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Driver-related risk factors of fatal road traffic crashes associated with alcohol or drug impairment

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ABSTRACT

Fatal road traffic crashes are often related to speeding, non-use of a seatbelt, and alcohol/drug-impaired driving. The aim of this study was to examine associations between driving under the influence of drugs and/or alcohol and driver-related risk factors that have been reported as significantly contributing causes of fatal road traffic crashes. The data were extracted from Norwegian road traffic crash registries and forensic toxicology databases. Drug/alcohol investigated car and van drivers and motorcycle riders fatally injured in road traffic crashes in Norway during 2005–2015 were included in this study (n = 772). Drug and alcohol concentrations corresponding to 0.5 g/kg alcohol in blood were used as the lower limits for categorising drivers/riders as impaired; 0.2 g/kg was the upper limit for being categorised as sober. Associations between driver-related risk factors and impairment from specific substance groups were calculated using multivariable logistic regression, adjusted for other substance groups, age, and sex, and were reported when the confidence intervals did not contain the value 1 or lower. Substances found in concentrations above the impairment limits were mainly alcohol (20%), medicinal drugs (10%: benzodiazepines, opioids, z-hypnotics), stimulants (5%: amphetamines, methylphenidate, and cocaine), and cannabis (4%: THC). The drug/alcohol-impaired drivers had compared to the sober drivers more often been speeding (68% versus 32%), not used a seatbelt (69% versus 30%), and been driving without a valid driver license (26% versus 1%). Logistic regression analysis showed that impairment from alcohol or stimulants (mainly amphetamines) was associated with all three risk factors, medicinal drugs with all except speeding, and impairment from cannabis (THC) with not having a valid driver license. Among motorcycle riders, drug/alcohol impairment was associated with not having a valid driver license and non-use of a helmet. At least one of the risk factors speeding, non-use of a seatbelt/helmet, and driving without a valid license were present among the vast majority of the drug/alcohol-impaired fatally injured drivers and riders, and also among more than half of the fatally injured sober drivers.

1. Introduction

Driver-related risk factors such as speeding, non-use of a seatbelt, distracted driving, drowsy driving, and drug/alcohol-impaired driving are often reported as contributing causes of fatal road traffic crashes (Pietrasik, 2018). Some risk factors of crashes or fatalities in a crash might be related, either through causal pathways or via personality traits, age, or health of the driver. A recent driving simulation experiment revealed that alcohol increased driver risk-taking and reduced the driver's ability to control the vehicle (Laude and Fillmore, 2015). Among several risk factors tested in a case-control study of motorcycle crashes in France, loss of control of the motorcycle was the most strongly associated with driving under the influence of alcohol (Wu et al., 2018). The adverse effect of alcohol on driving performance

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is well documented in the literature (Martin et al., 2013). Use of psychoactive drugs may also influence driver performance (Verstraete et al., 2014; Gjerde et al., 2015; Strand et al., 2016; Busardo et al., 2018).

Associations between impairment from drugs and unsafe driving behaviours have been previously investigated, basically in studies using data from the comprehensive US Fatality Analysis Reporting System (FARS) database (Bedard et al., 2007; Liu et al., 2016; Romano and Voas, 2011). These studies have found associations between drugs detected and inappropriate speeding, non-use of a seatbelt, passing violations, etc. among drivers involved in fatal crashes. Drawbacks with previous studies are that often a limited number of drugs have been included in analytical testing or limited data have been recorded in the databases used, and no distinction has been made between acute drug intoxication and earlier drug use, which limits the interpretation of the results from studies based on e.g. the FARS database (Berning and Smither, 2014; Compton and Berning, 2015; Romano et al., 2017). An example of insufficient distinction between acute intoxication and earlier drug use is use of detected cannabinoids, which both in the blood and urine may include both inactive and psychoactive substances, hence diluting the results. Use of delta-9-tetrahydrocannabinol (THC) detected in the urine is also likely to dilute the results as THC might be detected in the urine days after the driver was impaired by the drug (Compton, 2017; Hartman and Huestis, 2013). More studies distinguishing between acute drug intoxication and earlier drug use are therefore needed to supplement the existing literature on the associations between drug use and unsafe driving behaviours or road traffic crashes.

Since 2005, all fatal road traffic crashes in Norway have been analysed in-depth by multidisciplinary crash investigation teams. Information about each incidence is registered in a database. Using this information, the Norwegian Public Roads Administration revealed that in the period 2005–2015, 40% of fatal road traffic crashes in Norway were related to speeding, and at least 21% of the crashes were related to alcohol or drug use; 41% of car occupants killed had not used a seatbelt, and 19% of motorcycle riders killed had not used a helmet (Grimstad and Engebretsen, 2016). When considering only car/van drivers killed, 33.5% had not used a seatbelt during 2005–2015 (Valen et al., 2019).

A preliminary Norwegian study found that drug/alcohol impairment was associated with speeding or non-use of a seatbelt among car and van drivers (Bogstrand et al., 2015). That study was based on the high-quality Norwegian forensic toxicology database, which contains test results for alcohol and commonly abused drugs quantified in blood samples by accredited methods. Few study years and limited information from the crash investigation teams were however included in the preliminary study. The aim of the present study was to perform a more thorough investigation of the association between impairment from different psychoactive substances and driver-related risk factors reported to have significantly contributed to fatal road traffic crashes, including both car/van drivers and motorcycle/moped riders in the period 2005–2015.

2. Methods

2.1. Study design, setting, and selection of participants

This is a retrospective register-based study of car and van drivers and motorcycle (including moped) riders who were fatally injured in road traffic crashes in Norway between 2005 and 2015. Drivers and riders investigated for the use of drugs and/or alcohol were included, except if there was more than 24 h' time lag from the incidence to death without a blood sample being collected within 24 h after the incidence.

2.2. Data sources

2.2.1. Crash investigation team database

The police activate local crash investigators on call from the national road authorities in all fatal crashes, and in all other severe crashes where the police request technical support for their investigation. The local crash investigators go to the crash site to secure time-sensitive information, take pictures, estimate possible hazard scenarios, talk to other rescue personnel at the scene, etc. Technical documentation of the vehicle continues during the following days. In all cases where the driver died immediately or within 30 days from the injuries he/she suffered in the road traffic crash, documentation from the early investigation was further evaluated in multidisciplinary meetings where the significance of different risk factors related to the vehicle, driver, and road were evaluated. The purpose is to reveal the causes of the crashes and the causes of the fatal outcome of the crashes to suggest actions to prevent future fatal incidences. Included in the final reports are both technical information and risk factors evaluated by the multidisciplinary team to be of significant importance for the occurrence of the fatal road traffic crash. Assessments of likely undocumented factors, such as inattention and drowsy driving, are also made based on the available information. Data and conclusions from the reports are recorded in a database operated by the Norwegian Public Roads Administration. More information about these investigations and the data were recently published by Sagberg (2018).

2.2.2. Forensic toxicology databases

The police request alcohol and drug testing in approximately 70% of fatal road traffic crashes. The analyses are performed at two locations in Norway: the Forensic Toxicology Laboratory in Oslo, which is now a part of Oslo University Hospital, and the Department of Clinical Pharmacology at St. Olav University Hospital in Trondheim. Both forensic laboratories are accredited by Norwegian Accreditation (Lillestrøm, Norway; www.akkreditert.no/en). The analytical testing includes frequently used psychoactive drugs such as amphetamines, cocaine, cannabis, benzodiazepines, and opioids, in addition to alcohol and some other drugs with abuse potential. Immunological methods and/or high-performance gas or liquid chromatography with mass spectrometry detection (GC–MS or LC–MS) is used for drug screening; quantification is performed by accredited GC–MS or LC–MS methods.

