, urine test results cannot be used to measure drug impairment, only whether drug use occurred sometime in the past, up to a few weeks for cannabis (Kapur, 1994). Since urine tests are detecting those that are not under the influence of cannabis, the measure lacks specificity and, therefore, extremely large sample sizes may be needed to find a statistically significant increase in collision rates for those testing positive. Blood tests offer a more promising approach for the assessment of whether drivers are more likely to be under the influence; however, because of their more intrusive nature, they may only be feasible for studies using responsibility analysis of fatally injured drivers. Few studies that use drug tests have control groups, thereby making it difficult to determine whether drug presence is a risk factor. The likely reason few studies include controls is that consent from this group is usually required. Consent is likely to discourage the participation of drug users more than non-users, which would translate into inflated relative risks or odds ratios. Some studies have used comparison groups of pedestrians; however, this approach is likely too conservative because the pedestrian could also be at fault.

Some studies have noted that different drugs are used in combination with each other, possibly resulting in increased risk for injury. Drug metabolites, for example, are often found in combination with alcohol. Therefore, it is important to separate out the relative role of other drugs from alcohol. Although many studies reported the proportion of collisions that involve alcohol, research has largely failed to separate out the role of alcohol from cannabis in collisions.

Under these circumstances other means to assess the contribution of cannabis to collision risk are useful. One approach is to examine collision risks of known heavy users of cannabis, such as people in treatment for a cannabis abuse problem. A recent study found cannabis clients have significantly elevated rates of collisions compared with population controls (Macdonald et al., 2004b). Another approach is to examine collision risks associated with self-reported DUIC in survey data. Recent studies have found that collision risks are significantly elevated in samples on adolescents and adults who report DUIC (e.g. Asbridge et al., 2005). However, studies of clinical groups or survey samples are limited in their ability to draw causal inferences, or to control for potential

confounders. Other factors may be causally related to both drug use and collisions. Recent studies and reviews on set variables, such as aggression (Beirness, 1993; Deffenbacher et al., 2000; Wiesenthal et al., 2000; Gidron et al., 2001), risk-taking/impulsiveness (Beirness, 1993; Jonah, 1997; Vavrik, 1997), stress (Veneziano and Veneziano, 1992; Simon and Corbett, 1996; Norris et al., 2000), fatigue (Horstmann et al., 2000; Masa et al., 2000; Connor et al., 2001) and criminality (Wells-Parker et al., 1986; Denison et al., 1997) confirm the importance of these characteristics in predicting collisions. Studies have found that many of the characteristics described above are over-represented in substance abuse populations, which might also explain higher collision rates. Withdrawal effects from cannabis, such as exhaustion, anxiety, agitation, mood swings and depression, and long-term effects of abuse, such as chronic sleep disruption, distractibility and depression (Cohen and Sas, 1993; Coambs and McAndrews, 1994; Herscovitch, 1996) could also increase risks.

One of the strengths of studies of clinical and survey samples is the accessibility and validity of information gathered. Although these studies suffer from the same limitations as survey studies of non-clinical samples, the biases related to self-reports are likely much less pronounced in the clinical samples. Since those who seek treatment have already acknowledged that they have a problem, they are more likely to provide accurate accounts regarding that problem. Good validity of self-reports has been established among substance users both during and after treatment (Hindin et al., 1994; Nelson et al., 1998).

Detecting cannabis in drivers

The availability of accurate and simple-to-use breath tests for alcohol have been central to current efforts to reduce drink driving (Mann et al., 2001). There has been a continued interest in the development of a breath test for cannabis over the years, but to date no scientifically validated tests have been reported (Verstraete, 2000). Blood tests are the 'gold standard' for assessing levels of cannabis and metabolites in the body. Results of blood tests can be influenced by such factors as the temperature at which the sample is stored and binding to the inner surface of plastic vials (O'Kane et al., 2002). The logistic and legal issues involved in obtaining and testing blood samples from drivers suspected of DUIC are complex.

As noted earlier, the mere presence of cannabis in plasma may not indicate impairment. A current focus of research is to identify a relationship between THC in blood (and other body fluids) and behavioural change, drug influence and impairment (Martin and Cone, 1999). This has led to the suggestion that *per se* levels of cannabinoids in plasma may be identified for legal purposes, similar to the identification of *per se* levels for alcohol (Martin and Cone, 1999). Ramaekers et al. (2004), in considering this question, note

that meta-analyses of laboratory studies indicate that maximal performance impairment is seen at THC concentrations greater than 14 ng/mL in plasma or 7 ng/mL in whole blood. However, they note that the link between these levels and elevated collision risk has not been absolutely established.

