VEHICLE-RELATED INJURIES

with emphasis on fatality prevention

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Umeå 1993
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ABSTRACT

According to WHO, Sweden should aim to reduce unintentional fatalities, particularly vehicle-related injuries, by 25% by the year 2000. The aim of this thesis was to analyze vehicle-related injuries and injury events, especially the contributory effects of alcohol and disease and the injury reducing capacity of helmets and airbags in order to point out some preventive measures.

Alcohol: Alcohol is the main contributing factor in fatal traffic crashes. In a study on 121 traffic fatalities in Washtenaw County, Michigan, USA, different sources of data for alcohol involvement were compared. In police reports alcohol involvement was found in 51% of the fatalities, in autopsy reports in 63%, and in hospital emergency records in 91%. To avoid bias in the estimation of the fraction of alcohol-related fatalities, it is important to routinely investigate all severe and fatally injured cases in traffic crashes, ideally as soon as possible after the crash.

In a study on traumatic car fatalities (n=597) in northern Sweden, 58% of the single vehicle (SV) drivers were inebriated (multi-vehicle, MV 10%), the mean blood alcohol concentration (BAC) was 1.9 g/l (MV 1.6 g/l), and liver steatosis was found in 37% of the cases (MV 22%). Increased BAC was associated with fatty liver, indicating chronic alcohol abuse. To reduce injuries among these types of victims, passive protection is of great importance.

Disease: Autopsied drivers (n=126) in northern Sweden who had died from natural causes in traffic were studied. This fraction was 25% of all driver fatalities. Cardiovascular causes of death were found in 96% of the deceased. Neither the victims nor other occupants suffered severe traumatic injuries. A minority of the victims had experienced previous symptoms of disease. Further restriction of individuals with, for example, cardiovascular diseases would probably have no significant impact on traffic safety since at present the identification of high-risk individuals is difficult.

Helmets: Head injuries in 948 injured bicyclists, including 105 fatalities, were analysed. Head/face injuries were found in 64% of the fatal and 38% of the nonfatal cases with a median age of 55 years and 18 years, respectively. Head trauma was mostly blunt with only a few severe face injuries. Of the nonfatal cases with head injuries, 48% might have had an injury reduction effect if a bicycle helmet had been used, compared with 67% of the fatalities with head injuries.

A helmet with a hard shell, chin cover, accurate retention system, that reduces rotation and translation impact is recommended. To increase helmet use among bicyclists, a law is probably the most effective measure as has been shown for motorcyclists. However, head injuries were less frequent among snowmobile riders than among bicyclist and motorcyclist riders, and in most cases the snowmobile riders with head injuries but without helmet had broken other traffic laws, indicating that in this crash category there was a low compliance to compulsory laws.

Airbags: In a field study of car crashes where an airbag deployed, the effectiveness of the bag, as well as injuries to the skin and eye from the deployment of the bag, is reported. In laboratory tests with airbag deployment on human volunteers, tethering was found to eliminate skin abrasion within a distance of 250-300 mm. At a distance of 225 mm, the folding technique had the optimal influence on abrasions followed by a marginal effect of tethering. However, injuries due to airbag deployment must be considered as negligible compared with the airbag's role in reduction of severe and fatal injuries.

Key words: fatalities, injury, prevention, traffic, disease, alcohol, helmet, airbag
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Department of Forensic Medicine
Umeå University 1993
Two roads diverged in a wood, and I -
I took the one less traveled by,
And that has made all the difference.

Robert Frost
1916
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ABSTRACT

Vehicle-related injuries - with emphasis on fatality prevention

Mats Öström, Department of Forensic Medicine, Umeå University, Box 7642, S-907 12 Umeå, Sweden

According to WHO, Sweden should aim to reduce unintentional fatalities, particularly vehicle-related injuries, by 25% by the year 2000. The aim of this thesis was to analyze vehicle-related injuries and injury events, especially the contributory effects of alcohol and disease and the injury reducing capacity of helmets and airbags in order to point out some preventive measures.

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Key words: fatalities, injury, prevention, traffic, disease, alcohol, helmet, airbag
ORIGINAL PAPERS

This thesis is based on the following publications, which will be referred to by their Roman numerals:

I. Öström M, Eriksson A.
   Natural death while driving.

II. Öström M, Eriksson A.
    Single-vehicle crashes and alcohol: A retrospective study of passenger car fatalities in northern Sweden.
    Accident Analysis & Prevention 1993;25:171-176.

III. Öström M, Huelke D, Waller PF, Eriksson A, Blow F.
     Some biases in the alcohol investigative process.
     Accident Analysis & Prevention 1992;24:539-545.

IV. Björnstig U, Öström M, Eriksson A, Sonntag-Öström E.
    Head and face injuries in bicyclists.

V. Björnstig U, Öström M, Eriksson A.
   Would a helmet law for snowmobile riders reduce head injuries?
   Manuscript

VI. Huelke DF, Moore JL, Öström M.
    Air bag injuries and occupant protection.

VII. Schneider L, Johnson G, Öström M, Burney R, Flannagan C.
     Air-bag-induced skin abrasions.
     Manuscript
DEFINITIONS

Accident
An event that takes place without one's foresight or expectation; an event which proceeds from an unknown cause, or is an unusual effect of a known cause and therefore not expected.

Airbag
An inflatable crash protection device activated by a crash, creating a protective cushion between the person and the interior of the car.

Alcohol
Alcohol denotes ethanol (ethyl alcohol).

Inebriation
The victim was considered "inebriated" if alcohol was detected in the blood.

Injury
Any damage, unintentional or intentional, to the body, resulting from acute exposure to thermal, mechanical, electrical, or chemical energy or from the absence of such essential elements as heat or oxygen.

Interlock device
An ignition interlock device prevents a driver from starting a vehicle unless an alcohol-detecting breath test is passed.

Passive protection
Measures which protect the individual automatically, without any action on his part.

Smart card
A card (e.g. bank card) with integrated circuits and the possibility to store data. These data can be activated with electronic and/or optic signals.

