Perspective

Drug Testing and Analysis

Received: 3 July 2012 Revised: 18 July 2012 Accepted: 18 July 2012 Published online in Wiley Online Library

(www.drugtestinganalysis.com) DOI 10.1002/dta.1404

Cannabis and psychomotor performance: A rational review of the evidence and implications for public policy

Paul Armentano*

Introduction

Public policy debates regarding cannabis law reform, such as those surrounding the limited use of the plant for therapeutic purposes or the broader issue of legalizing and regulating personal, non-medical cannabis consumption by adults, invariably invoke the question: 'How does society address the public's growing concerns about cannabis consumption and driving?' The subject is one that warrants a response, particularly by those advocating for various forms of cannabis liberalization and regulation. In 1996, the Board of Directors of the National Organization for the Reform of Marijuana Laws (NORML) acknowledged its opposition to the notion of operating of a motor vehicle while under the influence cannabis, ratifying a strict 'no driving' clause to the organization's 'Principles of Responsible Cannabis Use'. This provision states, 'Although cannabis is said by most experts to be safer with motorists than alcohol and many prescription drugs, responsible cannabis consumers never operate motor vehicles in an impaired condition.'[1]

Nevertheless, questions remain regarding the extent to which cannabis intoxication influences psychomotor performance and to what degree cannabis consumption may play a role in on-road traffic accidents.[2] Questions also persist regarding the implementation of sensible and effective public policies to better identify cannabis-influenced driving behaviour and, ideally, to deter persons from engaging in this activity. This paper will attempt to summarize much of the available contemporary literature in order to better address these concerns and provide suggestions for ways society can better implement rational and evidence-based policies to address and deter cannabis-influenced driving behaviour.

Discussion

Prevalence of cannabis-influenced drugged driving: true threat or false panic?

In 2010, an estimated 22.6 million Americans age 12 or older self-identified as current (past month) illicit drug consumers. A majority of these respondents, some 17.4 million, acknowledged having consumed cannabis.[3]

Year 2010 survey data further estimates that some 10.6 million persons, or 4.2% of the population age 12 or older, reported driving under the influence of an illicit drug during the past year.[3] Those respondents who were age 18 to 25 were most likely to have reported engaging in this behaviour.

A previous US government analysis estimated that among those who acknowledge having driven following the consumption of an illicit substance, a majority of respondents, 70%, affirm having done so following the ingestion of cannabis.[4] While this total is far from negligible, it is far fewer than the number of respondents who acknowledge having driven while under the influence of alcohol.

The presence of cannabis' primary psychoactive ingredient, delta-9-tetrahydrocannabinol (THC), or THC's primary metabolite, carboxy THC, has frequently been identified in the blood or urine of drivers involved in fatal traffic accidents.[5] Explanations for this result are two-fold. First, cannabis is by far the most widely used illicit drug among the US population, with non-governmental polling data indicating that nearly one out of two Americans admit having tried it.[6] Second, cannabis is the illicit substance most readily detectable by toxicological tests. The presence of THC may be detectable in the blood of occasional cannabis consumers for several hours after past use.[7] In more chronic users, THC may be present at relatively low blood levels for a period of days after past use,[8,9] long after any performance-impairing effects have dissipated.[10,11] Carboxy THC may be present for far longer periods of time. In some cases, the presence of carboxy THC has been identified in the urine of chronic cannabis consumers for periods of 30 to 100 days post-abstinence.[12] Therefore, the mere presence of cannabis or its byproducts in the blood or urine of drivers is not necessarily indicative that cannabis use is a causal factor in traffic accidents.