Urine tests are used in situations where any relatively recent use of cannabis and other drugs is of interest (e.g. in sports, in addictions treatment), regardless of whether that use occurred in the previous few hours, days or even weeks. However, urine tests do not permit an accurate assessment of when drug use occurred (Kapur, 1994). A driver who has a positive urine test for cannabis may have used the drug in the preceding hours or days (or even weeks), and, thus, his or her driving skills may not be influenced by the drug at the time the sample is taken.

The detection of cannabinoids in saliva and sweat has been an active area of research. Current kits to measure saliva involve taking a swab from the mouth and include a rapid detection kit (O'Kane et al., 2002). Available data suggest that saliva THC levels arise from a drug that has remained in the mouth during smoking or ingestion, and initial data suggest that these levels are associated with degree of impairment observed (Menkes et al., 1991). The EU has run two projects, Rosita-1 and Rosita-2, to examine technology for enabling roadside drug screening. The first Rosita project in 1999–2000 established criteria for acceptable tests (sensitivity and specificity > 90 %, accuracy > 95 %) for amphetamines, benzodiazepines and cannabis. As rapid screening in a roadside situation should aim to be as non-invasive as possible, the Rosita-2 project aimed to evaluate the useability and analytical reliability of nine on-site oral fluid (saliva) drug testing devices between 2003 and 2005. Six European countries and four states in the USA took part. At the end of the period, none of those devices met the criteria proposed during the Rosita-1 project. Six devices registered a failure rate of greater than 25 %. The procedure of obtaining the saliva samples varied greatly in terms of handling, quantities and acceptance by officials testing and persons tested, sometimes easy to perform, sometimes difficult to follow.

Assessing behavioural effects of cannabis

There has been substantial recent interest in programmes involving the training of police officers and others to detect the physiological and behavioural effects of cannabis in individuals suspected of DUIC, and research on this topic is beginning to appear. Drug recognition expert (DRE) programmes have been developed to enable police officers to identify an individual who may be under the influence of a drug. These indicators can range from pupil size and body sway to the presence of drug paraphernalia in the vehicle. Walsh and Cangianelli (2002) reported that, in drivers suspected of driving under the influence of drugs (DUID) by DRE-trained police officers, subsequent blood

testing revealed that 32.5% were positive for at least one drug other than alcohol. This low level of sensitivity improved to 79.3% when officers were subsequently given an improved training programme. Tzambazis and Stough (2002) presented evidence that cannabis-induced impairment of performance on behavioural tests (standardized field sobriety tests, SFSTs) was significantly correlated with impairment of driving. Similarly, Papafotiou et al. (2004) showed that impairment of SFST performance increased with increasing dose of cannabis.

Driving under the influence of cannabis legislation in Europe

Currently, European Union countries have legal provisions on driving under the influence of drugs but impairment must be proven in court in most countries (Moeller et al., 1999; EMCDDA, 2007). Germany (in 1998), Belgium (in 1999), Sweden (in 1999; Jones, 2004) and Finland (in 2003; Lillsunde et al., 2004) passed laws that allow for sanctions based on detection of drugs alone and other countries have proposed similar laws. This type of legislation depends on the police force's authority to collect human specimens at the roadside for testing or for confirmatory analysis, and this authority is regulated by other legislation that differs by jurisdiction. Some countries allow the police to control and test the public randomly and suspicion is not necessary for testing. However, the majority of countries treat roadside testing as an infringement of civil rights and suspicion is necessary for testing. Some countries have improved the process for initial suspicion by training the police to identify intoxicated drivers on the basis of physical and psychomotor signs.

Germany and Belgium currently use roadside testing devices routinely (sweat and urine are collected) and some countries have used urine or saliva or sweat test devices on an experimental basis with the driver's consent. Very few European countries have regulations prohibiting the use of roadside drug testing devices. However, many do not use these devices because of concerns regarding their validity or because of their unavailability. The preferred test is a single use, multi-parameter test, which is able to provide a clear, unambiguous test result within 5 minutes. According to Moeller et al. (1999), saliva is the preferred test specimen for cannabis due to its easy availability, low invasiveness and good correlation with impairment. Sweat was the second in preference because it allows testing without collaboration of the driver, and its low invasiveness and good availability at the roadside. Roadside drug screening is being trialled in a number of European Member States at the time of writing (EMCDDA, 2007). There have been some teething issues. For example, tests carried out in France in the summer of 2007 used three different devices and required the presence of a doctor for validating a urine sample. Introduction of *Drugwipe* saliva tests in Luxembourg in 2007 required explicitly by the Transport Ministry that the tests would not serve to incriminate drivers taking

legal medicines ([3]). Portuguese police reported problems with a faulty batch of *Oratec-3* testing kits. Nonetheless, there is commitment at ministerial level to introducing saliva-based drug testing across many Member States.