Traffic injuries
In official Swedish traffic statistics, only injuries in road traffic are reported. Excluded are, victims who survived more than 30 days, intentional injuries, and off road injuries (cf Statistics Sweden 1992a). In this thesis, all fatalities are included regardless of time of survival, intention or road classification.

Trauma
Trauma and injury are used interchangeably.

USD
One United States Dollar (USD) was taken to be equivalent to 8 Swedish crowns (SEK).
INTRODUCTION

GENERAL
In the middle of the 19th century, about 50 people per 100,000 annually died from injuries in Sweden, which is about the same figure as today (Svanström 1985). Thus, the number of deaths caused by injuries has not decreased, as for example, infectious diseases, but the causes of injuries are not the same as they were in the 1850s. Today, the main contributing factor to severe and fatal injuries in the industrialized world is traffic. One-third of all fatal injuries are related to traffic (Svanström 1985). During the 1980s, according to official statistics, 8,126 people lost their lives in Swedish traffic and over 200,000 victims were injured. Traffic injuries is one of the leading causes of death among the 1-44 year age group in Sweden (Statistics Sweden 1992b).

To emphasize this problem, the Swedish Government has implemented the WHO's strategies to reduce the mortality of unintentional injuries by 25% (Svanström et al 1989) by the year 2000. To reach this goal, further analyses of contributory injury factors in traffic crashes are needed. However, it may be hard to convince the public of the importance of injury prevention in traffic. People protect themselves against disease by inoculation and the observance of appropriate nutritional and personal habits but they tend to look upon injuries as nonpreventable events (cf Haddon et al 1964). Maybe the last folklore is the belief that injuries are "accidents", i.e., events that takes place without one's foresight or expectation. A traffic fatality is seen as a separate, unique event, an "accident" and the cause of this event is seldom considered. Furthermore, some risk taking, for example, speeding, is glorified particularly among younger people and most individuals see themselves as being less at risk than others and as a safer-than-average driver (Weinstein 1980).

Risk of being killed in traffic
Each year, about half a million people are killed in traffic crashes world-wide (Hutchinson 1987). As the degree of motorization increases, the number of deaths per registrered vehicle decreases (Table 1).
Table 1. Vehicle related fatality rates for various countries (see Evans 1991, European conference of ministers of transport 1993, Thomas Lekander, personal communication*)

<table>
<thead>
<tr>
<th>Country</th>
<th>Vehicles/1000 people</th>
<th>Fatalities/year</th>
<th>Deaths/1000 veh.</th>
<th>Deaths/mill people</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>778</td>
<td>45500</td>
<td>0.24</td>
<td>184</td>
<td>1989</td>
</tr>
<tr>
<td>Canada</td>
<td>561</td>
<td>4120</td>
<td>0.28</td>
<td>158</td>
<td>1984</td>
</tr>
<tr>
<td>Australia</td>
<td>540</td>
<td>2821</td>
<td>0.34</td>
<td>186</td>
<td>1984</td>
</tr>
<tr>
<td>N Sweden*</td>
<td>493</td>
<td>104</td>
<td>0.23</td>
<td>114</td>
<td>1991</td>
</tr>
<tr>
<td>Norway</td>
<td>457</td>
<td>323</td>
<td>0.17</td>
<td>76</td>
<td>1991</td>
</tr>
<tr>
<td>Sweden</td>
<td>456</td>
<td>745</td>
<td>0.19</td>
<td>86</td>
<td>1991</td>
</tr>
<tr>
<td>Finland</td>
<td>441</td>
<td>632</td>
<td>0.28</td>
<td>126</td>
<td>1991</td>
</tr>
<tr>
<td>Japan</td>
<td>403</td>
<td>12456</td>
<td>0.26</td>
<td>103</td>
<td>1985</td>
</tr>
<tr>
<td>Danmark</td>
<td>367</td>
<td>606</td>
<td>0.32</td>
<td>117</td>
<td>1991</td>
</tr>
<tr>
<td>Netherland</td>
<td>355</td>
<td>1625</td>
<td>0.32</td>
<td>113</td>
<td>1984</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>322</td>
<td>5788</td>
<td>0.32</td>
<td>103</td>
<td>1984</td>
</tr>
<tr>
<td>Greece</td>
<td>176</td>
<td>2091</td>
<td>1.20</td>
<td>211</td>
<td>1984</td>
</tr>
<tr>
<td>South Africa</td>
<td>123</td>
<td>9621</td>
<td>2.5</td>
<td>305</td>
<td>1984</td>
</tr>
<tr>
<td>USSR</td>
<td>76</td>
<td>58651</td>
<td>2.7</td>
<td>204</td>
<td>1989</td>
</tr>
<tr>
<td>Thailand</td>
<td>17</td>
<td>4315</td>
<td>5.0</td>
<td>84</td>
<td>1985</td>
</tr>
<tr>
<td>India</td>
<td>4</td>
<td>30471</td>
<td>10.9</td>
<td>42</td>
<td>1983</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>1</td>
<td>1016</td>
<td>17</td>
<td>25</td>
<td>1983</td>
</tr>
</tbody>
</table>

Sweden is one of the countries with the lowest number of traffic fatalities per unit population in the industrialized world (Table 1). Furthermore, the risk of being killed per distance travelled on the Swedish roads has decreased from one fatality per 0.27 million kilometers in 1960 to one per 1.15 million kilometers in 1990 (Trafiksäkerhetsverket 1990). Generally, the number of deaths per vehicle declines by about 5% per year (Evans 1991).

Cost of traffic injuries

According to the Swedish National Road Administration, the average cost per fatality (in 1990 prices) is 7,400,000 SEK of which 900,000 SEK goes to material costs and 6,500,000 SEK to human value (see Persson 1992). With an average of 813 fatalities in Sweden during 1980 through 1989 (Statistics Sweden 1992a), the annual cost of
traffic fatalities is estimated to exceed 6,000 million SEK. In the U.S.A., the total cost of traffic crashes was estimated to be 74,200 million USD in 1986 (National Highway Traffic Safety Administration 1987). Thus, motor vehicle injuries are estimated to be more costly than heart disease, twice as costly as stroke, and exceeded only by the cost of cancer (Hartunian et al 1981). Although the monetary cost for the society is high, the most important reason to reduce the mortality is of course the human tragedy when victims are killed or disabled.

