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Land-traffic crash leading to passenger vehicle submersion, drowning and other fatal injuries: A 44-year study based on records from the Finnish Crash Data Institute

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ABSTRACT

Background: Land motor traffic crash (LMTC) -related drownings are an overlooked and preventable cause of injury death. The aim of this study was to analyze the profile of water-related LMTCs involving passenger cars and leading to drowning and fatal injuries in Finland, 1972 through 2015. *Materials and methods:* The database of the Finnish Crash Data Institute (FCDI) that gathers detailed information on fatal traffic accidents provided records on all LMTCs leading to drowning during the study period and, from 2002 to 2015, on all water-related LMTCs, regardless of the cause of death. For each crash, we considered variables on circumstances, vehicle, and fatality profiles. *Results:* During the study period, the FCDI investigated 225 water-related LMTCs resulting in 285 fatalities. The majority of crashes involved passenger cars (124), and the cause of death was mostly drowning (167). Only 61 (36.5%) fatalities suffered some–generally mild–injuries. The crashes frequently occurred during fall or summer (63.7%), in a river or ditch (60.5%), and resulted in complete vehicle's submersion (53.7 %). Half of the crashes occurred in adverse weather conditions and in over 40% of the cases, the driver had exceeded the speed limit. Among drivers, 77 (68.8%) tested positive for alcohol (mean BAC 1.8%). *Conclusion:* Multidisciplinary investigations of LMTCs have a much higher potential than do exclusive police and medico-legal investigations. The risk factors of water-related LMTCs are similar to those of other traffic crashes. However, generally the fatal event in water-related LMTC is not the crash itself, but drowning. The paucity of severe physical injuries suggests that victims' functional capacity is usually preserved during vehicle submersion. *Practical Applications:* In water-related LMTCs, expansion of safety measures is warranted from general traffic-injury prevention to prevention of drowning, including development of safety features for submerged vehicles and simple self-rescue protocols to escape from a sinking vehicle.

1. Introduction

Data on land-traffic crash leading to vehicle submersion is scarce, with general and in-depth studies being limited to only a few countries (Austin, 2011; Stjernbrandt, Öström, Eriksson, & Björnstig, 2008; Wintemute, Kraus, Teret, & Wright, 1990). According to these studies, vehicle submersion accounts for up to 11% of overall drowning deaths and 4.7% of all traffic fatalities (McDonald & Giesbrecht, 2013a, 2013b). In recent years, development of safety instructions and vehicle safety features specific for this type of crashes has gained attention (Giesbrecht and McDonald (2010 and 2011); McDonald & Giesbrecht, 2013a, 2013b; Gagnon, McDonald, Pretorius, & Giesbrecht, 2012; Giesbrecht, 2016; Giesbrecht et al., 2017; McDonald, Moser, & Giesbrecht, 2019). In Finland, motor-vehicle submersion accounts for approximately 5% of all fatal unintentional drownings and nearly 4% of all fatal land-traffic accidents (Lunetta & Haikonen, 2020).

In this study, based on data provided by the Finnish Crash Data Institute (FCDI), we evaluated the circumstantial and individual profile of land motor traffic crashes (LMTC) leading to vehicle submersion, involving drowning and other fatal injuries, in Finland, 1972 to 2015, Finnish Crash Data Institute (2020).

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2. Material and methods

2.1. Source of data

The Finnish Crash Data Institute (FCDI), a unit of the Finnish Motor Insurers' center, coordinates a national investigative system that assesses land traffic crashes leading to death or to severe trauma. The system includes 20 regional investigation teams, which have representatives from differing fields of expertise: police, traffic, and vehicle engineering, behavioral science and medicine, often forensic pathologists. The teams aim to assess the underlying cause of each crash and recommend ways to improve traffic safety, but their conclusions cannot be factors in any insurance, civil, or penal litigation.

In each accident, the investigation teams collect hundreds of variables, which are stored in a database maintained by the FCDI. Moreover, the FCDI archives the entire file of each investigation, which includes a detailed standard form filled in by each expert, documents of the police investigation and medico legal examination, photos, and possible drawings of the crash site, and a summary report. The database allows extraction of specific case groups by any individual variable. The FCDI makes available on request this data and original files for organizations and for individual researchers involved in road safety and traffic injury prevention. In addition to these tabulated data, we also performed a manual review of the original files.