2.2.3. The road traffic accident registry of Statistics Norway

The police report all serious road traffic crashes to the Road Traffic Accident Registry, which is operated by Statistics Norway and is the basis for national statistics on road traffic crashes. Suicide cases are excluded from the reported statistics, which is in accordance with international standards on reporting road traffic deaths (Adminaite et al., 2018).

2.2.4. Coupling of data sources

An overview of drivers and riders fatally injured in road traffic crashes, their age and sex and the date and time of the road traffic crash and results from alcohol and drug testing were obtained by combining data from the Road Traffic Accident Registry of Statistics Norway and the Forensic Toxicology Laboratory in Oslo. The coupling was performed based on the Norwegian national identity numbers. Toxicological results from cases investigated at St. Olav University Hospital were coupled based on crash site, date, time, age, and sex. Thereafter, relevant information from the Crash Investigation Team Database was added.

2.3. Variables

A research database was created containing data on age, sex, time period of the crash (day/night and weekday/weekend, where night was defined from 10 p.m. to 4 a.m. and weekend from Friday 10 p.m. to Monday 4 a.m.), single-vehicle crash (yes/no), vehicles older than 10 years (yes/no), the toxicological results (substances tested for are listed in Table 1), as well as the following recorded dichotomous data: valid driver license, speeding, use of a seatbelt/motorcycle helmet, incorrect

Table 1
Compounds included in the study, per se limits corresponding to BAC of 0.2 g/kg, and impairment limits corresponding to BAC of 0.5 g/kg.

Compound	Per se limit (ng/mL)	Impairment limit (ng/mL)	Findings at or above impairment limit n (%)[b]	
			Car or van drivers (n = 602)	Motorcycle riders (n = 170)
Benzodiazepines			***60 (10.0)***	***7 (4.1)***
Alprazolam	3.1	6.2	6 (1.0)	0 (0)
Bromazepam	32	79	0 (0)	0 (0)
Clonazepam	1.3	3.2	18 (3.0)	3 (1.8)
Diazepam	57	142	18 (3.0)	3 (1.8)
Phenazepam	1.6	4.7	0 (0)	0 (0)
Flunitrazepam	1.6	3.1	2 (0.3)	1 (0.6)
Nordiazepam	108	271	12 (2.0)	2 (1.2)
Nitrazepam	17	42	3 (0.5)	0 (0)
Oxazepam	172	430	6 (1.0)	0 (0)
Z-hypnotics			***16 (2.7)***	***0 (0)***
Zolpidem	31	77	4 (0.7)	0 (0)
Zopiclone	12	23	12 (2.0)	0 (0)
Stimulants			***32 (5.3)***	***9 (5.3)***
Amphetamine	41	205[a]	20 (3.3)	4 (2.4)
Cocaine	24	120[a]	0 (0)	0 (0)
MDMA	97	485[a]	1 (0.2)	1 (0.6)
Methamphetamine	45	225[a]	18 (3.0)	7 (4.1)
Methylphenidate	3.5	18[a]	1 (0.2)	0 (0)
Cannabis			***23 (3.8)***	***10 (5.9)***
Delta-9-tetrahydrocannabinol (THC)	1.3	3.1	23 (3.8)	10 (5.9)
Opioids			***6 (1.0)***	***3 (1.8)***
Buprenorphine	0.4	0.9	1 (0.2)	1 (0.6)
Methadone	25	62	3 (0.5)	1 (0.6)
Morphine	8.6	23	1 (0.2)	1 (0.6)
Oxycodone	16	38	1 (0.2)	0 (0)
Other drugs			***0 (0)***	***0 (0)***
Lysergic acid diethylamide (LSD)	1.0	5.0[a]	0 (0)	0 (0)
Alcohol			***122 (20.3)***	***19 (11.2)***
Ethanol	0.20 g/kg	0.50 g/kg	122 (20.3)	19 (11.2)

Abbreviation: BAC = Blood alcohol concentration; MDMA = 3,4-Methylenedioxymethamphetamine (Ecstasy).
[a] Limits are not defined in the Road Traffic Act. Five times the per se limits were used as impairment limits for these compounds.
[b] Percent of all samples analysed for drugs and/or alcohol, stratified by vehicle (car/van and motorcycle).

position on the road, incorrect driving decisions, technical driving errors, lack of driving or vehicle experience, inattention while driving, and fatigue/drowsy driving. Speeding was reported when the driver had been driving inappropriately fast according to the road/driving conditions, above the speed limit, or involved in hazardous driving. Other, more rarely recorded driver-related risk factors that to some degree were based on best judgement were disregarded, such as driving while stressed, driver overestimating his/her driving skills, partying atmosphere, and suspicion of suicide (not confirmed by the police). Variables considering illness or mental stability were disregarded as the evaluation and inclusion in the database was inconsistent during the study period; health personnel were included in the crash investigation teams in 2010. Age was categorised into four groups: < 25, 25–34, 35–44, and ≥45 years. The rationale was to separate drivers/riders at different stages in their lives; the young people, often without family responsibility (< 25 years); those in establishment phase, often with responsibility for children (25–44 years); those tending to get more spare time again and better economy (≥45 years). The group 25–44 years was divided in two to make results more comparable with other published studies. Older age groups were not made because the highest age observed among impaired riders was 53 years, and only 3% of the impaired drivers were aged above 65 years, meaning that adjusting for more age groups above age 45 most likely would have reduced the statistical power without resulting in significantly more accurate results.

2.3.1. Data processing based on the toxicological results

The drivers/riders were categorised as sober or impaired based on the toxicological results. The per se limits corresponding to a blood alcohol concentration of 0.2 g/kg and the graded sanction limits corresponding to a blood alcohol concentration of 0.5 g/kg in the Norwegian Road Traffic Act (Ministry of Transport and Communications, 2016) were used in this process. The drivers/riders were categorised as sober if analysed for both drugs and alcohol, with negative results or concentrations below the per se limits. Drivers/riders with drug or alcohol concentrations equal to or above the graded sanction limits were categorised as impaired. Drivers/riders with drug or alcohol concentrations above the per se limits but below the graded sanction limits were excluded from the study.

Limits for graded sanction have not been defined for amphetamine, methamphetamine, MDMA, cocaine, LSD, and methylphenidate; for those drugs, we considered drug concentrations five times the per se limits as indications of possible impairment. Those concentrations correspond to the peak concentrations observed after taking commonly used recreational drug doses (Vindenes et al., 2012); for amphetamine and methamphetamine those concentrations are higher than those observed after therapeutic use (Schulz et al., 2012; Schweitzer and Holcomb, 2002). For amphetamine and methamphetamine, the sum of their concentrations (if both were present) were required to be five times the per se limit for amphetamine.

Findings of diazepam and/or morphine resulting from documented or likely medical treatment after the crash were disregarded during the formation of the impairment group.

Findings of alcohol were disregarded if the analysis of ethyl glucuronide (EtG) and ethyl sulphate (EtS) was performed with negative results.