Cruising on cannabis: clarifying the debate

While it is well established that alcohol consumption increases accident risk, evidence of cannabis's culpability in on-road driving accidents and injury is far less robust, with some reviews acknowledging an association between cannabis consumption and an increased risk of motor vehicle crashes[13] while others have not.[14,15]

Although acute cannabis intoxication following inhalation has been shown to influence psychomotor skills in a dose-related manner,[16] these acute effects on performance are typically described by experts as 'modest' and are seldom long

* *Correspondence to: Paul Armentano, National Organization for the Reform of Marijuana Laws (NORML), 1600 K Street, NW, Mezzanine Level, Washington, DC 20006-2832. E-mail: paul@norml.org*

National Organization for the Reform of Marijuana Laws (NORML), 1600 K Street, NW, Mezzanine Level, Washington, DC 20006-2832

lasting.[15,17] In closed course and driving simulator studies, cannabis's acute effects on psychomotor performance may include increased break latency, variation in lateral positioning (weaving), increased headway (leaving greater distance between the subject's vehicle and the car in front of them), decreased performance in critical tracking and divided attention tasks, reduced speed, and decreased reaction time. Notably, these changes in performance are more likely to be manifested by subjects' performance on driver simulator tests as compared to assessment of subjects' actual on-road driving performance. For example, a 2001 study evaluating the impact of cannabis inhalation on driving proficiency on city streets among 16 subjects reported essentially no differences in subjects' driving performance after cannabis administration, concluding: 'Performance as rated on the Driving Proficiency Scale did not differ between treatments. It was concluded that the effects of low doses of THC ... on higher-level driving skills as measured in the present study are minimal.'[18] Similarly, a study funded by the United States National Highway Traffic Association (NTHSA) evaluated 32 subjects' driving performance after cannabis inhalation in high-density urban traffic. Investigators reported: 'Marijuana ... did not significantly change mean driving performance.'[19]

In general, cannabis-influenced variations in driving behaviour are often the opposite of those effects exhibited by subjects under the influence of alcohol.[11] Unlike subjects impaired by alcohol, individuals influenced by cannabis are typically aware of their impairment and 'tend to compensate effectively' for it,[15] either by driving more cautiously[19] or by expressing an unwillingness to drive altogether.[20]

Further, numerous studies report that experienced cannabis users develop tolerance to many of the changes in cognitive or psychomotor performance associated with acute cannabis intoxication.[21–23] More recently, a 2010 double-blind, placebo-controlled study of 21 heavy cannabis users assessed the impact of alcohol or THC inhalation on measures of perceptual motor control (critical tracking task), dual task processing (divided-attention task), motor inhibition (stop-signal task), and cognition (Tower of London). Authors concluded: 'Alcohol significantly impaired critical tracking, divided attention, and stop-signal performance. THC generally did not affect task performance. ... [T]he present study generally confirms that heavy cannabis users develop tolerance to the impairing effects of THC on neurocognitive task performance.'[24] Similarly, a 2012 study of ten chronic cannabis smokers reported physiological changes but no identifiable changes in psychomotor skills following acute cannabis administration. Authors concluded: 'No significant differences were observed in critical-tracking or divided-attention task performance in this cohort of heavy, chronic cannabis smokers. ... These findings support those reported by (others) documenting significant subjective response and minimal impairment in driving-related psychomotor tasks in chronic daily cannabis users.'[25]

For these reasons, cannabis influenced variations in performance do not typically appear to play a significant role in on-road traffic accidents when the THC levels present in a driver's blood are low and/or cannabis is not consumed in combination with alcohol. For example, a series of cannabis and driving studies commissioned by the National Highway Traffic Safety Administration concluded: 'THC's adverse effects on driving performance appear relatively small.'[19] A more recent assessment by Blows *et al*. noted that self-reported recent use of cannabis (within three hours of driving) was not significantly associated with car crash injury after investigators controlled for specific confounders (e.g. seat-belt use, sleepiness).[26] A 2004 observational case control study published in the journal *Accident, Analysis and Prevention* reported that only drivers under the influence of alcohol or benzodiazepines experienced an increased crash risk compared to drug-free controls. Investigators did observe increased risks, though they were not statistically significant, among drivers using amphetamines, cocaine and opiates, but acknowledged: 'No increased risk for road trauma was found for drivers exposed to cannabis.'[27] US government investigators are presently conducting a similarly designed study domestically. The results of this forthcoming study will arguably shed further light on the role cannabis exposure may play in incidences of traffic accidents or injury.

Other recent studies, however, suggest a positive association between presumed recent cannabis exposure and a gradually increased risk of vehicle accident.[28] However, this elevated risk is estimated to be substantially lower than the risk associated with alcohol-impaired drivers, including drivers who have consumed minor (within legal limits) quantities of alcohol.