Conclusions

The impact of cannabis on traffic safety is an issue of substantial public and political interest at present and will likely continue to be of interest for some time. As has become clear in this review, there is a substantial amount of information available that can shed light on this issue, but in many areas the available evidence is sparse or unclear.

First, it appears clear that, in laboratory settings, cannabis impairs the skills thought to be necessary for safe driving. This impairment is not restricted to high levels of the drug (see earlier note that this dosage level may need some explanation) and occurs at the dosage levels that result from typical use of the drug. Tolerance may occur with continued use, but even individuals who have acquired tolerance to some of the effects of cannabis may demonstrate impairment on task performance. Combining alcohol with cannabis will result in an increase in the effects of cannabis, and the interaction could be multiplicative.

After alcohol, cannabis is the drug most often found in fatally and non-fatally injured drivers. In recent, studies cannabis has been found in up to 27.5% of dead drivers (Macdonald et al., 2003). However, epidemiological studies employing control groups are necessary to identify more precisely the contribution of the drug to collision causation. While earlier reviews of the literature were unable to conclude that cannabis increased collision risk, more recent studies employing larger samples and more rigorous methods are demonstrating with more consistency that recent cannabis use will increase collision risk (e.g. Mura et al., 2003; Drummer et al., 2004; Laumon et al., 2005). Studies employing clinical samples or using survey data provide additional indications of an increase in collision risk associated with cannabis use, however, in these studies the possibility that the increased risk may be due to factors other than the effects of cannabis cannot yet be ruled out.

Central to the problems of assessing the impact of cannabis on collision risk and to the problem of detecting cannabis-impaired drivers is the problem of measuring the presence of cannabis in the body. Difficulties in measuring cannabis in the body have hampered research on the effects of cannabis and the potential development of legal initiatives to address cannabis-impaired driving. Research is now assessing issues of dose–response effects on skills and behaviour. As well, measures that may assist in the

([3]) See www.gouvernement.lu/salle_presse/communiques/2007/10/03lux/

detection of DUIC (saliva tests, DRE programmes, standardized field sobriety tests) show promising results in field trials.

While much information is now available, there is a clear need for more research to determine the degree and nature of the association between cannabis use and collision risk. The impact of several variables on the cannabis–collision risk relationship needs to be examined, including personality characteristics such as risk-taking, aggression, criminality and stressful life events. Additional research to discover and validate easily administrable measures of cannabis use and impairment is also needed. Nevertheless, recent research has provided a much clearer picture of the contribution of cannabis to collision risk than was available only a few years ago.

Bibliography

Adlaf, E.M., Mann, R.E., Paglia, A. (2003), 'Drinking, cannabis use and driving among Ontario students', *Canadian Medical Association Journal* 168(5): 565–566.

Albery, I., Strang, J., Gossop, M., Griffiths, P. (1999), 'Illicit drugs and driving: prevalence, beliefs and accident involvement among a cohort of current out-of-treatment drug users', *Drug and Alcohol Dependence* 58: 197–204.

Asbridge, M., Poulin, C., Donato, A. (2005), 'Motor vehicle collision risk and driving under the influence of cannabis: evidence from adolescents in Atlantic Canada', *Accident Analysis and Prevention* 37: 1025–1034.

Ashton, C. (2001), 'Pharmacology of cannabis: a brief review', *British Journal of Psychiatry* 178: 101–106.

Bates, M., Blakely, T. (1999), 'Role of cannabis in motor vehicle crashes', *Epidemiologic Reviews* 21(2): 222–232.

Beirness, D. (1993), 'Do we really drive as we live? The role of personality factors in road crashes', *Alcohol, Drugs and Driving* 9(3–4): 129–143.

Beirness, D., Vogel-Sprott, M. (1984), 'Alcohol tolerance in social drinkers — operant and classical conditioning effects', *Psychopharmacology* 84: 393–397.

Berghaus, G., Guo, B. (1995), 'Medicines and driver fitness — findings from a meta-analysis of experimental studies as basic information to patients, physicians and experts', in Kloeden, C. N., McLean, A. J. (eds), *Alcohol, drugs, and traffic safety — T'95*, University of Adelaide, Adelaide, Australia, 295–300.

Brookoff, D., Cook, C., Williams, C., Mann, C. (1994), 'Testing reckless drivers for cocaine and marijuana', *New England Journal of Medicine* 331: 518–522.

Budd, R., Muto, J., Wong, J. (1989), 'Drugs of abuse found in fatally injured drivers in Los Angeles county', *Drug and Alcohol Dependence* 23: 153–158.

Chait, L., Perry, J. (1994), 'Acute and residual effects of alcohol and marijuana, alone and in combination, on mood and performance', *Psychopharmacology* 115: 340–349.