The drivers categorised as impaired were grouped according to their drug/alcohol use as impaired by alcohol, stimulants (amphetamines, methylphenidate, and cocaine), cannabis, or medicinal drugs. The medicinal drug group included benzodiazepines, z-hypnotics, and opioids (Table 1).

Drivers/riders categorised as sober were excluded from the study if there were findings of tramadol and/or pregabalin (psychoactive compounds that are not included in the Norwegian Road Traffic Act) that may cause impairment. This was evaluated individually, and findings of tramadol above 263 ng/mL (1 μM) (Baselt, 2011; Strand et al., 2011) and findings of pregabalin above 1590 ng/mL (10 μM; the lowest value in the estimated range of therapeutic effect) (The Pharmacology Portal, 2018) were used as lower limits for the exclusion of drivers/riders.

2.4. Statistical methods

Data analyses were conducted using statistical package SPSS version 23 (IBM Corporation, Armonk, NY, USA). A significance level of 5% (generated p-value less than 0.05) was together with the confidence intervals used for the interpretation of the results.

Bivariate analyses using Pearson's chi-square statistics were used to compare recorded driver-related risk factors among sober and impaired drivers by assessing the crude odds ratios and p-values. Fisher's exact test was used to generate p-values in cases with an expected count less than five. None of the risk factors were excluded from further testing based on the crude odds ratios or p-values, as adjustment for confounding variables by logistic regression potentially can adjust a non-significant result to significant. Adjusted odds ratios for the associations between driver-related risk factors and impairment were generated in multivariable logistic regression models adjusted for age group and sex (Model 1) and for age group, sex, and the co-variables time of crash, single-vehicle crash, vehicle 10 years or older (Model 2). The models used were non-hierarchical; both the dependent variable (impairment) and all of the independent variables were included in one run. Two models of the adjusted odds ratios were made for each unsafe driver action/condition tested, because adjustment for several co-variables (Model 2) potentially could result in a more correct result for the association between impairment and unsafe driver action/condition, but on the other hand could result in a saturated model with less statistical power, potentially camouflaging a true association. The purpose of Model 2 was to test whether the associations found in Model 1 would be influenced when additionally correcting for possible differences in crash characteristics between the impaired and sober drivers.

Driver-related risk factors significantly and positively associated with being impaired from drugs and/or alcohol were included in the further analyses where the associations were tested across different substance groups compared to sober drivers. This was performed by including all individual substance groups and paired interaction terms in the same non-hierarchical multivariable logistic regression model for each individual driver action/condition tested. The interaction terms were excluded from the analyses if they resulted in empty cells. All of the analyses were adjusted for age group and sex by including those variables in the models.

The data set for motorcycle riders was smaller, and thus had less statistical power. The results from the multivariable analyses were therefore verified by an additional test, where impairment from the substance groups were tested one-by-one against sober riders, separately for each unsafe driver action/condition as a dependent variable, with age groups and sex as independent variables.

2.5. Ethical approval

Ethical approval was granted by the Regional Committee for Medical and Health Research Ethics, approval no. 2010/2191. Permission to include drivers killed in road traffic crashes was granted by the Higher Prosecution Authority of Norway and the Council for Confidentiality and Research of the Norwegian Ministry of Justice. The Norwegian Registry of Withdrawal from Biological Research Consent and the Registry of Autopsy Material Research Refusal were searched to reveal if any of the drivers/riders killed had not allowed the use of their data for research purposes.

3. Results

3.1. Participants

From 2005–2015, 602 (63%) of the 950 fatally injured drivers of cars or vans and 170 (63%) of the 270 fatally injured riders of motorcycles were investigated for drugs and/or alcohol and included in our research database. Among the investigated drivers, 31% (n = 186) were categorised as impaired by drugs and/or alcohol, and 56% (n = 338) were categorised as sober. Among the investigated riders, 20% (n = 34) were categorised as impaired by drugs and/or alcohol, and 69% (n = 118) were categorised as sober. The individual substances used by the investigated drivers and riders are given in Table 1. Characteristics of the investigated drivers and riders are shown in Table 2.

Table 2
Characteristics of crashes and fatally injured drivers and riders.

	Included in the database (n = 772)[c]	Car and van drivers (n = 602)		Motorcycle riders (n = 170)	
		Sober (n = 338)	Impaired (n = 186)	Sober (n = 118)	Impaired (n = 34)
Vehicle 10 years or older	446 (58%)	199 (59%)	143 (77%)	42 (36%)	12 (35%)
Single-vehicle crashes	303 (39%)	79 (23%)	135 (73%)	40 (34%)	24 (71%)
Time of crash[a]					
Weekday	465 (60%)	251 (74%)	65 (35%)	75 (64%)	11 (32%)
Weekend day	170 (22%)	63 (19%)	46 (25%)	28 (24%)	10 (29%)
Weeknight	41 (5%)	9 (3%)	20 (11%)	6 (5%)	2 (6%)
Weekend night	96 (12%)	15 (4%)	55 (30%)	9 (8%)	11 (32%)
Sex[b]					
Male drivers	633 (82%)	250 (74%)	165 (89%)	108 (92%)	34 (100%)
Age groups					
< 25	206 (27%)	82 (24%)	60 (32%)	29 (25%)	10 (29%)
25–34	157 (20%)	58 (17%)	51 (27%)	24 (20%)	10 (29%)
35–44	130 (17%)	45 (13%)	41 (22%)	27 (23%)	8 (24%)
≥45	279 (36%)	153 (45%)	34 (18%)	38 (32%)	6 (18%)

[a] Day was defined from 4 a.m. to 10 p.m.; night from 10 p.m. to 4 a.m. Weekend was defined as Friday at 10 p.m. to Monday at 4 a.m.
[b] Information about sex missing for one sober motorcycle rider.
[c] Among the included drivers and riders, 96 were categorised as neither sober nor impaired.

The age distributions of impaired versus sober drivers and riders were different (Table 2) as impairment was more common among the youngest age groups. The age distributions varied across different substance groups: the proportions of drivers aged below 25 years were 9% among those impaired by stimulants, 18% among those impaired by medicinal drugs, 42% among those impaired by alcohol, and 43% among those impaired by cannabis. For motorcycle riders, these numbers were 22%, 25%, 26%, and 30%, respectively. Impairment was rare among the oldest drivers and riders killed: 19% of the sober drivers were aged at or above 65 years compared to 3% of the impaired drivers; 3% of the sober riders were aged at or above 65 years compared to none of the impaired riders (the highest age observed among the impaired riders was 53 years).

A significantly higher proportion of the impaired than the sober drivers and riders were killed at night: 33% difference for drivers ($p < 0.0005$); 26% difference for riders ($p = 0.001$). A significantly higher proportion of the impaired than the sober drivers and riders were fatally injured in single-vehicle crashes: 49% difference for drivers ($p < 0.0005$); 37% difference for riders ($p < 0.0005$). Use of older cars, hence cars with less likelihood of having safety installations such as airbags, electronic stability control, and anti-lock braking systems, were more prevalent among the impaired than among the sober drivers (18% difference, $p < 0.0005$). No difference in the age of the motorcycle was observed between the sober and impaired riders (Table 2).

3.2. Prevalence of drugs and alcohol above graded sanction limits

A total of 92% (n = 555) of the drivers were investigated for both drugs and alcohol; 8% (n = 47) were investigated only for alcohol, of which 23% (n = 11) had a blood alcohol concentration above 0.5 g/kg and were regarded as impaired by alcohol.