**INJURY PREVENTION**

Traffic injuries is thus a public health problem because of its magnitude and because of its consequences upon health. They can be investigated with similar techniques to those used in epidemiology that have been applied, with increasing success, to infectious diseases (MacMahohan and Pugh 1970). By collecting and analyzing data about injuries, where, when, and how they occur, and in whom - it can be possible to understand their patterns of occurrence, to identify risk groups for specific injuries, and to design preventive measures.

**History of injury prevention**

*Hugh de Haven* was the first to investigate environmental factors that controlled deceleration and the distribution of the force over the body in airplane and automobile crashes (De Haven 1942) and a decade later, *J. Stapp* provided the first biomechanical information by subjecting himself to deceleration forces in sledge tests (Stapp 1955), and *J. E. Gordon* suggested that injuries behaved like classical infectious diseases and could be studied by using the same techniques (Gordon 1949). *J. J. Gibson* found that injuries to a living organism can be produced only by energy interchange (Gibson 1961). *W. Haddon Jr* modified Gibson's theory that physical energy is either mechanical, thermal, radiant, chemical or electrical. He included also injuries produced by the absence of such necessary elements as oxygen or heat (Haddon 1980b). Haddon also developed preventive approaches in "the Haddon matrix" (Haddon 1980a) (Table 2), which has been a useful method in analyzing factors contributing to injuries. The approach of this method is to prevent injuries
(precrash phase), reduce injuries (crash phase) and minimize injuries that have occurred (postcrash phase).

Table 2. The Haddon matrix (Haddon 1980a) designed for traffic injuries. The precrash phase determines whether a crash will take place. The crash phase determines whether an injury results from the crash. The postcrash phase determines whether the consequences of the injuries can be reduced.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Host (human)</th>
<th>Vector (vehicle)</th>
<th>Physical environment</th>
<th>Socioeconomic environment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Precrash</strong></td>
<td>Inebriation</td>
<td>Brakes, tires</td>
<td>Road curvature</td>
<td>Alcohol attitude</td>
</tr>
<tr>
<td></td>
<td>Driver vision</td>
<td>Speed</td>
<td>Divided highway</td>
<td>Speed limits</td>
</tr>
<tr>
<td></td>
<td>Experience</td>
<td></td>
<td>Signalization</td>
<td>Laws related to impaired driving</td>
</tr>
<tr>
<td><strong>Crash</strong></td>
<td>Safety belt use</td>
<td>Safety belts</td>
<td>Characteristics of road side objects</td>
<td>Airbag law</td>
</tr>
<tr>
<td></td>
<td>Osteoporosis</td>
<td>Vehicle size</td>
<td></td>
<td>Helmet law</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Airbags</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Postcrash</strong></td>
<td>Age</td>
<td>Fuel system integrity</td>
<td>Emergency communication systems</td>
<td>Support for trauma care systems</td>
</tr>
<tr>
<td></td>
<td>Physical conditions</td>
<td></td>
<td></td>
<td>Training of emergency personnel</td>
</tr>
</tbody>
</table>
Strategies

Injuries can be prevented by three general strategies, the effectiveness of which varies inversely with the degree of which people must change their behaviour patterns (Committee on Trauma Research 1985):

* **Persuade** persons at risk of injury to alter their behaviour for increased self-protection, for example, attitudes regarding impaired driving, helmets and airbags.
* **Require** individual behaviour change by laws or administrative rules, for example, by laws requiring safety belts, helmets or airbags.
* **Provide passive protection** by product and environmental design, for example, by the installation of airbags.

A basic finding from previous studies is that the second strategy, requiring behavioural changes, is generally more effective than the first and that passive protection is the most effective (Committee on Trauma Research 1985). A fundamental reason for this is that high-risk groups tend to be the hardest to influence either with voluntary or mandated changes in individual behaviour.

**Alteration of behaviour.** *Driver education* or increased driving skill and knowledge does not increase safety because traffic injuries result less from lack of knowledge than from failure to apply what is known (Evans 1991). Greater average number of crashes have been reported in groups with driver education (Williams and O'Neill 1974, Kraus et al 1975, Raymond and Tatum 1977) and no significant decrease in the crash rates was found among trained high-schools students in England (Shaoul 1975) or the U.S.A. (Robertson 1984). Instead, high-school driver education leads to an increase in the number of young immature drivers, resulting in a greatly increased exposure of a population which has the highest frequency of traffic fatalities. In September, 1993, the minimum age of educational driving in Sweden was lowered from 17 years and 9 months to 16 years (VVFS 1993:8) increasing the fraction of young Swedish drivers on the road. According to previous findings, this change cannot be expected to increase traffic safety.

*Mass media* has a limited value in this context, for example, TV and radio campaigns have been found to have no influence on the frequency of belt use (Fleischer 1972)
and *behaviour modification* with buzzers and lighted reminders for seat belt use have shown no statistically significant effect on belt use (Robertson and Haddon 1974).

**Introduction of laws.** Individual behaviour change to prevent injuries by law is more effective than by persuasion. To reach an acceptable proportion of, for example, safety belt use, compulsory laws are required (Williams and Lund 1986). In the absence of laws requiring the use of protective helmets, only about 50% of motorcyclists and up to 25-30% of bicyclists voluntarily wear them, while compulsory helmet laws result in almost 100% use (Watson et al 1980, Bader 1990, Leicester et al 1991).

**Passive protection.** It has been reported that human factors are the main cause in crashes and that only a small fraction, 5-6%, of all crashes cannot be linked to the road users (Rumar 1985). Voluntary behaviour change and laws tend, however, to be least effective among the highest risk groups of injury, for example, teenagers and persons inebriated by alcohol (Williams and O'Neill 1979), and mandatory laws do not reduce fatalities as much as would be expected (Robertson 1983). Findings showing that persons take greater risks to compensate for their increased safety, for example, in traffic (Peltzman 1975, Wilde 1982) support the "risk compensation theory". However, there are other findings that have not shown such an increase in risk-taking (Lund and Zador 1984).