Chesher, G. (1995), 'Cannabis and road safety: an outline of the research studies to examine the effects of cannabis on driving skills and actual driving performance', in *The effects of drugs (other than alcohol) on road safety, incorporating collected papers*, Government Printer, Melbourne, LV North, 67–96.

Christopherson, A., Morland, J. (1997), 'Drugged driving, a review based on the experience in Norway', *Drug and Alcohol Dependence* 47: 125–135.

Christopherson, A., Gjerde, H., Bjorneboe, A., Sakshaug, J., Morland, J. (1990), 'Screening for drug use among Norwegian drivers suspected of driving under the influence of alcohol or drugs', *Forensic Sciences International* 45: 5–14.

Cimbura, G., Lucas, D. M., Bennet, R., Donelson, A. (1990), 'Incidence and toxicological aspects of cannabis and ethanol detected in 1394 fatally injured drivers and pedestrians in Ontario (1982–1984)', *Journal of Forensic Science* 35(5): 1035–1041.

Coambs, R., McAndrews, M. (1994), 'The effects of psychoactive substances on workplace performance', in Macdonald, S., Roman, P. (eds), *Drug testing in the workplace*, Plenum Press, New York.

Cohen, P., Sas, A. (1993), *Ten years of cocaine. A follow-up study of 64 cocaine users in Amsterdam*, University of Amsterdam, Amsterdam.

Connor, J., Whitlock, G., Norton, R., Jackson, R. (2001), 'The role of driver sleepiness in car crashes: a systematic review of epidemiological studies', *Accident Analysis and Prevention* 33(1): 31–41.

Crouch, D., Birky, M., Gust, S., Rollins, D., Walsh, J., Moulden, J., Quinlan, K., Beckel, R. (1993), 'The prevalence of drugs and alcohol in fatally injured truck drivers', *Journal of Forensic Sciences* 38: 1342–1353.

Deffenbacher, J., Huff, M., Lynch, R., Oetting, E., Salvatore, N. (2000), 'Characteristics and treatment of high-anger drivers', *Journal of Counseling Psychology* 47(1): 5–17.

Denison, M., Paredes, A., Booth, J. (1997), 'Alcohol and cocaine interactions and aggressive behaviors', in Galanter, M. (ed), *Recent developments in alcoholism, 13: alcohol and violence: epidemiology, neurobiology, psychology, family issues*, Plenum Press, New York, 283–303.

Drummer, O. (1995), 'A review of the contribution of drugs in drivers to road accidents', in *Inquiry into the effects of drugs (other than alcohol) on road safety in Victoria, Incorporating Collected Papers*, LV North, Government Printer, Melbourne, 1–28.

Drummer, O., Gerostamoulos, J., Batziris, H., Chu, M., Caplehorn, J. R. M., Robertson, M. D., Swann, P. (2003), 'The incidence of drugs in drivers killed in Australian road traffic crashes', *Forensic Science International* 134: 154–162.

Drummer, O., Gerostamoulos, J., Batziris, H., Chu, M., Caplehorn, J., Robertson, M. D., Swann, P. (2004), 'The involvement of drugs in drivers of motor vehicles killed in Australian road traffic crashes', *Accident Analysis and Prevention* 36: 239–248.

Dussault, C., Brault, M., Bouchard, J., Lemire, A. (2002), 'The contribution of alcohol and other drugs among fatally injured drivers in Quebec: some preliminary results', in Mayhew, D. R., Dussault, C. (eds), *Alcohol, drugs and traffic safety — T'2002*, Société de l'assurance automobile du Québec, Québec, 423–430.

EMCDDA (2007), *Annual report 2007. Selected issue on drugs and driving*, European Monitoring Centre for Drugs and Drug Addiction, Lisbon.

Everest, J., Tunbridge, R. (1990), 'The incidence of drugs in road accident fatalities in Great Britain', in Perrine, M. (ed.), *Alcohol, drugs, and traffic safety — T'89*, National Safety Council, Chicago, 595–601.

Ferrara, S., Zancaner, S., Snenghi, R., Berto, F. (1990), 'Psychoactive drug involvement in traffic accidents in Italy', in Perrine, M. (ed), *Alcohol, drugs, and traffic safety — T'89*, National Safety Council, Chicago, 260–264.

Ferrara, S., Giorgetti, R., Zancaner, S. (1994), 'Psychoactive substances and driving: state of the art and methodology', *Alcohol, Drugs and Driving* 10: 1–55.

Fortenberry, J., Brown, D., Shevlin, L. (1986), 'Analysis of drug involvement in traffic fatalities in Alabama', *American Journal of Alcohol Abuse* 12(3): 257–267.