2.2. Data selection

All LMTCs resulting in fatal drowning from 1972 to 2015 were extracted from the FCDI database and individual files using WHO ICD injury codes (I-code) for drowning that were in use during the study period (ICD 8th and 9th: 994.1; ICD 10th: T75.1). Moreover, for the period 2002–2015, extraction of LMTCs resulting in vehicle submersion was possible—regardless of cause of death—utilizing the variable "*incomplete or complete vehicle submersion.*"

A total of 225 LMTCs were found involving 285 fatalities. These cases included 137 passenger motor-vehicle crashes (resulting in 182 fatalities), 32 crashes in vehicles other than passenger cars (resulting in 36 fatalities), and 56 snowmobile crashes (resulting in 67 fatalities). By a general definition, provided by Statistics Finland (SF), a passenger car is "a road motor vehicle, other than a moped or a motor cycle, intended for the carriage of passengers and designed to seat no more than nine persons (including the driver)" Statististics Finland, 2020. The 137 passenger motor-vehicle crashes included 124 crashes where drowning was the cause of death ($n = 167$) and 13 crashes were the cause of death was other than drowning ($n = 15$). This survey focuses on the 124 crashes where drowning was the cause of death. The 32 crashes involving non-passenger motor vehicles were examined separately. Snowmobile crashes related to vehicle submersion (56 accidents leading to 67 fatalities) were excluded from this report, as they have been the focus of separate, detailed surveys (Gustafsson & Eriksson, 2013; Öström & Eriksson, 2002). Crashes involving submersion of industrial vehicles are usually occupational events investigated by the Workers' The Finnish Workerś Compensation Center (2020), which publishes detailed reports on selected cases.

2.3. Data analysis

Throughout the study period (1972–2015), the following variables were considered in regard to each crash: number of vehicles involved, number of fatalities, level of submersion (complete or partial), position in water (upright, upside down, and on the side), type of watercourse, presence of guardrails, calendar month, weather conditions, and, from 2002 onwards, the target of the vehicle's first impact. As to the fatalities profile, we considered age, sex, manner and cause of death, location in vehicle, use of safety equipment, injuries sustained, and detectable alcohol and drugs.

Since 1984, the FCDI has tabulated injuries by means of the Abbreviated Injury Scale system (AIS), which classifies the location, type, and severity of the injury (Loftis, Price, & Gillich, 2018). Injury severity is classified on a scale from 1 to 6, where 3 or more is considered severe or life-threatening. From 1972 through to 1983, we retrospectively coded the injuries by reviewing the original autopsy reports.

Fatalities' blood alcohol concentration (BAC) was determined from samples collected at medico-legal autopsy. In surviving drivers, alcohol concentration was determined either by breath alcohol or by blood test. In this study, BAC and breath alcohol results were merged for practical reasons. The BAC unit used is per mille, ‰ (=1mg/g = ≈10 mg/100 mL). In addition to alcohol, we scrutinized medicinal drugs and drugs of abuse with the potential of impairing driving skills.

3. Results

Overall, 225 water-related LMTCs involving all types of motor vehicles and leading to 285 fatalities were extractable from the FCDI database. These comprised 124 passenger car crashes, which led to 167 drowning deaths, and 13 passenger car crashes in which 15 fatalities died from causes other than drowning: 11 from injury, 1 each from intoxication or mechanical asphyxia, 1 from suffocation by mud, and 1 from a medical condition. As to the manner of death, the majority of the drowning fatalities were accidents (139, 83.2%). The remaining cases included 9 suicides, 1 homicide, and 9 cases for which the intent remained undetermined after full investigations; in 9 cases, the manner of death was not recorded.

In addition, 32 crashes, accounting for 36 fatalities (30 drivers, 6 passengers), involved motor vehicles other than passenger cars: 12 tractors, 10 trucks, 4 all-terrain vehicles, 2 motorcycles, and 1 case each involving a mobility scooter, a light quadricycle, an excavator, and a riding lawn mower. The manner of death was in all these cases unintentional. Twelve drivers tested positive for alcohol and two for a psychotropic drug. In one single crash, four serviceman passengers drowned when an army truck on a bridge, trying to evade a collision with an oncoming vehicle, fell into a river. The driver died of mechanical asphyxia.