Interventions can be characterized as either "passive" or "active" (cf Haddon 1974). Passive countermeasures require little individual action on part of those being protected and are often described as being more effective than active countermeasures (Robertson 1984). For example, contrary to safety belts, airbags require no action from the occupant to reduce injuries and can reduce injuries also among individuals not using the safety belts.

**Vehicular and environmental changes.** The condition of the vehicle and the traffic environment is important in reducing the risk of a crash and injuries when a crash occurs. Due to insufficient exposure data, it is difficult to determine the exact
relationship between crash rates and road surface, but crash rates are almost certainly higher with reduced roadway friction and visibility (Evans 1991). For example, vehicles can become more conspicuous with high-mounted brake lights (Reilly et al 1980, Rausch et al 1982) and daytime use of headlights (Stein 1984) leading to a substantial risk reduction of a crash. When a crash occurs the environmental factors play a large role. For example, the driver in a car with small mass has a lower chance of survival than the driver in a car with a large mass (Table 3).

Table 3. Relative likelihood of driver fatality in a car of mass m(a) involved in a crash with a car of mass m(b) (modified from Evans and Wasielewski 1987).

<table>
<thead>
<tr>
<th>Mass (kg)</th>
<th>m(b)</th>
<th>500-</th>
<th>900-</th>
<th>1100-</th>
<th>1300-</th>
<th>1500-</th>
<th>1800-2399</th>
</tr>
</thead>
<tbody>
<tr>
<td>500-</td>
<td></td>
<td>7.04</td>
<td>12.12</td>
<td>15.15</td>
<td>16.05</td>
<td>16.86</td>
<td>16.51</td>
</tr>
<tr>
<td>900-</td>
<td></td>
<td>5.06</td>
<td>9.78</td>
<td>11.88</td>
<td>13.38</td>
<td>14.58</td>
<td>14.68</td>
</tr>
<tr>
<td>1100-</td>
<td></td>
<td>3.50</td>
<td>5.33</td>
<td>7.79</td>
<td>9.48</td>
<td>9.30</td>
<td>9.36</td>
</tr>
<tr>
<td>1300-</td>
<td></td>
<td>2.14</td>
<td>2.67</td>
<td>4.83</td>
<td>6.06</td>
<td>6.94</td>
<td>7.12</td>
</tr>
<tr>
<td>1500-</td>
<td></td>
<td>0.98</td>
<td>2.04</td>
<td>2.57</td>
<td>3.56</td>
<td>4.34</td>
<td>5.01</td>
</tr>
<tr>
<td>1800-2399</td>
<td></td>
<td>1.00</td>
<td>1.48</td>
<td>1.86</td>
<td>2.61</td>
<td>3.01</td>
<td>3.46</td>
</tr>
</tbody>
</table>
GENERAL AIM

The general aim of this thesis was to view some aspects of:

(i) the injury propagating effect in vehicle crashes of human factors, with emphasis on impairment by disease and alcohol,

(ii) the injury mitigating effect of passive and active safety, with emphasis on helmets and airbags.
MATERIALS AND METHODS

The materials in Papers I, II, IV, and V were based on autopsies performed at the Institute of Forensic Medicine in Umeå. The catchment area of this institute covers the northern 55% of Sweden, which has a population of 907,000 inhabitants (Fig. 1). The major part of the area is rural.

Figure. 1. Area under investigation
All police records, hospital records when available, and autopsy protocols, including histopathological and toxicological analyses, were examined. Blood samples were drawn from the femoral veins or heart and the toxicological analyses were performed at the Department of Forensic Chemistry, Linköping, Sweden.

Injuries were classified according to the Abbreviated Injury Scale (States et al 1980, Committee on Injury Scaling 1990).

In Paper I, all cases of vehicle-related sudden natural deaths autopsied at the Institute of Forensic Medicine in Umeå during 1980 through 1985 were analyzed. Paper II included all passenger car fatalities in the region 1980 through 1989.

In Paper IV, head and face injuries in bicyclists were studied in two series, one with fatal injuries and one with nonfatal injuries. The fatal injury material consisted of all bicyclist fatalities autopsied during 1977 through 1986. The nonfatal material consisted of patients treated at two hospitals, located in the cities of Umeå and Skellefteå, respectively, during 1985-1986 (Fig. 1). At these two hospitals, nearly all injury patients from the hospital's primary catchment areas were treated as out- or in-patients. All patients answered a questionnaire concerning the crash during the primary visit at the hospital. Hospital records were analyzed concerning injury.

In Paper V, series of fatal and nonfatal head injuries among snowmobile riders were analyzed. The fatal injury material consisted of all fatally injured snowmobile riders autopsied at the Institute of Forensic Medicine in Umeå during 1974 through 1992 and all injured snowmobile riders treated at the University Hospital of Northern Sweden in Umeå during 1985 through 1991. As in Paper IV, the nonfatally injured patients answered a questionnaire concerning the crash during the primary visit at the hospital. Hospital records were analyzed concerning injury.

Paper III included a comparison of all available death certificates and hospital and police records of all traffic fatalities occurring in Washtenaw County, Michigan, USA, from 1985 through 1987. Alcohol analyses performed before and/or after death was
studied. The catchment area of Washtenaw County is 1,849 km², with 261,000 inhabitants.

*Paper VI* included a selection of 190 crashes with airbag deployments. To obtain knowledge of these crashes, all Chrysler, Nissan, Infiniti, and some Ford dealerships throughout the U.S.A. were contacted, requesting the dealership to contact the investigation team if they received a vehicle involved in a crash where an airbag had deployed. The investigation included interviews with the individual exposed and an injury description was obtained.

In *Paper VII*, airbag deployment tests were performed on human volunteers. Injuries were analyzed with respect to various airbag conditions, including airbag tethering, inflation pressure, airbag material, fold technique, and distance from the airbag module to the surface of the skin. In addition, the kinematics and velocity of air bag deployment were studied.