Gidron, Y., Davidson, K., Illia, R. (2001), 'Development and cross-cultural and clinical validation of a brief comprehensive scale for assessing hostility in medical settings', *Journal of Behavioral Medicine* 24(1): 1–15.

de Gier, J. (2000), 'Review of European investigations of illicit drug prevalence in road traffic', in *Alcohol, drugs, and traffic safety — T'2000*, Stockholm, Sweden, 278.

Hall, W., Solowij, N. (1998), 'Adverse effects of cannabis', *Lancet* 352(9140): 1611–1616.

Herscovitch, A. G. (1996), *Cocaine: the drug and the addiction*, Gardner Press, New York.

Hindin, R., McCusker, J., Vickers-Lahti, M., Bigelow, C., Garfield, F., Lewis, B. (1994), 'Radioimmunoassay of hair for determination of cocaine, heroin, and marijuana exposure: comparison with self-report', *International Journal of the Addictions* 29(6): 771–789.

Hollister, L. E., Gillespie, H. K., Ohlsson, A., Lindgren, J.-E., Wahlen, A., Agurell, S. (1981), 'Do plasma concentrations of Δ^9 tetrahydrocannabinol reflect the degree of intoxication?' *Journal of Clinical Pharmacology* 21: 171S–177S.

Holmgren, P., Holmgren, A., Ahlner, J. (2005), 'Alcohol and drugs in drivers injured in traffic accidents in Sweden during the years 2000–2002', *Forensic Science International* 151: 11–17.

Horstmann, S., Hess, C. W., Bassetti, C., Gugger, M., Mathis, J. (2000), 'Sleepiness-related accidents in sleep apnea patients', *Sleep* 23(3): 383–389.

Hunter, C., Lokan, R., Longo, M., White, J., White, M. (1998), 'Appendices to: The prevalence and role of alcohol, cannabinoids, benzodiazepines and stimulants in non-fatal crashes', Forensic Science Department for Administrative and Information Services, South Australia.

Johns, A. (2001), 'Psychiatric effects of cannabis', *British Journal of Psychiatry* 178: 116–122.

Jonah, B. A. (1990), 'Age differences in risky driving', *Health Education and Research* 5: 139–149.

Jonah, B. A. (1997), 'Sensation seeking and risky driving: a review and synthesis of the literature', *Accident Analysis and Prevention*, 29(5): 651–665.

Jones, A. W. (2004), 'Update on Sweden's zero-concentration law for narcotic drugs in blood of drivers', in Oliver, J., Williams, P., Clayton, A. (eds), *Alcohol, drugs and traffic safety — T2004*, Scottish Executive, Glasgow, UK.

Kalant, H. (2004), 'Adverse effects of cannabis on health: an update of the literature since 1996', *Progress in Neuro-Psychopharmacology and Biological Psychiatry* 28(5): 849–863.

Kalant, H., Leblanc, A. E., Gibbins, R. J. (1971), 'Tolerance to, and dependence on, some non-opiate psychotropic drugs', *Pharmacological Reviews* 23: 135–158.

Kapur, B. (1994), 'Drug-testing methods and interpretations of test result', in Macdonald, S., Roman, P. (eds), *Drug testing in the workplace*, Plenum Press, New York.

Kintz, P., Crimele, V., Mairot, F., Muhlmann, M., Ludes, B. (2000), 'Drug tests in 198 drivers implicated in non-fatal traffic accidents', *Presse Medicale* 29(23): 1275–1278.

Laemers, C., Ramaekers, J. (2001), 'Visual search and urban city driving under the influence of marijuana and alcohol', *Human Psychopharmacology: Clinical and Experimental Research* 16: 393–401.

Laumon, B., Gadegbeku, B., Martin, J.-L., Biecheler, M.-B. and the SAM Group (2005), 'Cannabis intoxication and fatal road crashes in France: population-based case-control study', *British Medical Journal* 331: 1371–1376.

Lenne, M. G., Fry, C. L. M., Dietze, P., Rumbold, G. (2001), 'Attitudes and experiences of people who use cannabis and drive: implications for drugs and driving legislation in Victoria, Australia', *Drugs: Education, Prevention and Policy* 8(4): 307–313.

Lenne, M., Triggs, T., Regan, M. (2004), *Cannabis and road safety: a review of recent epidemiological, driver impairment, and drug screening literature*, Monash University Accident Research Centre, Victoria.

Liguori, A., Gatto, C., Jarrett, D. (2002), 'Separate and combined effects of marijuana and alcohol on mood, equilibrium and simulated driving', *Psychopharmacology* 163: 399–405.

Lillsunde, P., Gunnar, T., Mykkanen, S., Seppa, H. (2004), 'Zero tolerance law for drugs and driving in Finland — effects on annual statistics', in Oliver, J., Williams, P., Clayton, A. (eds), *Alcohol, drugs and traffic safety — T'2004*, Scottish Executive, Glasgow, UK.