Among the drivers investigated for both drugs and alcohol, the prevalence of alcohol impairment was 20% (n = 111) compared to 16% (n = 89) for drugs. Impairment from medicinal drugs was found in 11% (n = 61) of the drivers, impairment from stimulants in 6% (n = 32), and impairment from cannabis in 4% (n = 23). Some of these drivers had combined substances from different substance groups; those exclusively impaired by alcohol or by substances within the drug groups medicinal drugs, stimulants, or cannabis constituted 15% (n = 86), 4% (n = 23), 2% (n = 11), and 1% (n = 7) of the drivers, respectively; the prevalence of impairment from only alcohol (15%) was significantly higher than the prevalence of impairment from only one drug group (7%), ($\chi 2 = 15{,}945$, $p < 0.0005$).

A total of 96% (n = 164) of the riders were investigated for both drugs and alcohol; 4% (n = 6) were investigated only for alcohol. Of the latter group, one rider was regarded as impaired by alcohol.

Among the riders investigated for both drugs and alcohol, the prevalence of alcohol impairment was 11% (n = 18) as was the prevalence of impairment from drugs (11%, n = 18). Impairment from medicinal drugs was found in 5% (n = 8) of the riders, impairment from stimulants in 5% (n = 9), and impairment from cannabis in 6% (n = 10). Those exclusively impaired by alcohol or by substances within the drug groups medicinal drugs, stimulants, or cannabis constituted 9% (n = 15), 0.6% (n = 1), 1% (n = 2), and 2% (n = 4) of the riders, respectively.

3.3. Driver-related risk factors associated with drug/alcohol impairment

The frequency of recorded driver-related risk factors evaluated by the multidisciplinary crash investigation teams to have been significant causes of the road traffic crashes or the fatal outcome of the crashes are reported in Table 3. Non-use of a seatbelt and lack of a valid driver license were reported in all cases when present, not only when evaluated by the crash investigation teams to be of significance.

For car and van drivers, not having a valid driver license, speeding, and non-use of a seatbelt were significantly associated with being impaired by drugs and/or alcohol.

If studying only drivers fatally injured in single-vehicle crashes (n = 214), 79 were categorized as sober and 118 as impaired. The proportions not having a valid driver license among sober and impaired drivers were 4% and 27%, respectively; these proportions are slightly larger than among the total sample of killed drivers. Similarly, the proportions not using a seatbelt were 44% and 76%, and speeding 44% and 76%, among sober and impaired drivers, respectively. Due to lower statistical power, we did not investigate single-vehicle fatalities further.

For motorcycle riders, not having a valid license and non-use of a helmet were significantly associated with being impaired from drugs and/or alcohol, except for non-use of a helmet when adjusting for all of the co-variables listed in Table 2.

3.4. Prevalence of risk factors across substance groups

Car/van drivers impaired by drugs only had less often been speeding or not used a seatbelt compared to those impaired by alcohol only, but were more often driving without a valid driver license (Table 4). Cannabis-impaired drivers had most often not a valid driver license.

Not having a valid driver license was more prevalent among all of the substance groups among the motorcycle riders than among the car/van drivers. Driving without a helmet, however, was less prevalent than driving without a seatbelt (Table 4). Speeding was frequently reported both among impaired and sober riders (prevalence 65% and 53%, respectively), whereas speeding was half as prevalent among sober (32%) compared to impaired drivers (prevalence 68%).

3.5. Associations between driver-related risk factors and impairment across substance groups

Among the car/van drivers, not having a valid driver license was significantly associated with impaired driving from all of the substance groups (Table 5). Speeding prior to the crash was significantly associated with impaired driving from alcohol and stimulants, whereas non-use of a seatbelt was significantly associated with impairment from all of the substance groups except cannabis. Motorcycle riders impaired by alcohol were significantly associated with both not having a valid driver license and non-use of a helmet (Table 5). Riders impaired by stimulants were significantly associated with not having a valid driver license. No other substance groups were significantly associated with the risk factors tested.

As the sample size was not sufficiently large to include interaction terms in the regression model for motorcycle riders, the substance groups were additionally tested one-by-one against sober riders, separately for each recorded unsafe driver action/condition as a dependent variable, with age groups and sex as independent variables. The results obtained for motorcycle riders impaired by alcohol only (excluding other drugs) were similar as those reported in Table 5; impairment from alcohol only was significantly associated with both not having a valid driver license (OR 6.37, 95% CI 1.68–24.2, $p = 0.006$) and non-use of a helmet (OR 11.2, 95% CI 3.12–40.3, $p < 0.0005$) compared to sober riders. Having a valid driver license among those impaired by stimulants only was however not applicable to testing by this procedure.

4. Discussion

The most prevalent substance found among impaired drivers was alcohol. The prevalence of psychoactive drugs was lower and dominated by benzodiazepines, followed by amphetamines and THC. This finding corresponds to the results of European and US studies (Bernhoft et al., 2012; Brady et al., 2014), except that cocaine was not found in this report, and opioids were rare compared to among fatally injured drivers in the US.

We found strong and significant associations between impairment

Table 3
Frequency of risk factors among car/van drivers and among motorcycle riders, reported separately for sober and impaired drivers/riders. Odds ratios (OR) report associations between impairment from drugs and/or alcohol (as dependent variable) and the individual risk factors.