For details of airbag construction, refer to *Paper VII*. 
RESULTS

The results are presented in detail in each paper but summarized here.

Paper I (Natural deaths while driving)

Of the 126 deceased, 69 were car drivers (including 4 lorries and 1 bus), 35 bicyclists, 11 snowmobile riders, 6 mopedists, 4 kick-sledge riders, and 1 motorcycle rider. The mean age of the 69 car drivers was 59 years and of the other victims, 66 years. In 7 cases (10%), the vehicles were in commercial traffic. The car crashes were relatively evenly distributed by month and day but a strong seasonal variation of the deaths in the other vehicle categories were found.

Cardiovascular disease was the underlying cause of death in 67 of the 69 car drivers. Coronary atherosclerosis with an old and/or recent myocardial infarction or both were the predominant findings (49 cases, 71%). Among the 57 noncar cases, coronary atherosclerosis with recent or old myocardial infarction or both accounted for 14 deaths, coronary atherosclerosis with old infarction for 19 deaths.

Premonitory symptoms before the crash were present in 25% of the car cases. In 39%, the deceased had not mentioned any symptoms, and in 36% there was no record as to whether the victim had complained of any symptoms. Among the noncar victims, the corresponding figures were 14%, 46%, and 40%, respectively.

Injuries were totally absent in 87% of the car drivers. Thirteen percent of the drivers were injured (5 cases MAIS=1, 2 cases MAIS=2, 2 cases MAIS=3). Only 2 of 20 passengers "at risk" suffered minor injuries. In three cases, vehicular collisions resulted, but the other road users were not injured in any of these. In two of the noncar cases, skull fractures were seen, but they were not considered to be of significance as a cause of death.

In 74% of the cases, there was no damage to the car, extensive damage was found in only 6%. In at least 65%, the car driver was able to slow down considerably before unconsciousness or death occurred. In 23% of the car cases, the victims could be classified as a danger in traffic (if unable to stop the vehicle or if the vehicle crossed over to the wrong side of the road).
None of the car victims was under the influence of alcohol, whereas two noncar victims were inebriated. It should be noted, however, that in 56% of the noncar cases, no toxicological analyses were performed.

**Paper II (Single vehicle crashes and alcohol)**

The study of passenger car occupants included 201 (34%) single vehicle fatalities and 396 multiple vehicle fatalities. In total, alcohol was detected in 27% of those tested, with a mean BAC (blood alcohol concentration) of 1.8 o/oo. Fifty-eight percent of the tested drivers in single vehicle crashes were under the influence of alcohol compared to only 10% in the multiple vehicle group. Only 3% of the inebriated single vehicle drivers, compared to 20% of the inebriated multiple vehicle drivers, had a BAC below 0.5 o/oo.

Of the single vehicle fatalities, 32% had a fatty liver, compared to 20% in the multiple vehicle group. Among the fatalities where alcohol was not detected, 18% had a fatty liver, compared to 43% in the inebriated group. The mean BAC of the victims with both alcohol in their blood and fatty liver was 2.2 o/oo, and the mean age was 35 years. Of those with a BAC of 1.5 o/oo or above, 52% had fatty liver.

The mean age of all victims in single vehicle crashes was lower (34 years) than that of multiple vehicle fatalities (45 years). The mean age of the drivers in single and multiple vehicle crashes was 36 and 47 years, respectively.

Under the age of 25, 35% of the victims were inebriated, with a mean BAC of 1.4 o/oo. Inebriated victims aged 25-49 had a mean BAC of 2.1 o/oo (39%), and the victims aged 50 and above had a mean BAC of 1.1 o/oo (6%).

Only a minority of the victims under the influence of alcohol wore the safety belt. Of the 20 drivers without a valid drivers license, 85% were inebriated.

Of the single vehicle fatalities, 81% occurred during May through October, compared to only 41% of the multiple vehicle fatalities. Only 18% of the single vehicle fatalities occurred during the snowy season, compared to 59% of the multiple vehicle fatalities. Two-thirds (66%) of the single vehicle fatalities, and half (48%) of the multiple vehicle fatalities, occurred from Fridays through Sundays. Most single vehicle fatalities (52%) occurred in the late evening and early morning, compared to only 11% of the multiple vehicle fatalities.
Clear weather dominated (single vehicle fatalities 85%, multiple vehicle fatalities 80%) and of the documented single vehicle cases, the surface was dry in 59% (multiple vehicle fatalities 33%).

**Paper III (Biases in alcohol investigative process)**

A total of 121 fatally injured victims (72 drivers, 33 passengers, 15 pedestrians, 1 bicyclist) from 112 crashes were studied. Most victims were male (77%), and 40% of all victims were aged between 15 and 24 years.

The frequency of alcohol-related traffic fatalities varied between the different data sources. The police records revealed 51%, the emergency records 91%, and the medical examiner records 63% with alcohol involvement.

In 36% of the cases (41% of all males and 18% of all females), the police report indicated whether or not the victim had been drinking. The deceased driver was at fault in 93% of the crashes in which judgement of alcohol use or nonuse was recorded, compared with 81% in the group with no judgement recorded. The mean age for the alcohol-impaired group was 27 years versus 44 years for those judged not to have been drinking. Alcohol was detected in two cases in which the investigating officer had judged that the victim was sober.

Body fluid (11 cases blood, 1 case urine) was drawn for alcohol analysis prior to death in 12 cases. Eleven of the victims were male. Apart from one sample, all the other blood samples contained alcohol with a mean BAC of 1.6 o/oo. Samples were obtained after death in 60% of the cases. Alcohol was present in 63% of these cases with a mean BAC of 1.4 o/oo.

**Paper IV (Bicycle helmets)**

**Nonfatal cases.** Of 843 injured bicyclists, 321 (38%) sustained injuries to the head, face, or both, and were unhelmeted. Cerebral concussion/contusions were distributed relatively evenly in all age groups (11-14% of all injuries).