The availability of data differed between variables, but generally, it was high. Data were complete for season of the event, type of watercourse, age and sex of fatalities, number of vehicles involved, injuries, each at 100%, and near complete for weather conditions (98.4%), vehicle submersion (97.6%), position of the fatalities in the vehicle (97.6%), road design for crashes that occurred on a public road (96.9%), blood alcohol content for fatalities (94.6%) and breath or blood alcohol content for all drivers (90.3%). The percentage of available information was lower for guardrails, position of the submerged vehicle, and vehicles speed: 83.8%, 70.8%, and 58%, respectively.

Tables 1 and 2 summarize the crash, vehicle, and fatality characteristics of land-traffic crash resulting in passenger vehicle submersion leading to drowning (1972–2015), and those of similar crashes leading to other injury deaths (2002–2015). Furthermore, the following sections display additional information for the former cases of drowning deaths.

3.1. Crash and vehicle characteristics

Guardrails were present in 36 (34.6%) crashes. In 16 crashes, the vehicles went over the rail, in 7 penetrated the rail, and in 13

Table 1
Crash and vehicle characteristics of land-traffic crashes resulting in passenger vehicle[1] submersion and drowning (1972–2015: 124 crashes) and other causes of death (2002–2015: 13 crashes).

Crash and vehicle characteristics	Drowning n (%)[3]	Death other than drowning[2] n (%)[3]
Total number of crashes	124 (100)	13 (100)
Season		
Fall	44 (35.5)	4 (30.8)
Summer	35 (28.2)	2 (15.4)
Winter	23 (18.5)	2 (15.4)
Spring	22 (17.8)	5 (38.5)
Data unavailable	0	0
Weather type		
Dry (summer)	54 (44.3)	8 (66.7)
Snow or ice	38 (31.1)	0
Wet	23 (18.9)	1 (8.3)
Dry (winter)	7 (5.7)	3 (25.0)
Data unavailable	2	1
Watercourse		
River or ditch	75 (60.5)	10 (76.9)
Lake or pond	28 (22.6)	2 (15.4)
Sea	21 (16.9)	1 (7.7)
Data unavailable	0	0
Guardrails		
In place	36 (34.6)	2 (25.0)
No guardrails (public road)	40 (38.5)	6 (75.0)
No guardrails (off road)	28 (26.9)	0
Data unavailable	20	5
Road profile of crash site (public road)		
Curve	57 (61.3)	7 (58.3)
Straight road	36 (38.7)	5 (41.7)
Data unavailable	3	0
Speed limit		
Exceeded	42 (43.4)	3 (25.0)
Data unavailable	52	1
Level of submersion of vehicle		
Complete	65 (53.7)	2 (15.4)
Partial	52 (43.0)	11 (84.6)
Vehicle did not submerge (victim ejected into water)	4 (3.3)	0
Data unavailable	3	0
Position of vehicle in water		
Upside down	54 (63.5)	5 (62.5)
Upright	20 (23.5)	1 (12.5)
On side	11 (13.0)	2 (25.0)
Data unavailable	35	5

[1] Passenger vehicle is "a road motor vehicle, other than a moped or a motor cycle, intended for the carriage of passengers and designed to seat no more than nine persons (including the driver)"(Statistics Finland).
[2] Other causes of death included injuries, intoxication, mechanical asphyxia, and natural death.
[3] Percentage of cases for which information was available.

Table 2
Characteristics of fatalities in passenger vehicle land-traffic crashes resulting in vehicle submersion and death by either drowning (1972–2015: 124 crashes) or other causes (2002–2015: 13 crashes).

Fatalities' characteristics	Drowning n (%)[2]	Death other than drowning[1] n (%)[2]
Total number of fatalities	167 (100)	15 (100)
Manner of death		
Accident	139 (88.0)	13 (86.7)
Suicide	9 (5.7)	1 (6.7)
Homicide	1 (0.6)	0
Undetermined	9 (5.7)	0
Natural death	0	1 (6.7)
Data unavailable	9	0
Location of victim		
Driver's seat	95 (58.3)	11 (73.3)
Front passenger seat	40 (24.5)	2 (13.3)
Rear passenger seat	28 (17.2)	2 (13.3)
Data unavailable	4	0
Seatbelt		
In use	49 (29.5)	8 (53.3)
Not in use or unknown[3]	117 (70.5)	7 (46.7)
Safety seat	1	0
Injuries		
Any injury	61 (36.5)	
Head region	45 (26.9)	11 (73.3)
Bone fracture	13 (7.8)	
Internal organs	7 (4.2)	
Crush injury/multiple severe injuries	0	11 (73.3)
Data unavailable	0	0
Alcohol positive[4]		
Overall fatalities	103 (65.2)	5 (33.3)
Driver fatalities	60 (53.6)	4 (36.4)
Passenger fatalities	43 (69.4)	2 (50)
Data unavailable, overall fatalities	9	0
Other drugs positive		
Driver fatalities	17	1