Risk factors	Sober	Impaired	Crude OR (95% CI)	p-value	Model 1 Adjusted OR (95% CI)	p-value	Model 2 Adjusted OR (95% CI)	p-value
Car and van drivers	**n = 338**	**n = 186**						
No valid driver license	4 (1%)	49 (26%)	29.9 (10.6 – 84.4)	< 0.0005	23.1 (8.05 – 66.0)	< 0.0005	18.5 (6.03 – 57.0)	< 0.0005
Non-use of a seatbelt	103 (30%)	129 (69%)	5.16 (3.50 – 7.61)	< 0.0005	4.27 (2.85 – 6.41)	< 0.0005	2.61 (1.64 – 4.17)	< 0.0005
Speeding	107 (32%)	127 (68%)	4.65 (3.16 – 6.83)	< 0.0005	3.97 (2.58 – 6.11)	< 0.0005	2.51 (1.52 – 4.12)	< 0.0005
Wrong or missing signal lights	2 (1%)	0 (0%)	n/a	0.541	n/a	n/a	n/a	n/a
Incorrect position on road[a]	25 (7%)	4 (2%)	0.275 (0.094 – 0.803)	0.012	0.236 (0.079 – 0.707)	0.010	0.289 (0.085 – 0.987)	0.048
Incorrect decisions[b]	26 (8%)	4 (2%)	0.264 (0.091 - 0.768)	0.009	0.248 (0.082 – 0.745)	0.013	0.412 (0.127 – 1.33)	0.139
Technical driving errors[c]	17 (5%)	12 (6%)	1.30 (0.608 – 2.79)	0.496	1.45 (0.641 – 3.28)	0.372	0.847 (0.302 – 2.37)	0.751
Inattention[d]	48 (14%)	17 (9%)	0.608 (0.339 – 1.09)	0.093	0.631 (0.341 – 1.17)	0.141	0.910 (0.440 – 1.88)	0.800
Fatigue /drowsy driving	68 (20%)	22 (12%)	0.533 (0.317 – 0.894)	0.016	0.654 (0.378 – 1.13)	0.128	0.611 (0.322 – 1.16)	0.132
Lack of driving /vehicle experience	33 (10%)	17 (9%)	0.930 (0.503 – 1.72)	0.816	0.613 (0.315 – 1.19)	0.149	0.478 (0.218 – 1.05)	0.065
Motorcycle riders	**n = 118**	**n = 34**						
No valid driver license	12 (10%)	21 (62%)	14.3 (5.72 – 35.6)	< 0.0005	17.4 (6.05 – 49.9)	< 0.0005	15.2 (4.54 – 50.7)	< 0.0005
Non-use of a helmet	15 (13%)	12 (35%)	3.75 (1.54 – 9.10)	0.002	3.67 (1.45 – 9.26)	0.006	2.76 (0.945 – 8.07)	0.063
Speeding	62 (53%)	22 (65%)	1.66 (0.751 – 3.65)	0.209	1.28 (0.544 – 3.02)	0.570	1.07 (0.409 – 2.81)	0.888
Wrong or missing signal lights	0 (0%)	0 (0%)	n/a	n/a	n/a	n/a	n/a	n/a
Incorrect position on road[a]	12 (10%)	1 (3%)	0.268 (0.034 – 2.14)	0.299	0.274 (0.033 – 2.29)	0.232	0.155 (0.016 – 1.54)	0.111
Incorrect decisions[b]	15 (13%)	3 (9%)	0.665 (0.181 – 2.45)	0.765	0.661 (0.172 – 2.54)	0.547	1.01 (0.231 – 4.38)	0.994
Technical driving errors[c]	18 (15%)	5 (15%)	0.958 (0.327 – 2.80)	0.937	0.894 (0.297 – 2.68)	0.841	1.02 (0.307 – 3.40)	0.973
Inattention[d]	21 (18%)	0 (0%)	n/a	0.004	n/a	n/a	n/a	n/a
Fatigue /drowsy driving	2 (2%)	1 (3%)	1.76 (0.155 – 20.0)	0.535	1.32 (0.113 – 15.3)	0.825	0.379 (0.027 – 5.38)	0.474
Lack of driving /vehicle experience	20 (17%)	7 (21%)	1.27 (0.486 – 3.32)	0.625	1.33 (0.478 – 3.69)	0.587	0.889 (0.273 – 2.89)	0.845

Model 1: Adjusted by age group and sex.
Model 2: Adjusted by age group, sex, time of crash, single-vehicle crashes, and vehicle 10 years or older.
[a] Wrong lane, too close to the vehicle in front, incorrect position for leaving the road, etc.
[b] The driver adjusted without taking into consideration the consequences of other road users, for example, when trying to pass the front car when there is no clear sight.
[c] Wrong automatic response, for example, speeding instead of stopping, wrong gear, etc.
[d] Inattention included failing to gather/see important and easily observable traffic information, use of a mobile phone, or adjusting the media player or radio.

from drugs and/or alcohol and not having a valid driver license, speeding, and non-use of a seatbelt. When divided into substance groups, both alcohol and stimulants were significantly associated with all three risk factors, medicinal drugs with all except speeding, and cannabis was associated with not having a valid driver license. Among the fatally injured motorcycle riders, alcohol impairment was significantly associated with not having a valid driver license and non-use of a helmet.

4.1. Car/van drivers

Alcohol impairment was significantly more prevalent than drug impairment, which is in accordance with the findings of other studies. In a study of fatal crashes using the FARS database, Bedard et al. (2007) found a clear relationship between increasing blood alcohol concentration and risky driving behaviour. Also our findings of associations between alcohol or drug impairment and speeding and non-use of a seatbelt comply with findings in other studies. Liu et al. (2016) found

Table 4
Driver-related risk factors associated with impaired driving among fatally injured car and van drivers and motorcycle riders investigated for drug/alcohol use. Impairment is disaggregated into substance groups.

	No valid driver license	Speeding	Non-use of a seatbelt	Speeding and/or non-use of a seatbelt
Car and van drivers				
Sober (n = 338)	4 (1%)	107 (32%)	103 (30%)	176 (52%)
Impaired (n = 186)	49 (26%)	127 (68%)	129 (69%)	171 (92%)
Impaired by				
Alcohol only (n = 97)	18 (19%)	77 (79%)	74 (76%)	94 (97%)
Drugs only (n = 64)	21 (33%)	31 (48%)	38 (59%)	53 (83%)
Alcohol (n = 122)[a]	28 (23%)	96 (79%)	91 (75%)	118 (97%)
Stimulants (n = 32)[a]	14 (44%)	19 (59%)	20 (63%)	28 (88%)
Cannabis (n = 23)[a]	13 (57%)	17 (74%)	14 (61%)	21 (91%)
Medicinal drugs (n = 61)[a]	20 (33%)	28 (46%)	37 (61%)	51 (84%)
Motorcycle riders				
Sober (n = 118)	12 (10%)	62 (53%)	15 (13%)	69 (59%)
Impaired (n = 34)	21 (62%)	22 (65%)	12 (35%)	28 (82%)
Impaired by				
Alcohol only (n = 16)	6 (38%)	9 (56%)	9 (56%)	14 (88%)
Drugs only (n = 15)	12 (80%)	10 (67%)	2 (13%)	11 (73%)
Alcohol (n = 19)[a]	9 (47%)	12 (63%)	10 (53%)	17 (89%)
Stimulants (n = 9)[a]	8 (89%)	5 (56%)	2 (22%)	6 (67%)
Cannabis (n = 10)[a]	7 (70%)	7 (70%)	1 (10%)	7 (70%)
Medicinal drugs (n = 8)[a]	8 (100%)	5 (63%)	1 (13%)	6 (75%)

[a] Including combinations with other drugs and/or alcohol.

Table 5
Associations between driver-related risk factors and impairment from different substance categories compared to sober car/van drivers and motorcycle riders. The associations are presented as odds ratios (OR) adjusted for age, sex, and use of other substance groups.[a]

	No valid driver license		Speeding		Non-use of a seatbelt	
	Adjusted OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value
Car and van drivers						
Impaired by						
Alcohol	10.4 (3.66 – 29.5)	< 0.0005	6.61 (3.65 – 12.0)	< 0.0005	5.33 (3.14 – 9.07)	< 0.0005
Stimulants	15.7 (2.54 – 96.7)	0.003	20.0 (3.69 – 108)	0.001	4.31 (1.20 – 15.6)	0.026
Cannabis	37.8 (7.08 – 202)	< 0.0005	1.21 (0.250 – 5.83)	0.815	0.978 (0.220 – 4.35)	0.977
Medicinal drugs	9.47 (1.93 – 46.5)	0.006	1.32 (0.491 – 3.53)	0.584	3.74 (1.59 – 8.81)	0.002
Interaction terms						
Alcohol by cannabis		0.037		0.807		0.932
Alcohol by stimulants		0.987		0.140		0.555
Alcohol by medicinal drugs		0.140		0.283		0.028
Stimulants by cannabis		–		0.437		–
Cannabis by medicinal drugs		0.278		0.180		0.999
Stimulants by medicinal drugs		0.482		0.005		0.027
Motorcycle riders						
Impaired by						
Alcohol	7.01 (1.88 – 26.2)	0.004	0.895 (0.304 – 2.64)	0.841	12.6 (3.63 – 43.6)	< 0.0005
Stimulants	15.1 (1.08 – 212)	0.044	0.466 (0.070 – 3.12)	0.431	7.26 (0.646 – 81.6)	0.108
Cannabis	5.84 (0.843 – 40.4)	0.074	2.47 (0.518 – 11.8)	0.256	0.196 (0.018 – 2.14)	0.181
Medicinal drugs	n/a	n/a	1.81 (0.235 – 14.0)	0.569	0.216 (0.013 – 3.71)	0.291

n/a = no resulting values obtained, but the variable remains included in the analysis.
"-" = not included in the analysis.
[a] Analysis was conducted separately for each recorded unsafe driver action/condition as a dependent variable using the substance groups, age groups, and sex as independent variables. As interaction terms, two-drug combinations were included in the analyses if not resulting in empty cells. For motorcycle riders, no interaction terms were used due to limited statistical power.