Logan, B., Schwilke, E. (1996), 'Drug and alcohol use in fatally injured drivers in Washington state', *Journal of Forensic Science* 41(3): 505–510.

Longo, M., Hunter, C., Lokan, R., White, J. M., White, M. A. (2000a), 'The prevalence of alcohol, cannabinoids, benzodiazepines and stimulants amongst injured drivers and their role in driver culpability. Part I: The prevalence of drug use in drivers and characteristics of drug positive group', *Accident Analysis and Prevention* 32: 613–622.

Longo, M. C., Hunter, C. E., Lokan, R. J., White, J. M., White, M. A. (2000b), 'The prevalence of alcohol, cannabinoids, benzodiazepines and stimulants amongst injured drivers and their role in driver culpability. Part II: The relationship between drug prevalence and drug concentration, and driver capability', *Accident Analysis and Prevention* 32: 623–632.

McBay, A. (1986), 'Drug concentrations and traffic safety', *Alcohol Drugs and Driving* 2(3–4): 51–59.

Macdonald, S., Anglin-Bodrug, K., Mann, R., Erickson, P., Hathaway, A., Chipman, M., Rylett, M. (2003), 'Review: injury risk associated with cannabis and cocaine use', *Drug and Alcohol Dependence* 72: 99–115.

Macdonald, S., DeSouza, A., Mann, R., Chipman, M. (2004a), 'Driving behaviour of alcohol, cannabis and cocaine abuse treatment clients and population controls', *American Journal of Drug and Alcohol Abuse* 30: 429–444.

Macdonald, S., Mann, R., Chipman, M., Anglin-Bodrug, K. (2004b), 'Collisions and traffic violations of alcohol, cannabis and cocaine abuse clients before and after treatment', *Accident Analysis and Prevention* 36: 795–800.

McLean, S., Parsons, R. S., Chesterman, R. B., Dineen, R., Johnson, M. G., Davies, N. W. (1987), 'Drugs, alcohol and road accidents in Tasmania', *Medical Journal of Australia* 147(1): 6–11.

Maes, V., Charlier, C., Grenez, O., Verstraete, A. (1999), 'Drugs and medicines that are suspected to have a detrimental impact on road user performance' www.rosita.org/

Mann, R., Vogel-Sprott, M. (1981), 'Control of alcohol tolerance by reinforcement in nonalcoholics', *Psychopharmacology* 75: 315–320.

Mann, R., Vogel-Sprott, M., Genest, M. (1983), 'Alcohol and cognitions: some preliminary observations', *Journal of Studies on Alcohol* 44: 900–905.

Mann, R., Anglin, L., Vingilis, E., Larkin, E. (1993), 'Self-reported driving risks in a clinical sample of substance users', in Utzelmann, H. D., Berghaus, G., Kroj, G. (eds), *Alcohol, drugs and traffic safety — T'92*, TUV Rheinland, Cologne, Germany, 860–865.

Mann, R., Anglin, L., Rahman, S., Blessing, L., Vingilis, E., Larkin, E. (1995), 'Does treatment for substance abuse improve driving safety? A preliminary evaluation', in Kloeden, C. N., McLean, A. J. (eds), *Alcohol, drugs and traffic safety — T'95*, NHMRC Road Accident Research Unit, University of Adelaide, Adelaide, Australia, 817–820.

Mann, R., Macdonald, S., Stoduto, G., Bondy, S., Jonah, B., Shaikh, A. (2001), 'The effects of introducing or lowering legal per se blood alcohol limits for driving: an international review', *Accident Analysis and Prevention* 33: 569–583.

Mann, R., Adlaf, E., Zhao, J. (2005), 'Cannabis use, driving after cannabis use, and collision involvement in the Ontario adult population', paper presented at the conference 'Issues of Substance', Markham, Ontario, 13–16 November.

Marquet, P., Delpla, P.-A., Kerguelen, S., Bremond, J., Facey, F., Garnier, M., Guery, B., Lhermitte, M., Mathé, D., Pelissier, A.-L., Renaudeau, C., Vest, P., Seguela, J.-P. (1998), 'Prevalence of drugs of abuse in urine of drivers involved in road accidents in France: a collaborative study', *Journal of Forensic Sciences* 43(4): 806–811.

Martin, B., Cone, E. (1999), 'Chemistry and pharmacology of cannabis', in Kalant, H., Corrigall, W., Hall, W., Smart, R. (eds), *The health effects of cannabis*, Addiction Research Foundation, Toronto, 21–68.

Masa, J., Rubio, M., Findley, L. (2000), 'Habitually sleepy drivers have a high frequency of automobile crashes associated with respiratory disorders during sleep', *American Journal of Respiratory and Critical Care Medicine* 62(4): 1407–1412.