For example, a 2007 case-control study published in the *Canadian Journal of Public Health* reviewed ten years of US auto-fatality data. Investigators found that US drivers with blood alcohol levels of 0.05%, a level well below the legal limit for *per se* intoxication in the United States, were three times as likely to have engaged in unsafe driving activities prior to a fatal crash as compared to individuals who tested positive for cannabis.[29] A 2005 review of auto accident fatality data from France reported similar results, finding that drivers who tested positive for any amount of alcohol had a four times greater risk of having a fatal accident than did drivers who tested positive for THC in their blood.[30] In the latter study, even drivers with low levels of alcohol present in their blood (below 0.05%) experienced a greater elevated risk as compared to drivers who tested positive for higher concentrations of cannabis (above 5ng/ml). Both studies noted that, overall, relatively few traffic accidents were attributable to drivers operating a vehicle while presumed to be under the influence cannabis.

Following the publication of these and similar studies, various investigators attempted to associate specific levels of THC in blood or blood plasma with elevated risks of driver accident. These estimated cannabis DUI *per se* threshold range from levels as low as 1ng/ml[33] of THC in whole blood to levels as high as 10ng/ml[31] of THC in whole blood. One of the more prominent papers on this subject estimated a range of 3.5 to 5ng/ml of THC in whole blood, stating 'a suitable numerical limit for THC may fall in that range'.[32]

However, there are many reasons why such estimated *per se* thresholds for THC should be interpreted with caution. First, peak THC blood levels following inhalation do not consistently correspond with levels of peak behavioural impairment. Rather, subjects who inhale THC typically ascertain their highest THC blood levels within minutes, well before the substance's adverse cognitive or psychomotor effects are at their most significant. As a result, some experts caution that it is virtually impossible to make inferences regarding a subject's impairment based upon the presence of THC alone in a single sample.[19]

Second, cannabis' effect on psychomotor performance varies widely among individual subjects, particularly among those who are cannabis experienced versus those who are naïve. As a result of these extreme variations, even experts who are on record in support of estimated blood/THC impairment standards acknowledge that such thresholds 'are not necessarily applicable to each and every driver as an individual'.[33]

Third, as noted previously, studies of chronic cannabis consumers indicate that residual levels of THC may be present in blood without associated impairment of performance for several days after past use. Experts have cautioned that this accumulation of THC in chronic consumers 'leads to cannabinoid concentrations in sober phases that resemble concentrations found in occasional users after acute cannabis use',[8] therefore making the universal application of a specific blood/THC impairment standard in many cases inappropriate.

Finally, there is presently no practical method for law enforcement officers at the scene to collect blood samples from suspected DUI cannabis drivers in a timely manner. This delay in collection (which may typically be as long as several hours), combined with the THC's complex and inconsistent pharmacokinetics, make it virtually impossible to infer whether, or to what extent, a subject was previously impaired based solely on a positive blood test result.[34]

For these reasons, NORML does not endorse the imposition of *per se* criminal laws for drivers who test positive for THC in the blood without additional demonstrable evidence of psychomotor impairment. In particular, NORML opposes the imposition of so-called 'zero tolerance' *per se* standards, which legally define a motorist impaired if he or she tests positive for the presence of any amount of THC or THC metabolites in their blood or urine. To date, the implementation of such policies has not been associated with lower incidences of driving under the influence of illicit drugs.[35] As a result, even the advocates of such standards acknowledge that *per se* drug laws for cannabis and other illicit substances 'cannot yet be characterized as "evidence based"'.[36]