that speeding violations were significantly higher for drivers who tested positive for stimulants, alcohol, and/or cannabinoids compared to drivers with no drug or alcohol detected; speeding violations among those testing positive for medicinal drugs were not significantly different from the sober drivers. Romano and Voas (2011) used a similar multivariable regression model as the one presented in our study and found that speeding was associated with the same substance classes as in our study: stimulants and alcohol. In a study of drivers killed in road traffic crashes in Finland during 2006–2008, a higher frequency of crashes related to speed over 120 km/h was reported among drivers testing positive for alcohol (31%) or drugs (23%) than among sober drivers (10%) (Karjalainen et al., 2012). In our study, the same tendency was observed, although with a much higher prevalence, as we reported speeding as driving above the speed limit or inappropriately according the road/driving conditions. Bedard et al. (2007) also found that drivers who tested positive for cannabis had more often been speeding, and been erratic, reckless, careless or negligent while operating the vehicle. We did not find a similar association for use of cannabis in our study.

Liu et al. (2016) found increased odds ratios of non-use of a seatbelt among those testing positive for alcohol, stimulants, and medicinal drugs, which were within the confidence intervals of our odds ratios for the same associations. Romano and Voas (2011) reported that non-use of a seatbelt was associated with cannabinoids in addition to the substance classes found in our study. Also Beasley et al. (2011) found in a Canadian study that the use of a seatbelt was significantly lower in crashes where the driver tested positive for drugs. This was also the case in a US roadside survey, where the prevalence of drugs was significantly higher in drivers who did not wear a seatbelt (Lacey et al., 2009).

Lack of a driving license does not directly affect the outcome of a crash, but might indicate that the driver is unskilled or not motivated to drive safely. An investigation of fatalities and traffic offences in Western Australia found that those driving/riding without a valid license were approximately 3.5 times more likely to test positive for an illicit substance (Palamara et al., 2014). In our study, lack of a valid driver license was associated with impaired driving within all of the substance groups tested. This extensive association between lack of a driver license and impaired driving could possibly be explained by a high recidivism rate among drugged and drunk drivers, even after their driver license has been suspended (Christophersen et al., 2002; National Mobile Police Service, 2009).

In contrast to cannabis and stimulants, the psychoactive medicinal drugs included in this study are per definition legal in use among drivers if used according to prescription doses administered by general practitioners and if no driving restriction has been given. The concentrations found in this study indicate, however, that higher doses than those prescribed were used. The drivers might also have obtained the medicinal drugs from other illegal sources; that 62% had combined medicinal drugs with illegal drugs or alcohol further support this theory. Lack of compliance with other safety rules among those drivers might be more common than among drivers using the same drugs according to prescriptions. The medicinal drugs most frequently detected were clonazepam, diazepam, and zopiclone, which are drugs that might reduce alertness. The associations found among fatally injured drivers between impairment from medicinal drugs and not having a valid driver license and non-use of a seatbelt might therefore be confounded by high-risk personality traits, not necessarily indicating that the medicinal drugs caused risk-taking behaviour.

In our study, 91% of the cannabis-impaired drivers had been speeding and/or not used a seatbelt prior to the crash. However, cannabis impairment was not significantly associated with risky driving actions such as speeding or non-use of a seatbelt when adjusting for age, sex, and the use of other drug groups. The explanation might be that young age was a confounder associated with both cannabis use and risk-taking behaviour. From previous studies, we know that the majority of the arrested cannabis-using drivers in Norway are of young age (Valen et al., 2017a,b), which in itself is likely associated with speeding and non-use of a seatbelt due to higher risk-taking behaviour among young adults (Steinberg, 2010), especially when driving with peers (Scott-Parker and Weston, 2017). Adjustment for age and sex in this study resulted in a more accurate assessment of the effect of cannabis impairment on risky driver actions. However, a high prevalence of speeding and non-use of a seatbelt combined with a reduced reaction time due to impairment from cannabis among young drivers may be a problem for traffic safety, regardless of the age of these drivers and the lack of a direct association between cannabis and unsafe driving behaviours.

4.2. Motorcycle riders

Lack of a significant association between risk factors and impairment from drugs other than alcohol among motorcycle riders in this study might be due to the low sample size. However, the association found in this study between alcohol impairment and non-use of a helmet or not having a valid motorcycle driving license was in accordance with results reported in other countries. Among fatally injured motorcycle riders in the US, increased odds of not wearing a helmet were individually associated with use of alcohol, cannabis, or other drugs (Rossheim et al., 2014). Brown et al. (2011) found that a higher blood alcohol level was associated with a decreasing incidence of wearing a helmet among injured motorcycle riders sent to trauma centres in Texas.

Not having a valid license to operate a motorcycle was previously found to be more prevalent among crash-involved motorcycle riders than among non-crash-involved riders (Kraus et al., 1991) and was associated with being fully or partly responsible for a road traffic crash (Moskal et al., 2012). Riding under the influence of alcohol was also associated with being responsible for a road traffic crash, but the association between alcohol impairment and not having a valid license was not tested (Lardelli-Claret et al., 2005; Moskal et al., 2012). No association between not having a valid license and testing positive for alcohol or drugs was found among fatally injured riders in Ohio (Connor, 2014), contradicting our results.

When comparing fatally injured motorcycle riders with car/van drivers, our results showed that a higher proportion of the investigated fatally injured car/van drivers were categorised as impaired (31%) compared to the investigated motorcycle riders (20%). Furthermore, a higher proportion of both sober and impaired drivers had not used seatbelt or were tired compared to the proportion of riders without a helmet or who were tired. This difference between drivers and riders might be explained by the higher risk of injuries for motorcycle riders when involved in a crash than for car drivers. More mistakes might be necessary for a car driver to be fatally injured in a crash and hence included in this study. However, a higher proportion of both sober and impaired riders had no valid driver license, and a substantially higher proportion of the sober riders had been speeding prior to the crash compared to the sober drivers. Riding a motorcycle when impaired from drugs and/or alcohol was in our study not significantly associated with speeding, as speeding was approximately equally frequently recorded among the fatally injured sober riders.

4.3. Strengths and limitations

This study has some important strengths but also some limitations. The main strengths are that fatally injured drivers who were investigated for use of drugs were analysed for the same types of substances using accredited sensitive and specific analytical methods, only drug findings in blood samples were used, the same cutoff concentrations were systematically used, and there was no limitation in the number of substances reported. For those reasons, our toxicological test results are better suitable for this type of study than those using data from fatality databases with poorer quality of toxicology data.