[1] Other causes of death included injuries, intoxication, mechanical asphyxia, and natural death.
[2] Percentage of cases for which information was available.
[3] Including cases where the individual had possibly unbuckled the seatbelt before death.
[4] The study material disclosed also 17 crashes where the vehicle's driver survived but tested positive for alcohol.

missed the rail or hit the head of the rail and were redirected towards the water.

In 42 (43.3%) cases, the speed limit had been exceeded. Average excess speed was 35 km/h (range 5–120 km/h).

In only four crashes were two or more vehicles involved. As the first target of the crash, other than water itself or a guardrail, these were reported from 2002 onwards: a tree or a sign or light pole in each of two cases, and in one case each, the target was a junction embankment or an elk.

3.2. Fatalities' characteristics and autopsy findings

Fatalities' overall mean age was 34.7 years (range 1–92; SD: 19). Mean age for drivers was 39.4 (range 16–92; SD: 18.5) and for passengers 28.4 years (range 1–76; SD: 18).

Overall, in fatal crashes, 95 drivers died and 29 survived. In 29 (24.4%) crashes, more than one fatality was involved, the average number of fatalities being, in these cases, 2.5. There were no crashes in which one of the fatalities drowned and the other(s) died of other cause(s).

Information about survival time after the crash was available only from 2002 to 2015, in a total of 52 cases. Most fatalities died at the crash site (45, 86.5%). Two died 1 to 3 h after the crash, four after 4 to 7 h, and one died 2 months later at hospital. Eight fatalities received resuscitation at the crash site: one died at the scene, the remaining died during transport to hospital or at hospital.

The investigation team concluded that in 26 cases, the use of a seatbelt could have improved the probability of survival. On the other hand, in one fatality, the seatbelt and airbag might have contributed to death by hampering the attempts to escape.

In the cause-of-death certificate, injuries—6 of which were intracranial—represented a contributing factor in 20 cases, and a medical condition, mostly a cardiac disease, in 15. Moreover, hypothermia and thoracic compression were contributing factors, each in one case.

Among the 61 fatalities who suffered injuries, 45 (73.8%) had severe injuries in the head region. Only nine, however, were intracranial (subdural and subarachcnoidal hemorrhages, brain contusions, brain edema; AIS code $\geq$ 3). Mild external head injuries (AIS code 1-2) included bruising, abrasion, or laceration of the scalp or face. Bone fractures (AIS $\geq$ 3) occurred in 13 fatalities, and included fractures of the femur, humerus, or ribs. Only seven fatalities sustained severe injuries (AIS 4 or 5) to the internal organs (lungs, heart, aorta, or liver).

Among all drivers, including fatalities and survivors, mean breath alcohol content (BAC) was 1.8‰ (range 0.3–4.2‰). For fatalities of all ages, drivers or passengers, BAC was also 1.8‰ (range 0.2–4.2‰), as well as for passengers alone (range 0.3–4‰). Additionally, 17 deceased drivers tested positive for one or more psychotropic drugs (benzodiazepines, tramadol, citalopram, amitriptyline, carbamazepine, amphetamine, cannabis). Ten of these drivers were under the influence of both alcohol and psychotropic drugs. Six of the passengers tested positive for psychotropic drugs (benzodiazepines, citalopram, amphetamine, cannabis), and three of them were also under the influence of alcohol.