Of the 321 victims who sustained injuries to the head, face, or both, 55% were males. The median age of the victims was 18 years. In almost all (92%) victims with head injuries, the impact was blunt. The proportion of bicyclists with head injuries, face injuries or both, decreased with increasing age. About 50% of the group aged less
than 10 years had head and face injuries, compared with 30% in the age group 10-39 years, and 25% in the age group 40 years and older. In 14%, a collision with a motor vehicle occurred. In at least 12% of the cases, the bicyclist was noticeably impaired by alcohol. Cerebral concussion or contusion was found in 31% of the bicyclists with head injuries, face injuries or both. Of these, at least 69% had an impact within the area protected by a helmet. In 39%, abrasions or lacerations of the skin or superficial contusion of the head and face was within the area expected to be protected by a helmet.

In total, 18% of all injured bicyclists and 48% of the bicyclist with head injuries, face injuries, or both, might have had a reduction in injury if a bicycle helmet had been used.

**Fatal cases.** In 67 of the 105 bicycle fatalities, head injury was considered the sole cause of death. The median age of these 67 victims was 55 years. A collision with a motor vehicle occurred in 91% and all injuries arose from blunt impact. In only two cases, the fatal impact was located outside the helmet protective area (face injuries). The predominant location of the fatal impact was in the occipital and temporal regions (23 and 20, respectively). In 42 cases, brain contusions were found, predominately located in the frontal lobes (n=21), and in 12 cases a subdural hematoma and in 2 cases, epidural hematoma was found. In 50 cases, skull fractures were documented. In 22 victims a maximum AIS score (MAIS) of 6 was found, in 20 MAIS 5, in 23 MAIS 4, and in 2 MAIS 3. Overall, in 64% of the 67 fatalities with a head injury as the (only) cause of death or in 41% of the total material, a helmet might have reduced the severity of the injuries.

**Paper V (Snowmobile helmets)**

**Nonfatal cases.** A total of 35 (14%) of the 245 injured persons suffered head and/or face injuries, most of them minor (AIS 1). The median age of head and/or the face injuries group was 22 years, 74% being males. The most common crash mechanism for this group was a crash against a solid object, for example, a tree (29%), followed by an abrupt stop, for example, driving into a ditch (26%). Nine percent were hit in the face by a branch of a tree. Two persons with unknown helmet use had a non-
minor (AIS ≥ 2) head and/or face injuries which would have been expected to be reduced by use of a helmet. However, one of these had not obeyed the traffic temperance law and was driving in a forbidden area and the other was a reindeer herder who probably would not have used a helmet due to the uncomfortable working situation. All riders with head injuries (AIS ≥ 3) had used a helmet.

**Fatal cases.** Of 104 victims in snowmobile crashes, 26 (25%) had fatal head injuries without other fatal injuries. The median age of these head injury victims was 32 years and 96% were males. Also here, the most common crash mechanism was a collision with a solid object (35%).

No helmet was used or no documentation of helmet use was found in 21 cases, of which 19 had major impacts only within the area protected by a helmet. However, all of these 19 victims were inebriated or had violated other laws.

**Paper VI (Airbag field study)**

Out of a total series of 190 crashes where an airbag had deployed, five illustrative crashes are presented.

**Injury reduction by airbag**

**Case 1:** A pickup truck and a passenger car were involved in an extremely severe head-on crash. The passenger car was travelling at an estimated speed of 96 km/h, the speed of the pickup truck was unknown. The velocity change was approximately 80 km/h for each vehicle. The driver in the passenger car was wearing a three point restraint and the vehicle was airbag equipped. He sustained muscle contusions, a patellar fracture and skin lacerations. No airbag-induced injuries were reported. The unrestrained driver of the pickup died at the scene.

**Case 2:** At an estimated speed of 80 km/h, a passenger car struck the rear end of a trailer, resulting in extensive damage to the front of the car. The car driver was wearing a three point safety belt and the vehicle was equipped with an airbag. He sustained muscle contusions and skin lacerations and abrasions. No airbag-induced injuries were reported.
Airbag-induced injuries

Case 3: In this unusual crash, a maple tree fell across the hood and windshield of a passenger car. The airbag deployed on the safety belt restrained driver, who sustained a corneal abrasion and an abrasion on the cheek, probably due to the deployment of the airbag.

Case 4: An unrestrained driver struck the rear of another car, resulting in minor car damages. The driver's face came in contact with the airbag, yielding a scleral laceration and a minor abrasion on the chin. In addition, part of the driver's polyester blouse melted, probably due to the hot gases generated as the bag deployed, yielding erythema of the upper chest.

Case 5: In this intersection collision, the driver of the airbag equipped car was wearing the lap-shoulder belt improperly under her left arm. The deployment of the airbag was probably the cause of a large punctate abrasion of her left cornea and contusions to her cheek. As in case 4, part of the driver's polyester blouse melted, yielding erythema of the upper chest.

Paper VII (Airbag experimental study)

Preliminary tests indicated: (i) a risk of severe injuries to tissues not closely supported by bone, (ii) that tethering eliminates contact for distances above 250-300 mm, and (iii) that airbag material was not a major factor influencing abrasions.

Of the 8 final tests, 5 resulted in abrasions. In all except one abrasion, the airbag fold was accordion. In no case was the abrasion considered to be severe (≥5mm wide). With statistics, the airbag fold was found to have the most dramatic effect on abrasions, followed by a marginal effect of tethering, and a very weak effect of inflator pressure. Two different airbag kinematics, corresponding to the abrasions, were found. With the accordion-type, the two primary flaps deployed to the left and right while the reverse fold was more at the center of the target yielding a stamping contact.

The airbag mean velocities during the second half of the deployment were estimated to be 163 km/h with tether and 217 km/h without the tether. The top velocity was estimated to be 250 km/h (untethered).
DISCUSSION

Validity

Selection. Obviously, data on fatalities and fatal crashes are more complete than data on injuries at other levels. Further, the definition of fatality involves less uncertainty than that of other type of injuries. The fatality material studied in this thesis is not a sample from which statistical inference can be drawn, since almost all vehicle-related fatalities in the areas of investigation were covered. There may be a few cases, hospitalized for a long period of time, which were not reported to the police. However, these cases are probably too few to have any significant effect on the results. Since the present results on fatalities are specific for a certain area and for certain periods of time, it can be difficult to extrapolate these findings for other areas and other periods of time.