Conclusions

Defining a rational 'drugged driving' policy

This review illustrates the need for further study regarding the complex relationship between cannabis intoxication and driving behaviour. While inhaled cannabis' influence on psychomotor skills is arguably less severe than that induced by the consumption of alcohol, including relatively low doses of alcohol, driving under the acute influence of cannabis nevertheless does appear to be associated with an elevated risk of accident in certain situations. This elevated risk is dose-dependent and appears most likely to be manifested in situations involving an unexpected change in the driving environment that requires a complex psychomotor response. Drivers at greatest risk are likely to be those who are inexperienced cannabis consumers who are less tolerant to the substance's effects. (It is plausible that orally consumed cannabinoids, such as cannabis food products, may exert greater influence on psychomotor skills for longer periods of time; however, to date, this issue has not been subject to rigorous study.) However, because inhaled cannabis' influence on psychomotor behaviour is often subtle, particularly in contrast to those associated with alcohol, and short-lived, consumers of the substance can greatly reduce their risk by refraining from driving for a period of several hours immediately following their cannabis use. One recent literature review summarizing 'recommended ways to reduce risks related to cannabis use' suggests that a time span of '3 to 4 hours after use ... could be recommended to users as a minimum wait period before driving'.[37]

By contrast, motorists should never be encouraged to operate a vehicle while actively engaged in inhaling cannabis, as its peak effects upon the user tend to manifest relatively rapidly. Drivers should also be advised that engaging in the simultaneous use of both cannabis and alcohol in many instances appears to pose an additive adverse effect on psychomotor skills and behaviour compared to the consumption of either substance alone,[38] thereby significantly increasing one's potential risk of accident. Past use of cannabis, as defined by the detection solely of inactive cannabis metabolites in the urine of drivers, is not associated with an increased accident risk[38] and should not be characterized by prosecutors as sufficient evidence of cannabis-induced impairment or recency of use.

In order to best educate the public as to the potential risks of cannabis-influenced driving and to discourage such behaviour, public awareness campaigns should be aimed at and marketed towards the younger driving population aged 18 to 25, as this group is most likely to consistently use cannabis and is also likely to acknowledge having operated a motor vehicle shortly after consuming the substance. In addition, this population possesses less actual on-road driving experience, may be more prone to engaging in risk-taking driving behaviour, and may be more naïve to the substance's psychoactive effects. This younger population also reports a greater likelihood of having driven after using cannabis in combinations with other illicit drugs or alcohol. Such an educational campaign was implemented nationwide in Canada by the Canadian Public Health Association and could readily be replicated in the United States. Arguably, such a campaign would enjoy enhanced credibility among its intended audience if coordinated by a private health association or traffic safety organization, such as the American Public Health Association or the AAA Automobile Club, as opposed to the White House Office of National Drug Control Policy, whose previous public service campaigns have demonstrated limited influence among younger audiences.[39]

Increased efforts should be made within the law enforcement community to encourage officers to engage in drug recognition expert (DRE) or equivalent training (such as ARIDE: Advanced Roadside Impaired Driving Enforcement) so that a greater number of police may be able to better identify drivers who may be operating a vehicle while influenced by cannabis. Further, the reliability of standard field sobriety testing ought to be critically assessed regarding whether these procedures are presently sensitive enough to reliably identify cannabis-influenced subjects. At present, standard field sobriety tests (SFSTs) have been validated for alcohol, but their sensitivity to subjects influenced by cannabis is far less consistent.[40–42] While some individual components of the SFST, such as the one-leg-stand test,[40,43] have been documented to be fairly consistent predictors of cannabis-influenced behaviour, other SFST components, such as the walk-and-turn test and the horizontal-gaze-nystagmus test, have not been shown to be reliable methods for identifying subjects who have recently inhaled cannabis.[40] One recent trial of 12 heavy and 12 occasional cannabis consumers administered oral doses of THC determined: '[C]urrent SFSTs are insufficiently sensitive to detect (oral) THC induced driving impairment. ... This study clearly points to the need for the development of field tests to detect drugs (e.g. THC) induced impairment.'[44] Clearly, further research ought to be conducted in this arena to identify more sensitive and reliable behavioural, performance, and clinical indicators of cannabis intoxication.