Mason, A., McBay, A. (1984), 'Ethanol, marijuana, and other drug use in 600 drivers killed in single-vehicle crashes in North Carolina, 1980–1981', *Journal of Forensic Science* 29(4): 987–1026.

Mason, A., McBay, A. (1985), 'Cannabis: pharmacology and interpretation of effects', *Journal of Forensic Science* 30: 615–631.

Menkes, D. B., Howard, R. C., Spears, G. F. S., Cairns, E. R. (1991), 'Salivary THC following cannabis smoking correlates with subjective intoxication and heart rate', *Psychopharmacology* 103: 277–279.

Mercer, G. W., Jeffery, W. K. (1995), 'Alcohol, drugs and impairment in fatal traffic accidents in British Columbia', *Accident Analysis and Prevention* 27(3): 335–343.

Meulemanns, A., Hooft, P., Van Camp, L., De Vrieze, N., Buylaert, W., Verstraete, A., Vansnick, M., Baumans, P., Bruynseels, P., Charlier, C., Corne, L., Decroix, O., Desmet, K., D'Orio, V., Fox, A., Haenecaert, G., Hardy, M. A., Hassoun, A., Hubloue, I., Millan, G., Leyssens, L., Maes, V., Martens, F., Sabbe, M., Vanhaute, O., Vergnion, M., Wauters, A., Wenning, R. (1996), *Belgian toxicology and trauma study: une étude portant sur la présence d'alcool, de médicaments et de drogues illicites chez des conducteurs victimes d'accidents de la route*, Toxicological Society of Belgium and Luxembourg.

Moeller, M., Steinmeyer, S., Aberl, F. (1999), *Operational, user and legal requirements across EU member states for roadside drug testing equipment*, University Homburg/Saar, Institute for Legal Medicine, Homburg, Germany.

Morland, J. (2000), 'Driving under the influence of non-alcohol drugs', *Forensic Science Review* 12(1): 80–105.

Moskowitz, H. (1985), 'Marihuana and driving', *Accident Analysis and Prevention* 17(4): 323–345.

Movig, K., Mathijssen, M., Nagel, P., van Egmond, T., de Gier, J., Leufkens, H., Egberts, A. (2004), 'Psychoactive substance use and the risk of motor vehicle accidents', *Accident Analysis and Prevention* 36: 631–636.

Mura, P., Kintz, P., Ludes, B., Goulier, J. M., Marquet, P., Martin-Dupont, S., Vincent, F., Kaddour, A., Goullé, J.-P., Nouveau, J., Mouslsma, M., Tihet-Courtet, S., Pourrat, O. (2003), 'Comparison of the prevalence of alcohol, cannabis and other drugs between 900 injured drivers and 900 control subjects: results of a French collaborative study', *Forensic Science International* 133: 79–85.

Nelson, D., Kotranski, L., Semann, S., Collier, K., Lauby, J., Feighan, K., Halbert, J. (1998), 'The validity of self-reported opiate and cocaine use by out-of-treatment drug users', *Journal of Drug Issues* 28(2): 483–494.

Norris, F., Matthews, B., Riad, J. (2000), 'Characterological, situational, and behavioral risk factors for motor vehicle accidents: a prospective examination', *Accident Analysis and Prevention* 32(4): 505–515.

O'Kane, C., Tutt, D., Bauer, L. (2002), 'Cannabis and driving: a new perspective', *Emergency Medicine* 14(3): 296–303.

Orsay, E. M., Doan-Wiggins, L. Lewis, R., Lucke, R., RamaKrishnan, V. (1994), 'The impaired driver: hospital and police detection of alcohol and other drugs of abuse in motor vehicle crashes', *Annals of Emergency Medicine* 24(10): 51–55.

Papafotiou, K., Carter, J., Stough, C. (2004), 'An evaluation of the sensitivity of the Standardised Field Sobriety Tests (SFSTs) to detect impairment due to marijuana intoxication', *Psychopharmacology* 180(1): 107–114.

Peel, H., Jeffrey, W. (1990), 'A report on the incidence of drugs and driving in Canada', *Canadian Society of Forensic Sciences Journal* 23: 75–79.

Poklis, A., Maginn, D., Barr, J. (1987), 'Drug findings in "Driving Under the Influence of Drugs" cases: a problem of illicit drug use', *Drug and Alcohol Dependence* 20(1): 57–62.

Ramaekers, J., Berghaus, G., van Laar, M., Drummer, O. (2004), 'Dose related risk of motor vehicle crashes after cannabis use', *Drug and Alcohol Dependence* 73: 109–119.

del Rio, M. C., Alvarez, F. J. (2000), 'Presence of illegal drugs in drivers involved in fatal road traffic accidents in Spain', *Drug and Alcohol Dependence* 57(3): 177–182.