4. Discussion

Data collected by SF, with cross-examination of ICD-10 I- and E codes for drowning, allow extraction of data on all LMTCs leading to drowning (Lunetta, Penttilä, & Sajantila, 2002). During the period 1971–2013, 547 fatal drownings occurred as a result of LMTCs, (i.e., annually 2.5 fatalities/ 1,000,000 inhabitants; Lunetta & Haikonen, 2020). In Finland, LMTC-related drowning represents 3.8% of all land-traffic accidents and 5.1% of all unintentional drowning (Lunetta & Haikonen, 2020). In other high-income countries, vehicle submersion accounts for up to 4.7% (New Zealand) of all traffic fatalities and up to 11.6% (New Zealand) of all unintentional drowning deaths (McDonald & Giesbrecht, 2013a, 2013b). In Sweden, a Nordic country like Finland, the share of LMTC-related drownings of all traffic deaths was 1.5% (Stjernbrandt et al., 2008), whereas in the United States it was 1% (Austin, 2011), even though the latter number of drowning fatalities could be underestimated. The differences between these countries might be a result from differences in geography and in extent of road networks adjacent to watercourse or from the studies' differing inclusion criteria for cases.

The rational for WHO ICD classification under "traffic accidents" of land-traffic related drowning is the collection of data for road safety work and crash prevention. However, this approach hinders assessment of the actual burden of drowning (Lunetta, Penttilä, & Sajantila, 2002; Smith & Langley, 1998).

SF data does not allow in-depth survey of LMTCs and provide no information on LMTCs that result in vehicle submersion and death for causes other than drowning. The FCDI, established in 1967 as the Traffic Safety Committee of Insurance Companies (VALT), maintains a database, which provides more comprehensive data. These data was the basis of the present study.

Although the FCDI aims, by statute, to investigate all fatal LMTCs in Finland, coverage is not 100%, however. During the period 1996–2013, the FCDI covered approximately 84.3% of passenger vehicle and 56.7% of snowmobile-submersion related drownings reported in a recent study based on SF data (Lunetta & Haikonen, 2020). Missing cases may be due, at least in part, to absent or delayed communications between the local police and the FCDI, resulting in a lack of adequate investigations.

A thorough analysis of the sequence of events in LMTCs leading to vehicle submersion and drowning may allow the disentangling of factors that may be targeted for primary, secondary, and tertiary preventive actions.

Our survey discloses risk factors crucial for primary prevention; these are similar to those in all other LMTCs: hazardous road conditions (adverse weather, inadequate design, poor management), drivers' human errors, speeding, use of alcohol, and use of other drugs. Indeed, 61 of the crashes happened in adverse weather conditions, and in 17 of these, the driver was speeding. Enforcing the speed limit during the dark winter season has contributed to reduction in fatal traffic accidents (VTT Technical Research center). Furthermore, adapting speed limits to weather conditions is already the practice on motorways in several EU countries (European Commission mobility and transport), including Finland, and expansion of this measure on other public roads could be beneficial.

In our study, only one-third of the crash sites were equipped with guardrails, and of these, some were ineffective in preventing the vehicle entering the body of water. Similar reports have appeared in other studies (Wintemute et al., 1990). Developing the network of effective guardrails near water systems might reduce crash-related drowning.

Driving under the influence of alcohol or psychotropic drugs is a well-known risk factor for fatal and nonfatal LMTCs (Penning, Veldstra, Daamen, Olivier, & Verster, 2010; Brady & Li, 2014). In our study, alcohol was the most important single risk factor for LMTC-related drowning. Our percentage of alcohol-positive LMTC-related drowning (65.2%) is much higher than that reported in Finland for overall land-traffic crashes (about 20%), but is similar to that reported for accidental drowning (about 55%; Pajunen et al., 2017; Lunetta & Haikonen, 2020). This percentage is much higher than that reported in Sweden (Stjernbrandt et al., 2008), but somewhat lower than in a U.S. survey (Wintemute et al., 1990). Moreover, the percentage in our study is higher than in the data provided by SF (Lunetta & Haikonen, 2020). This could be, at least in part, due to inconsistencies in determining alcohol as a contributing factor in the cause-of-death certificate, primarily in the earlier years of our study period.

Alcohol and psychotropic drugs play a role in the chain of events leading to the crash itself, but may also hamper drivers' and passengers' attempts to escape from the submerged vehicle. In our study, the high percentage of alcohol-positive fatalities among passengers corroborates this hypothesis. As for psychotropic drugs, only 17 of the drivers and 6 of the passengers tested positive. The effects of alcohol and other drugs in hampering the occupants' escape from submerged vehicles could be emphasized in preventive campaigns.

A medical condition, most often cardiac, was considered a contributing factor in only 15 cases. It may, however, be almost impossible to assess whether a disease has initiated the course of events leading to a crash, has precipitated the fatal outcome after submersion, or has had no effect at all.