Though the development of roadside cannabis-specific detection testing technology is still in its infancy, an argument may be

made for the provisional use of such tests by specially trained members of law enforcement. The use of point-of-collection cannabis-sensitive technology to rapidly identify the presence of THC in drivers, such as a roadside saliva test, would provide utility to law enforcement in their efforts to better identify suspected intoxicated drivers. (Since this technology presently possesses only a narrow window of detection, these devices are likely to be a more reliable barometer of recent use than urine collection or, in some cases, even blood.) Since THC concentrations in saliva have yet to be correlated with behavioural or psychomotor impairment, a positive test result should not be inferred as *per se* evidence of driver impairment, but rather as a potential indicator of recent cannabis ingestion. Aside from providing an additional identification tool for police, the development and use of such technology would also increase public support for the regulation of cannabis use by adults by helping to assuage concerns that liberalizing cannabis laws could potentially lead to an increase in incidences of drugged driving or limit the state's ability to successfully identify and prosecute said behaviour.[45] Such concerns are presently a significant impediment to the enactment of marijuana law reform, and arguably must be sufficiently addressed before a majority of the public will embrace any public policy that proposes legalizing and regulating adult cannabis use like alcohol.

References

[1] National Organization for the Reform of Marijuana Laws. Principles of Responsible Cannabis Use, Adopted by NORML's Board of Directors, February 3, **1996**.
[2] R. Elvik. Risk of road accident associated with the use of drugs: A systematic review and meta-analysis of evidence from epidemiological studies. *Accident Anal. Prev.* **2012**. http://dx.doi.org/10.1016/j.aap.2012.06.017
[3] Substance Abuse and Mental Health Services Association. *Results from the 2010 National Survey on Drug Use and Health: Summary of National Findings*, Office of Applied Studies, Rockville, MD, **2011**.
[4] Substance Abuse and Mental Health Services Association. *Driving After Drug or Alcohol Use: Finding from the 1996 National Household Survey on Drug Abuse*, Office of Applied Studies, Rockville, MD, **1998**.
[5] J. Copeland, S. Gerber, W. Swift. Evidence-Based Answers to Cannabis Questions: A Review of the Literature – A Report Prepared for the National Drug and Alcohol Research Centre, University of New South Wales, **2004**.
[6] CNN/Time poll: "[H]ave you tried marijuana?" Conducted by Harris Interactive. October 23–24, **2002**. Available at: http://norml.org/library/item/cnntime-magazine-poll [17 July 2012].
[7] M.A. Huestis, J.E. Henningfield, E.J. Cone. Blood cannabinoids. 1. Absorption of THC and formation of 11-OH-THC and THCCOOH during and after smoking marijuana. *J. Anal. Toxicol.* **1992**, *16*, 276.
[8] S.W. Toennes, J.G. Ramaekers, E.L. Theunissen, M.R. Moeller, G.F. Kauert. Comparison of cannabinoid pharmacokinetic properties in occasional and heavy users smoking a marijuana or placebo joint. *J. Anal. Toxicol.* **2008**, *32*, 470.
[9] E.L. Karschner, E.W. Schwilke, R.H. Lowe, W.D. Darwin, H.G. Pope, R. Herning, *et al.* Do Delta- 9-tetrahydrocannabinol concentrations indicate recent use in chronic cannabis users? *Addiction* **2009**, *104*, 2041.
[10] G. Skopp, L. Potsch. Cannabinoid concentrations in spot serum samples 24–48 hours after discontinuation of cannabis smoking. *J Anal Toxicol.* **2008**, *32*, 160.
[11] A. Ronen, P. Gershon, H. Drobiner, A. Rabinovish, R. Bar-Hamburger, R. Mechoulam, *et al.* Effects of THC on driving performance, physiological state and subjective feelings relative to alcohol. *Accident Anal. Prev.* **2008**, *40*, 926.
[12] F. Musshoff, B. Madea. Review of biological matrices (urine, blood, and hair) as indicators of recent or ongoing cannabis use. *Ther. Drug Monit.* **2006**, *28*, 155.
[13] M. Asbridge, J.A. Hayden, J.L. Cartwright. Acute cannabis consumption and motor vehicle collision risk: Systematic review of observational studies and meta-analysis. *Brit. Med. J.* **2012**, *344*: e536. doi: 10.1136/bmj.e536