The drop-out rate in the clinical material in Papers IV and V is more difficult to evaluate. However, the hospital is the only one serving the area and outpatient clinics in the area provide very limited trauma service. Among the clinical material in Paper IV, a cross-check against the compulsory coding of the external cause of injury (E-code) (World Health Organization 1977) ensured a negligible drop-out of in-patients in the analysis. The drop-out in the registration of out-patients was estimated to be 5-10% and there will probably be no difference in the clinical material in Paper V.

Alcohol. Femoral vein and heart blood for alcohol analyses (Papers I, II, IV and V) was drawn and analysed separately with headspace gas chromatography at the Department of Forensic Chemistry in Linköping, Sweden (Jones and Schuberth 1989). Blood samples were drawn for alcohol analysis if the victim died within 24 hours, yielding some missing cases where the alcohol had been eliminated from the body before the time of death. Thus, the figures presented in the papers are minimal. In Paper I, the mean BAC of heart and femoral vein blood was used. Usually, no statistical difference in BAC is noted between femoral vein and heart blood (cf Prouty and Anderson 1987, Briglia et al 1992). However, to avoid problems associated with heart blood, for example, in extensive massacration the heart blood can get
contaminated by stomach content, femoral vein blood samples were preferred in later studies. Alcohol is absorbed rapidly and distributed widely throughout the body, including the brain. To avoid errors, analyses on victims who had obtained large amounts of blood replacement fluid prior to death were excluded. This was the case in only a few victims who survived several hours after the crash leading to a lowering of the BAC or no BAC at all.
The content of alcohol in this thesis was set to weight alcohol per weight blood. If other units, for example, weight/volume are used, an inconsequential error of a few percent at the most (cf Evans 1991) will result, which is insignificant for practical purposes. An international agreement using standard units is highly desirable (cf Valverius 1993).

Disease (Paper I)
We spend more time travelling in Sweden than ever before. It is estimated that in 1991, we travelled a total of 117,300 million kilometers of which 78% of the distance was in passenger cars (Statistics Sweden 1992a). In addition, the proportion of more physically active elderly in the population is rising. Therefore, cases of incapacitation due to disease and natural death while driving will probably increase in number. To reduce the risk of traffic injuries due to medical incapacitation, restrictions for some diseases, i.e., ischemic heart disease, diabetes, epilepsy, and mental disorders have been implemented (SOSFS 1984:31, TSVFS 1991:29). However, with an expected increase in the number of cases of incapacitation in traffic due to disease, suggestions regarding more driving restrictions to people with major diseases have been discussed.

The nature of natural death in traffic. It is reported that natural death in traffic is not frequent (Peterson and Patty 1962, Herner et al 1966, Baker and Spitz 1970, Wikland 1971, Krauland 1978). In northern Sweden during 1980 through 1985, 126 cases of natural deaths while driving were reported (Paper I). During the same time period, 382 traumatic driver fatalities occurred in the same region (Öström unpublished data, 1993). Thus, the proportion of natural deaths constituted 1/4 of all driver fatalities.
The higher proportion in our study compared to other studies using medical examiner data may be due to a high autopsy rate for these victims since all traffic deaths in Sweden were strongly recommended to be autopsied during the time of study (SOSFS 1989:34 and previous versions). Of course, the figures presented may be even higher since cases may be missing and since cases of natural deaths may exist among victims with severe trauma (see below).

When comparing natural versus traumatic deaths in traffic, a dominance of males is found in both groups (cf Peterson and Petty 1962, West et al 1968, Paper I) but victims who died of natural causes are elderly (cf Peterson and Petty 1962, West et al 1968, Paper I) and much less likely to be inebriated by alcohol (cf Peterson and Petty 1962, Antecol and Roberts 1990). Actually, in Paper I, none of the cases tested had alcohol detectable in their blood.

As shown in Paper I, natural deaths while driving are more likely to happen in the daytime and on weekdays, than are traumatic deaths (cf West et al 1968, Krantz 1979). Moreover, natural deaths in traffic cause only minor injuries to people (cf West et al 1968, Christian 1988) and minor property damages (cf Herner et al 1966).

Risk of incapacitation due to disease in traffic. In northern Sweden (Paper I), ischemic heart disease was the dominant cause among victims who died of natural causes in traffic (cf West et al 1968), probably due to a ventricular fibrillation and often an old myocardial infarction was the main pathological finding. If a myocardial infarction of the heart is less than approximately 6 hours old at the moment of death, no morphological signs are found, which of course may reduce the number of recent myocardial infarctions found.

In an oncoming study (Sjögren et al 1993b), the contribution of disease in fatal collisions among 480 drivers was judged. It was found that disease was "probably" the underlying cause of the crash in 6% of all traumatic driver fatalities, and in 1/3 of these victims, this probability of incapacitation was "strong". In the study, as much as 85% of the +70-year-old group had medical intrinsic factors (mainly cardiovascular) that were judged to constitute a risk of sudden incapacitation.

In Sweden, people suffering from ischemic heart disease are required to have permission from a specialist in internal medicine to drive (SOSFS 1984:31). If the
patient has a pacemaker, the physician must be a cardiologist. However, previous symptoms are not always present in victims of natural death at the wheel (Paper I), and the symptoms in victims of cardiac death in traffic do not differ from those in other out-of-hospital cardiac deaths (Antecol and Roberts 1990). Moreover, there are many drivers who can be incapacitated with no previous known disease (cf Paper I) and even when the drivers are carefully medically examined, such as professional drivers, it can still be difficult to identify risk drivers. In line with this concept, 30% of the drivers who had died of cardiac causes in traffic had no previous documentation of heart disease (Norman 1958). Thus, it is difficult to correctly evaluate the patient regarding the risk of incapacitation while driving.

**Diabetes.** In northern Sweden, only one of 480 fatally injured car drivers suffered from diabetes but the disease was not considered as a strong contributing factor to the crash (Sjögren et al 1993b). Studies on drivers with diabetes mellitus have shown no (Ysander 1966) or only slightly increased risk of traffic crashes (Hansotia and Broste 1991).