Similarly to other surveys (Hammett, Watts, Hooper, Pearse, & Naito, 2007; Stjernbrandt et al., 2008; Wintemute et al., 1990), our study showed that only a minority of fatalities (14.4%) sustained severe injuries. This suggests that, if sober and not limited by age or by any medical condition, a victim's capability to escape a submerged vehicle is in most cases preserved, although even minor head traumas may also affect a victim's state of consciousness.

The present study also emphasizes the potential role of secondary prevention. Contrary to other land-traffic crashes, the fatal event is not the crash itself, but drowning following vehicle submersion. Once the vehicle is submerged, preventive countermeasures shift significantly from traffic safety issues to drowning prevention.

In addition to rescue service planning, general swimming- and lifesaving education and resuscitation training, secondary prevention includes development of vehicle safety features and safety instruction on how to escape promptly from a submerged vehicle.

This will be based on knowledge of the chronological sequence of vehicle submersion (Giesbrecht, 2016).

The "vehicle in water" emergency dispatch protocol includes instructions on how to escape from a sinking vehicle by unfastening seatbelts and exiting through a window while the vehicle is still floating. When performed rapidly, within approximately one minute, the self-rescue and escape SWOC protocol (Seatbelts off, Windows open or broken, Out immediately, Children first) can contribute efficiently to prevent the fatal outcome of these vehicle accidents (Giesbrecht, 2016; McDonald et al., 2019). Since many victims may not know, or forget, that they must open a window to escape, an automatic window opening system that operates upon contact with water could improve the chances of survival (Giesbrecht et al., 2017).

An issue under debate regarding a submerged vehicle is whether a seatbelt (or an airbag) may hamper the victim's attempt to promptly escape. In our study, this occurred likely in only one case. Moreover, the present study disclosed that only one-third of the fatalities were found wearing a seat-belt, a figure lower than the 52% reported in the United States (Austin, 2011). In some crashes, however, the investigation team did not report whether fatalities were found wearing their seatbelt or not; it is also likely that some fatalities had unfastened their seatbelts after the crash but were unable to exit the vehicle. Here, most of the submerged vehicles were in an upside down position. If the passenger compartment is not filled completely with water, for example in cases of partial vehicle submersion, the victim's body weight can prevent opening the seatbelt buckle. Mechanisms that make unbuckling the belt easier in this situation could be useful. Our paucity of data on the response of rescue and emergency services after the crash lessens the possibility of any adequate evaluation of such measures. Although most fatalities died at the scene before any intervention, tertiary prevention measures such as first intervention and medical care after rescue should be developed with a focus not only on injuries but also on drowning.

Water-related LMTCs resulting in deaths other than drowning were infrequent and almost exclusively characterized by partial submersion of the vehicle. In these fatalities, aspiration of liquid may be difficult to assess at autopsy even it may play a contributing role in the chain of events leading to death.

5. Conclusion and practical applications

The nationwide investigation system operated by the FCDI provides detailed data on LMTCs leading to vehicle submersion, drowning, or other injury deaths, more so than do regular police and medico-legal investigations. Regardless of this, what is warranted is more systematic data collection and the introduction of further variables such as water depth and temperature at the site of vehicle submersion. In Finland, water-related LMTCs are an overlooked but preventable cause of death. Instead of the crash itself, in the majority of the cases, the fatal event is drowning. Therefore, LMTCs resulting in vehicle submersion call for specific preventive counter-measures that encompass not only those of typical LMTCs but also partially overlap those developed for general drowning. Counter-measures could include public education on how to escape from a sinking vehicle and automatic window opening systems that provide an exit when a vehicle is submersed in water.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Austin, R. (2011). Drowning deaths in motor vehicle traffic accidents. National Highway Traffic Safety Administration, USA.11-0170.

Brady, J. E., & Li, G. (2014). Trends in alcohol and other drugs detected in fatally injured drivers in the United States, 1999–2010. *American Journal of Epidemiology., 179*, 692–699.

Finnish Crash Data Institute; [accessed 2020 Jan 11]. https://www.oti.fi/en/oti/.

European Commission, mobility and transport, road safety. Current speed limit policies; accessed 2020 Jan 11. https://ec.europa.eu/transport/road_safety/specialist/knowledge/speed/speed_limits/current_speed_limit_policies_en.