[14] G. Chesher, M. Longo. Cannabis and alcohol in motor vehicle accidents. in *Cannabis and Cannabinoids: Pharmacology, Toxicology, and Therapeutic Potential*, (Eds: F. Grotenhermen, E. Russo). Haworth Integrative Healing Press, New York, **2002**, pp. 313–323.
[15] R.A. Sewell, J. Polling, M. Sofuoglu. The effect of cannabis compared to alcohol on driving. *Am. J. Addict.* **2009**, *18*, 185.
[16] J.G. Ramaekers, G. Kauert, P. van Ruitenbeek, E.L. Theunissen, E. Schneider, M.R. Moeller. High potency marijuana impairs executive function and inhibitory motor control. *Neuropsychopharmacology* **2006**, *31*, 2296.
[17] US Department of Transportation, National Highway Traffic Safety Administration. *State of Knowledge of Drug-Impaired Driving: FINAL REPORT*, National Technical Information Service, Springfield, VA, **2003**.
[18] C.T. Lamers, J.G. Ramaekers. Visual search and urban driving under the influence of marijuana and alcohol. *Human Psychopharmacol.* **2001**, *16*, 393.
[19] H.W. Robbe, J.F. O'Hanlon. *Marijuana and Actual Driving Performance*. US Department of Transportation, National Highway Traffic Safety Administration. National Highway Traffic Safety Administration, Washington, DC, **1993**.
[20] A. Menetrey, M. Augsburger, B. Favrat, M.A. Pin, L.E. Rothuizen, M. Appenzeller, *et al.* Assessment of driving capability . . . following oral administration of 20 mg dronabinol or of a cannabis decoction made with 20 or 60 mg Delta9-THC. *J. Anal. Toxicol.* **2005**, *29*, 327.
[21] D.C. D'Souza, M. Ranganathan, G. Braley, R. Gueorguieva, Z. Zimolo, T. Copper, *et al.* Blunted psychotomimetic and amnestic effects of delta-9-tetrahydrocannabinol in frequent users of cannabis. *Neuropsychopharmacology* **2008**, *33*, 2505.
[22] J.G. Ramaekers, G. Kauert, E.L. Theunissen, S.W. Toennes, M.R. Moeller. Neurocognitive performance during acute THC intoxication in heavy and occasional cannabis users. *J. Psychopharmacol.* **2009**, *23*, 266.
[23] C.L. Hart, E.B. Ilan, A. Gevins, E.W. Gunderson, K. Role, J. Colley, *et al.* Neurophysiological and cognitive effects of marijuana in frequent users. *Pharmacol. Biochem. Behav.* **2010**, *96*, 333.
[24] J.G. Ramaekers, E.L. Theunissen, M. de Bower, S.W. Toennes, M.R. Moeller, G. Kauert. Tolerance and cross-tolerance to neurocognitive effects of THC and alcohol in heavy cannabis users. *Psychopharmacology (Berl)* **2010**, *214*, 391.
[25] D.M. Schwope, W.M. Bosker, J.G. Ramaekers, D.A. Goerlick, M.A. Huestis. Psychomotor performance, subjective and physiological effects of whole blood delta-9-THC concentrations in heavy, chronic cannabis smokers following acute smoked cannabis. *J. Anal. Toxicol.* **2012**, *36*, doi:10.1093/jat/bks044.
[26] S. Blows, R.Q. Ivers, J. Conner, S. Ameratunga, M. Woodward, R. Norton. Marijuana use and car crash injury. *Addiction* **2004**, *100*, 605.
[27] K.L. Movig, M.P. Mathijssen, P.H. Nagel, T. van Egmond, J.J. de Gier, H.G. Leufkens, *et al.* Psychoactive substance use and the risk of motor vehicle accidents. *Accident Anal. Prev.* **2004**, *36*, 631.
[28] O.H. Drummer, J. Gerostamoulos, H. Batziris, M. Chu, J. Caplehorn, M. D. Robertson, *et al*. The involvement of drugs in drivers killed in Australian road traffic crashes. *Accident Anal. Prev.* **2004**, *36*, 239.
[29] M. Bedard, S. Dubois, B. Weaver. The impact of cannabis on driving. *Can. J. Public Health* **2007**, *98*, 6.
[30] B. Laumon, B. Gadegbeku, J.L. Martin, M.B. Biecheler, S.A.M. Group. Cannabis intoxication and fatal road crashes in France: A population base case–control study. *Brit. Med. J.* **2005**, *331*, 1371.
[31] F. Grotenhermen, G. Leson, G. Berhaus, O.H. Drummer, H.P. Kruger, M. Longo, *et al. Developing Science-Based Per Se Limits for Driving Under the Influence of Cannabis (DUIC): Findings and Recommendations by an Expert Panel*, Marijuana Policy Project, Washington, DC, **2005**.
[32] F. Grotenhermen, G. Leson, G. Berhaus, O.H. Drummer, H.P. Kruger, M. Longo, *et al*. Developing per se limits for driving under cannabis. *Addiction* **2007**, *102*, 1910.
[33] J.G. Ramaekers, G. Berhaus, M.W. van Laar, O.H. Drummer. Dose related risk of motor vehicle crashes after cannabis use: an update. in *Drugs, Driving, and Traffic Safety* (Eds: J.C. Verster, D.R. Pandi-Perumai, J.G. Raemakers, J.J. de Gier). Birkhauser, Basel, Switzerland, **2010**, pp: 501–518.
[34] S.M. Wille, M.M. Ramirez-Fernandez, N. Samyn, G. De Boeck. Conventional and alternative matrices for driving under the influence of cannabis. *Bioanalysis* **2010**, *2*, 791.