A possible limitation of this study is that only approximately 70% of the fatally injured drivers and riders were investigated for drugs. Results from the Department of Clinical Pharmacology in Trondheim were available only for 2011–2015, and in this period represented 11% of the total number of investigated drivers and riders.

The associations between impairment from drugs and/or alcohol and unsafe driving behaviours observed in this study cannot necessarily be generalised to drivers in general, as only fatally injured drivers were included.

We cannot exclude that a few drivers/riders might have used substances not tested for in this study that may have affected their ability to drive safely.

In post-mortem samples, drug and alcohol concentrations might not necessary reflect concentrations at the time of incidence due to post-mortem changes, such as redistribution, metabolism, degradation, and formation, among others (Pelissier-Alicot et al., 2003; Drummer, 2004).

Accurate information regarding driver-related risk factors in fatal crashes might be difficult to obtain, especially variables such as inattention and fatigue/drowsy driving. Some data recorded in the Crash Investigation Team Database were therefore based on best judgement if obtaining accurate documentation was impossible.

Data on potentially significant confounders, such as risk-taking behaviour or impulsivity, were not available for this study.

Conclusions from the crash investigation teams regarding crash culpability were not available for multiple vehicle crashes. If including only culpable drivers, it is likely that less marked differences between impaired and sober drivers may have been observed for some risk factors. Culpable drivers have been investigated in several previous studies, with the advantage that probably more equal groups of drivers were compared; hence, better isolating the effect of drugs/alcohol on driving behaviour. Our results do, however, better represent the differences between the whole population of sober and impaired drivers who get fatally injured in road traffic crashes.

With a higher number of studied drivers and riders, more detailed information about the association between individual substance types and risky driving behaviour may be obtained.

5. Conclusions

Drug/alcohol impairment among car/van drivers was significantly associated with not having a valid driver license, speeding, and non-use of a seatbelt; among motorcycle/moped riders, significant associations were found for not having a valid driver license and non-use of a helmet. At least one of these risk factors was also reported in a substantial proportion of the sober drivers and riders. Actions to reduce the impact of speeding on road traffic safety may therefore also reduce the number of fatal crashes related to alcohol or drug impairment, and use of seatbelt alarms may reduce the injury severity among crash-involved drivers. Also, better enforcement of speed limits and legislation regarding use of protective devices may reduce the number of road traffic crashes. Further investigation is needed to understand the contribution of risk-taking personality on both drug/alcohol-impaired driving and other risky driving behaviours.

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References

Adminaite, D., Jost, G., Stipdonk, H., Ward, H., 2018. An Overview of Road Death Data Collection in the EU - PIN Flash Report 35. European Transport Safety Council, Brussels, Belgium. Available at: https://etsc.eu/an-overview-of-road-death-data-