Risser, D., Stichenwirth, M., Klupp, N., Schneider, B., Stimmpfl, T., Vycudilik, W., Bauer, G. (1998), 'Drugs and driving in Vienna', *Austria Journal of Forensic Sciences* 43(4): 817–819.

Robbe, H. (1998), 'Marijuana's impairing effects on driving are moderate when taken alone but severe when combined with alcohol', *Human Psychopharmacology: Clinical and Experimental Research* 13: S70–S78.

Robbe, H., O'Hanlon, J. (1993), *Marijuana and actual driving performance*, National Highway Traffic Safety Administration, US Department of Transportation, Washington DC, 9.

Seymour, A., Oliver, J. (1999), 'Role of drugs and alcohol in impaired drivers and fatally injured drivers in the Strathclyde police region of Scotland, 1995–1998', *Forensic Science International* 103(2): 89–100.

Simon, F., Corbett, C. (1996), 'Road traffic offending, stress, age, and accident history among male and female drivers', *Ergonomics* 39(5): 757–780.

Smart, R., Schmidt, W., Bateman, K. (1969), 'Psychoactive drugs and traffic accidents', *Journal of Safety Research* 1: 67–73.

Smiley, A. (1999), 'Marijuana: on-road and driving-simulator studies', in Kalant, H., Corrigall, W., Hall, W., Smart, R. (eds), *The health effects of cannabis*, Addiction Research Foundation, Toronto, 173–191.

Soderstrom, C., Dischinger, P., Kerns, T., Trifillis, A. (1995), 'Marijuana and other drug use among automobile and motorcycle drivers treated at a trauma center', *Accident Analysis and Prevention* 27(1): 131–135.

Stoduto, G., Vingilis, E., Kapur, B., Sheu, W.-J., McLellan, B., Liban, C. (1993), 'Alcohol and drug use among motor vehicle collision victims admitted to a regional trauma unit: demographic, injury, and crash characteristics', *Accident Analysis and Prevention* 25(4): 411–420.

Sugrue, M., Seger, M., Dredge, G., Davies, D., Ieraci, S., Baumann, A., Deane, S., Sloane, D. (1995), 'Evaluation of the prevalence of drug and alcohol abuse in motor vehicle trauma in south western Sydney', *Australia and New Zealand Journal of Surgery* 65(12): 853–856.

Terhune, K., Fell, J. (1982), 'The role of alcohol, marijuana and other drugs in the accidents of injured drivers', *Alcohol and Driving* 3(6): 3–6.

Tzambazis, K., Stough, C. (2002), 'The SFST and driving ability. Are they related?' in Mayhew, D., Dussault, C. (eds), *Alcohol, drugs and traffic safety — T'2002*, Société de l'assurance automobile du Québec, Quebec.

Vavrik, J. (1997), 'Personality and risk-taking: a brief report on adolescent male drivers', *Journal of Adolescence* 20(4): 461–465.

Veneziano, C., Veneziano, L. (1992), 'Psychosocial characteristics of persons convicted of driving while intoxicated', *Psychological Reports* 70(3): 1123–1130.

Verstraete, A. G. (2000), 'Perspectives for the detection of cannabis in breath', in *Alcohol, drugs and traffic safety — T'2000*, Economy Press, Stockholm, Sweden, 337–341.

Vingilis, E., Macdonald, S. (2002), 'Review: drugs and traffic collisions', *Traffic Injury Prevention* 3: 1–11.

Vogel-Sprott, M. (1992), *Alcohol tolerance and social drinking*, Guilford Press, New York.

Walsh, G., Mann, R. (1999), 'On the high-road: driving under the influence of cannabis in Ontario', *Canadian Journal of Public Health* 90: 260–263.

Walsh, J., Cangianelli, L. (2002), 'New training in detection of illicit drugs in drivers', in Mayhew, D. R., Dussault, C. (eds), *Alcohol, drugs and traffic safety — T'2002*, Société de l'assurance automobile du Québec, Québec.

Wells-Parker, E., Cosby, P., Landrum, J. (1986), 'A typology of drinking driver offenders: methods for classification and policy implications', *Accident Analysis and Prevention* 18(6): 443–453.
Wiesenthal, D., Hennessey, D., Gibson, P. (2000), 'The Driving Vengeance Questionnaire (DVQ): the development scale to measure deviant drivers' attitudes', *Violence Victimization* 15(2): 115–136.
Williams, A., Peat, M., Crouch, D. (1985), 'Drugs in fatally injured young male drivers', *Public Health Reports* 100: 19–25.
Zack, M., Vogel-Sprott, M. (1993), 'Response outcomes affect the retention of behavioural tolerance to alcohol: information and incentive', *Psychopharmacology* 113: 269–273.