Gagnon, D., McDonald, G. K., Pretorius, T., & Giesbrecht, G. G. (2012). Clothing buoyancy and underwater horizontal swim distance after exiting a submersed vehicle simulator. *Aviation, Space and Environmental Medicine, 83*, 1077–1083.

Giesbrecht, G. G., & McDonald, G. K. (2010). My car is sinking: automobile submersion, lessons in vehicle escape. *Aerospace Medicine and Human Performance*, 81:779–784.

Giesbrecht, G. G., & McDonald, G. K. (2011). Exit strategies and safety concerns for machinery occupants following ice failure and submersion. *Aerospace Medicine and Human Performance*, 82:52–57.

Giesbrecht, G. G. (2016). The evidence base for a new "Vehicle in Water" emergency dispatch protocol. Annals of Emergency Dispatch and Response, 4:3–9.

Giesbrecht, G. G., Percher, M., Brunet, P., Richard, Y., Alexander, M., Bellemare, A., ... Pham, D. (2017). An automatic window opening system to prevent drowning in vehicles sinking in water. *Cogent Engineering, 4*, 1347990.

Gustafsson, T., & Eriksson, A. (2013). Off-road vehicle fatalities: A comparison of all-terrain vehicle and snowmobile accidents in Sweden. *IATSS Research, 37*, 12–15.

Hammett, M., Watts, D., Hooper, T., Pearse, L., & Naito, N. (2007). Drowning deaths of U.S. Service personnel associated with motor vehicle accidents occurring in Operation Iraqi Freedom and Operation Enduring Freedom, 2003–2005. *Military Medicine, 172*, 875–878.

Loftis, K. L., Price, J., & Gillich, P. J. (2018). Evolution of the Abbreviated Injury Scale: 1990–2015. *Traffic Injury Prevention, 19*, 109–113.

Lunetta, P., Penttilä, A., & Sajantila, A. (2002). Drowning in Finland: "external cause" and "injury" codes. *Injury Prevention, 8*, 342–344.

Lunetta, P., & Haikonen, K. (2020). Land motor vehicle-related fatal drowning in Finland: A nation-wide population-based survey. *Traffic Injury Prevention*, DOI: 10.1080/15389588.2020.1810678.

McDonald, G. K., & Giesbrecht, G. G. (2013). Vehicle submersion: A review of the problem, associated risks, and survival information. *Aviation, Space and Environmental Medicine, 84*, 498–510.

McDonald, G. K., & Giesbrecht, G. G. (2013). Escape from a submersible vehicle simulator wearing different thermoprotective flotation clothing. *Aviation, Space and Environmental Medicine, 84*(7), 708–715.

McDonald, G. K., Moser, C. A., Giesbrecht, G. G. (2019). Public knowledge, attitudes and practices of vehicle submersion incidents: a pilot study. *Injury Epidemiology* 6:21.

Öström, M., & Eriksson, A. (2002). Snowmobile fatalities aspects on preventive measures from a 25-year review. *Accident Analysis and Prevention, 4*, 563–568.

Pajunen, T., Vuori, E., Vincenzi, F. F., Lillsunde, P., Smith, G., & Lunetta, P. (2017). Unintentional drowning: Role of medicinal drugs and alcohol. *BMC Public Health, 17*, 388.

Penning, R., Veldstra, J. L., Daamen, A. P., Olivier, B., & Verster, J. C. (2010). Drugs of abuse, driving and traffic safety. *Current Drug Research Reviews, 3*, 23–32.

Smith, G. S., & Langley, J. D. (1998). Drowning surveillance: How well do E codes identify submersion fatalities. *Injury Prevention, 4*, 135–139.

Stjernbrandt, A., Öström, M., Eriksson, A., & Björnstig, U. (2008). Land motor vehicle-related drownings in Sweden. *Traffic Injury Prevention, 9*(6), 539–543.

Statistics Finland. [accessed 2020 Sep 16]. https://www.stat.fi/til/mkan/kas_en.html.

Wintemute, G. J., Kraus, J. F., Teret, S. P., & Wright, M. A. (1990). Death resulting from motor vehicle immersions: The nature of the injuries, personal and environmental contributing factors, and potential interventions. *American Journal of Public Health, 80*, 1068–1070.

The Finnish Workers' Compensation Center. [accessed 2020 Jan 11]. https://www.tvk.fi/en/.

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