collection-in-the-eu-pin-flash-35/. (Accessed 10 March 2019).
Baselt, R.C., 2011. Disposition of Toxic Drugs and Chemicals in Man, 9th ed. Biomedical Publications, Seal Beach, CA.
Beasley, E.E., Beirness, D.J., Porath-Waller, A.J., 2011. A Comparison of Drug and Alcohol Involved Motor Vehicle Driver Fatalities. Canadian Centre on Substance Abuse, Ottawa, Ontario, Canada. Available at: https://ccsa.ca/comparison-drug-and-alcohol-involved-motor-vehicle-driver-fatalities. (Accessed 17 June 2019).
Bedard, M., Dubois, S., Weaver, B., 2007. The impact of cannabis on driving. Can. J. Public Health 98 (1), 6–11.
Bernhoft, I.M., Hels, T., Lyckegaard, A., Houwing, S., Verstraete, A.G., 2012. Prevalence and risk of injury in Europe by driving with alcohol, illicit drugs and medicines. Proc. – Soc. Behav. Sci. 48, 2907–2916.
Berning, A., Smither, D.D., 2014. Understanding the Limitations of Drug Test Information, Reporting, and Testing Practices in Fatal Crashes (Research Note DOT HS 812 072). National Highway Traffic Safety Administration, Washington, DC (Accessed 9 April 2019). https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812072.
Bogstrand, S.T., Larsson, M., Holtan, A., Staff, T., Vindenes, V., Gjerde, H., 2015. Associations between driving under the influence of alcohol or drugs, speeding and seatbelt use among fatally injured car drivers in Norway. Accid. Anal. Prev. 78, 14–19.
Brady, J.E., Li, G., 2014. Trends in alcohol and other drugs detected in fatally injured drivers in the United States, 1999–2010. Am. J. Epidemiol. 179 (6), 692–699.
Brown, C.V., Hejl, K., Bui, E., Tips, G., Coopwood, B., 2011. Risk factors for riding and crashing a motorcycle unhelmeted. J. Emerg. Med. 41 (4), 441–446.
Busardo, F.P., Pichini, S., Pellegrini, M., Montana, A., Lo Faro, A.F., Zaami, S., Graziano, S., 2018. Correlation between blood and oral fluid psychoactive drug concentrations and cognitive impairment in driving under the influence of drugs. Curr. Neuropharmacol. 16 (1), 84–96.
Christophersen, A.S., Skurtveit, S., Grung, M., Mørland, J., 2002. Rearrest rates among Norwegian drunken drugged drivers compared with drivers. J. Alcohol. Drug Depend. 66 (1), 85–92.
Compton, R., 2017. Marijuana-Impaired Driving – a Report to Congress. (DOT HS 812 440). National Highway Traffic Safety Administration, Washington, DC (Accessed 30 April 2019). https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/812440-marijuana-impaired-driving-report-to-congress.pdf.
Compton, R.P., Berning, A., 2015. Drug and Alcohol Crash Risk (Research Note DOT HS 812 117). National Highway Safety Administration, Washington, DC (Accessed 9 April 2019). http://www.nhtsa.gov/staticfiles/nti/pdf/812117-Drug_and_Alcohol_Crash_Risk.pdf.
Connor, S.M., 2014. Involvement of unendorsed motorcycle operators in fatal crashes in Cuyahoga county, Ohio, 2005–2011. Traffic Inj. Prev. 15 (5), 508–512.
Drummer, O.H., 2004. Postmortem toxicology of drugs of abuse. Forensic Sci. Int. 142 (2–3), 101–113.
Gjerde, H., Strand, M.C., Mørland, J., 2015. Driving under the influence of non-alcohol drugs–an update part i: epidemiological studies. Forensic Sci. Rev. 27 (2), 89–113.
Grimstad, V., Engebretsen, A., 2016. Dybdeanalyser av dødsulykker i vegtrafikken 2015 [In-Depth Analyses of Fatal Road Accidents in The Year 2015]. Norwegian Public Roads Administration, Oslo, Norway.
Hartman, R.L., Huestis, M.A., 2013. Cannabis effects on driving skills. Clin. Chem. 59 (3), 478–492.
Karjalainen, K., Blencowe, T., Lillsunde, P., 2012. Substance use and social, health and safety-related factors among fatally injured drivers. Accid. Anal. Prev. 45, 731–736.
Kraus, J.F., Anderson, C., Zador, P., Williams, A., Arzemanian, S., Li, W.C., Salatka, M., 1991. Motorcycle licensure, ownership, and injury crash involvement. Am. J. Public Health 81 (2), 172–176.
Lacey, J.H., Kelley-Baker, T., Furr-Holden, D., Voas, R.B., Romano, E., Ramirez, A., Brainard, K., Moore, C., Torres, P., Berning, A., 2009. 2007 National Roadside Survey of Alcohol and Drug Use by Drivers - Drug Results (DOT HS 811 249). National Highway Safety Administration, Washington, DC. Available at: www.nhtsa.gov/DOT/NHTSA/Traffic%20Injury%20Control/Articles/Associated%20Files/811249.pdf, (Accessed 17 June 2019).
Lardelli-Claret, P., Jimenez-Moleon, J.J., De Dios Luna-Del-Castillo, J., Garcia-Martin, M., Bueno-Cavanillas, A., Galvez-Vargas, R., 2005. Driver dependent factors and the risk of causing a collision for two wheeled motor vehicles. Inj. Prev. 11 (4), 225–231.
Laude, J.R., Fillmore, M.T., 2015. Simulated driving performance under alcohol: effects on driver-risk versus driver-skill. Drug Alcohol Depend. 154, 271–277.
Liu, C., Huang, Y., Pressley, J.C., 2016. Restraint use and risky driving behaviors across drug types and drug and alcohol combinations for drivers involved in a fatal motor vehicle collision on U.S. Roadways. Inj. Epidemiol. 3 (1), 9.
Martin, T.L., Solbeck, P.A., Mayers, D.J., Langille, R.M., Buczek, Y., Pelletier, M.R., 2013. A review of alcohol-impaired driving: the role of blood alcohol concentration and complexity of the driving task. J. Forensic Sci. 58 (5), 1238–1250.
Ministry of Transport and Communications, 2016. Forskrift om endring i forskrift om faste grenser for påvirkning av andre berusende eller bedøvende middel enn alkohol m.m. (forskrift om faste grenser) [Revision of Fixed Limits for Drugs in The Traffic]. Ministry of Transport and Communications, Oslo, Norway (Accessed 30 April 2019). https://lovdata.no/dokument/LTI/forskrift/2016-01-12-19.
Moskal, A., Martin, J.-L., Laumon, B., 2012. Risk factors for injury accidents among moped and motorcycle riders. Accid. Anal. Prev. 49, 5–11.
National Mobile Police Service, 2009. Hvem fortjener politiets oppmerksomhet? En studie av dødsulykkene i trafikken i 2004 og 2005 [Who Deserves Police Attention? A Study of Fatal Road Traffic Accidents in 2004 and 2005]. National Mobile Police Service, Stavern, Norway.
Palamara, P., Broughton, M., Chambers, F., 2014. Illicit Drugs and Driving: An Investigation of Fatalities and Traffic Offences in Western Australia, Report No. Rr 13-001. Curtin-Monash Accident Research Centre, Bentley, Australia (Accessed 30 April 2019). http://c-marc.curtin.edu.au/local/docs/final-drugs-and-driving-november-2014_upload.pdf.
Pelissier-Alicot, A.L., Gaulier, J.M., Champsaur, P., Marquet, P., 2003. Mechanisms underlying postmortem redistribution of drugs: a review. J. Anal. Toxicol. 27 (8), 533–544.
Pietrasik, T., 2018. Road Traffic Injuries. World Health Organization, Geneva Switzerland (Accessed 30 April 2019). https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries.
Romano, E., Torres-Saavedra, P., Voas, R.B., Lacey, J.H., 2017. Marijuana and the risk of fatal car crashes: what can we learn from FARS and NRS data? J. Prim. Prev. 38, 315–328.
Romano, E., Voas, R.B., 2011. Drug and alcohol involvement in four types of fatal crashes. J. Stud. Alcohol Drugs 72 (4), 567–576.
Rossheim, M.E., Wilson, F., Suzuki, S., Rodriguez, M., Walters, S., Thombs, D.L., 2014. Associations between drug use and motorcycle helmet use in fatal crashes. Traffic Inj. Prev. 15 (7), 678–684.
Sagberg, F., 2018. Characteristics of fatal road crashes involving unlicensed drivers or riders: implications for countermeasures. Accid. Anal. Prev. 117, 270–275.
Schulz, M., Iwersen-Bergmann, S., Andresen, H., Schmoldt, A., 2012. Therapeutic and toxic blood concentrations of nearly 1,000 drugs and other xenobiotics. Crit. Care 16 (4), R136.
Schweitzer, J.B., Holcomb, H.H., 2002. Drugs under investigation for attention-deficit hyperactivity disorder. Curr. Opin. Invest. Drugs 3 (8), 1207–1211.
Scott-Parker, B., Weston, L., 2017. Sensitivity to reward and risky driving, risky decision making, and risky health behaviour: a literature review. Transp. Res. Part F Traffic Psychol. Behav. 49, 93–109.
Steinberg, L., 2010. A dual systems model of adolescent risk-taking. Dev. Psychobiol. 52 (3), 216–224.
Strand, M.C., Fjeld, B., Arnestad, M., Mørland, J., 2011. Psychomotor Relevant Performance: 1. After Single Dose Administration of Opioids, Narcoanalgesics and Hallucinogens to Drug Naïve Subjects 2. In Patients Treated Chronically with Morphine or methadone/buprenorphine. Norwegian Institute of Public Health, Oslo, Norway (Accessed 30 April 2019). https://www.bast.de/Druid/EN/deliverales-list/downloads/Deliverable_1_1_2_C.pdf.
Strand, M.C., Gjerde, H., Mørland, J., 2016. Driving under the influence of non-alcohol drugs–an update. Part ii: experimental studies. Forensic Sci. Rev. 28 (2), 79–101.
The Pharmacology Portal, 2018. Farmakologiportalen - norsk portal for legemiddel- og rusmiddelanalyser [The Pharmacology Portal - Norwegian Portal for Drug Analyses]. The Norwegian Association of Clinical Pharmacology, Oslo, Norway (Accessed 30 April 2019). http://www.farmakologiportalen.no/content/3729/Information-in-English.
Valen, A., Bogstrand, S.T., Vindenes, V., Gjerde, H., 2017a. Increasing use of cannabis among arrested drivers in Norway. Traffic Inj. Prev. 18 (8), 801–806.
Valen, A., Bogstrand, S.T., Vindenes, V., Gjerde, H., 2017b. Toxicological findings in suspected drug-impaired drivers in Norway - trends during 1990–2015. Forensic Sci. Int. 280, 15–24.
Valen, A., Bogstrand, S.T., Vindenes, V., Frost, J., Larsson, M., Holtan, A., Gjerde, H., 2019. Fatally injured drivers in Norway 2005-2015 – trends in substance use and crash characteristics. Traffic Inj. Prev. 20 (5), 460–466. https://doi.org/10.1080/15389588.2019.1616700.
Verstraete, A.G., Legrand, S.A., Vandam, L., Hughes, B., Griffiths, B., 2014. Drug Use, Impaired Driving, and Traffic Accidents, Second edition. Publications Office of the European Union, Luxembourg (Accessed 30 April 2019). http://www.emcdda.europa.eu/publications/insights/2014/drugs-and-driving.
Vindenes, V., Jordbru, D., Knapskog, A.B., Kvan, E., Mathisrud, G., Slørdal, L., Mørland, J., 2012. Impairment based legislative limits for driving under the influence of non-alcohol drugs in Norway. Forensic Sci. Int. 219 (1–3), 1–11.
Wu, D., Hours, M., Martin, J.L., 2018. Risk factors for motorcycle loss-of-control crashes. Traffic Inj. Prev. 19 (4), 433–439.