[35] A.W. Jones. Driving under the influence of drugs in Sweden with zero concentration limits in blood for controlled substance. *Traffic Inj. Prev.* **2005**, *6*, 317.
[36] R. Dupont. *Drugged Driving Research: A White Paper Prepared for the National Institute on Drug Abuse*. Institute for Behavior and Health, Rockville, MD, **2011**.
[37] B. Fischer, V. Jeffries, W. Hall, R. Room, E. Goldner, J. Rehm. Lower Risk Cannabis use Guidelines for Canada (LRCUG): A narrative review of evidence and recommendations. *Can. J. Public Health* **2011**, *102*, 324.
[38] J.G. Ramaekers, G. Berghaus, M. van Laar, O.H. Drummer. Dose related risk of motor vehicle crashes after cannabis use. *Drug Alcohol Depend.* **2004**, *7*, 109.
[39] US Government Accountability Office, ONDCP Media Campaign: Contractor's National Evaluation Did Not Find that the Youth Anti-Drug Media Campaign Was Effective in Reducing Youth Drug Use: Report to the Subcommittee on Transportation, Treasury, the Judiciary, Housing and Urban Development, and Related Agencies, Committee on Appropriations, U.S. Senate. Washington, DC, August 25, **2006**.
[40] W.M. Bosker, E.L. Theunissen, S. Conen, K.P. Kuypers, W.K. Jefferey, H.C. Walls, *et al*. A placebo-controlled study to assess standard field sobriety tests performance during alcohol and cannabis intoxication in heavy cannabis users and accuracy of point of collection testing devices for detecting THC in oral fluid. *Psychopharmacology (Berl)* **2012**, *13*, doi: 10.1007/s00213-012-2732-y.
[41] D. Shinar, E. Schechtman. Drug identification performance on the basis of observable signs and symptoms. *Accident Anal. Prev.* **2005**, *37*, 843.
[42] K. Papafotiou, J.D. Carter, C. Stough. The relationship between performance on the SFSTs, driving performance and the level of THC in the blood. *Forensic Sci. Int.* **2004**, *155*, 172.
[43] C. Stough, M. Boorman, E. Ogden, K. Papafotiou. *An Evaluation of the Standardised Field Sobriety Test for the Detection of Impairment Associated With Cannabis With and Without Alcohol*, Australian Government Department of Health and Aging, Canberra, **2006**.
[44] W.M. Bosker, K.P. Kuypers, E.L. Theunissen, A. Surinx, R.J. Blankespoor, G. Skopp, *et al*. Medicinal THC (dronabinol) impairs on-the-road driving performance of occasional and heavy cannabis users but is not detected in standardized field sobriety tests. *Addiction* **2012**, doi: 10.1111/j.1360- 0443.2012.03928.x.
[45] A. Looby, M. Earleywine, D. Gieringer. Roadside sobriety tests and attitudes toward a regulated cannabis market. *Harm. Reduct. J.* **2007**, *4*, 4.