In Sweden, the diabetic patient is required to have a good control of the blood glucose, particularly to avoid hypoglycemia. The patient is controlled every fifth year, or if the diabetic disease has been present for more than ten years, every other year. Persons with insulin dependent diabetes are not allowed to drive commercially (SOSFS 1984:31, TSVFS 1991:29).

**Epilepsy.** Two drivers of 480 driver fatalities in northern Sweden suffered from epilepsy. In one case, the epilepsy most probably played a casual role in the crash (Sjögren et al 1993b). A standardized crash mishap ratio for epileptic patients have been estimated to 1.33 suggesting that further driving restrictions are not warranted (Hansotia and Broste 1991).

In Sweden, a seizure-free interval of two years and EEG free from bilateral synchronized spike-wave activities is required before a driver with epilepsy can be permitted to drive. In addition, the patient must be examined by a physician with "knowledge in neurology" and the patient has to be followed up after one year, two years and five years.
Disorders of the central nervous system. In Sweden, there is objection to drivers with organic brain disease (e.g. severe brain injury, meningitis), alcoholism, and drug addiction. Dementing illnesses are found in 6% of the population aged 65 and above (Cummings and Benson 1992) with high risk figures for traffic crashes (Dubinski et al 1992). Preliminary results from an ongoing study in Sweden show that 3 of the first 20 elderly (above 65 years) fatalities of car drivers studied had morphological signs of Alzheimer's encephalopathy (Johansson 1993). Mental disorders will of course increase the risk for intentional injuries and suicides (cf Öström et al 1993f). The proportion of reported traffic suicides varies from 15% (Edland 1968, Pokorny 1972) to only 1-3% of all traffic fatalities (Schmidt et al 1977, Haendel 1982, Lamble 1982). In northern Sweden, the proportion of intentional traffic deaths has been estimated to be 1-2% and in these crashes, 57% had documented mental disorders (Öström et al 1993e). These variations in the proportion of intentional traffic deaths are probably not explained by a true variation but indicate biased investigations. One explanation may be that no explicit criteria exist for determining whether a traffic death is intentional or not. Suicides in traffic are probably underreported and misclassified as undetermined or accidental deaths. The need for further crash investigation, e.g., psychological autopsies and specific questionnaires (Rosenberg et al 1988) are needed to further evaluate suicides in traffic.

Alcohol (Papers II, III)
Alcohol is the most significant single factor contributing to serious and fatal traffic crashes (cf Evans 1991). In addition to an increased risk to crash when inebriated by alcohol, the drunken drivers are more likely to die than sober drivers in crashes of comparable severity (Waller et al 1986, Evans and Frick 1991). In Sweden, which is one of the pioneers in strict policy against drunken driving, alcohol is detected in about 20-25% of all driver fatalities (Öström et al 1993b). In the U.K., the corresponding figure is 30% (Clayton and Everest 1993), and in the U.S.A. 46% (Stewart and Voas 1993). The legal limit in the U.S.A. in 1990 varied between the
different states using per se laws from 0.8 to 1.2 o/oo (Evans 1991), and in Sweden in 1990, the limit of drunken driving was lowered from 0.5 o/oo to 0.2 o/oo.

As shown in Paper II, the average BAC of drunken drivers involved in fatal crashes is often well above the legal limit (U.S. Dept of Health and Human Services 1988, Öström et al 1993b). The same trend is seen among drunken drivers caught at sobriety check points, and of all drunken drivers penalized in Sweden in 1988, 58% had a BAC of 1.5 o/oo or above (Jones et al 1989). Drunken driving is mainly a male problem, and in northern Sweden, the proportion of drunken drivers fatalities during the 1980s among males was 30%, compared to 12% among females (Öström et al 1993d).


<table>
<thead>
<tr>
<th>Category (drivers)</th>
<th>Alcohol analyses (n)</th>
<th>Alcohol detected (%)</th>
<th>Mean BAC (o/oo)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger car</td>
<td>384</td>
<td>27</td>
<td>1.8</td>
</tr>
<tr>
<td>Truck, bus</td>
<td>28</td>
<td>25</td>
<td>1.2</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>47</td>
<td>21</td>
<td>1.2</td>
</tr>
<tr>
<td>Moped</td>
<td>41</td>
<td>7</td>
<td>1.6</td>
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<tr>
<td>Bicycle</td>
<td>59</td>
<td>8</td>
<td>2.3</td>
</tr>
<tr>
<td>Snowmobile</td>
<td>42</td>
<td>64</td>
<td>1.4</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>172</td>
<td>16</td>
<td>1.8</td>
</tr>
</tbody>
</table>

There are also large variations in the proportion of inebriated victims among different vehicle categories (Table 4). In all categories, a mean BAC well above 1.0 o/oo was found and in only 22 cases (11%), the inebriated victims had a BAC less than the Swedish former legal limit for drunken driving of 0.5 o/oo. The highest proportion was found among snowmobile fatalities (cf Eriksson and Björnstig 1982).
Biases. The reliability of data concerning alcohol inebriation in traffic depends on the investigative process. According to official Swedish statistics, based on police judgement, only 10% of the driver fatalities are inebriated, while the chemical analyses of the same cases shows that the real proportion is about twice as high (Öström et al 1993b). Paper III, based on material from Michigan, USA, revealed different proportions of inebriated victims depending on whether the police, the emergency department, or the medical examiner records were used. The main reason for these differences was a selection of victims by the different personnel (police, emergency room and medical examiners) and a low reporting rate. To avoid selections and subjective judgements, the importance of an objective reliable investigation with chemical analyses as soon as possible after the crash routinely in all victims is stressed. Unreliable data, such as the Swedish official data regarding alcohol inebriation, cannot be used because they mislead both the general public and policy makers and gives rise to a false sense of security.

Drunken driving and alcoholism. For effective countermeasures against inebriation in traffic, the fraction of chronic alcohol abusers among, for example, traffic fatalities has to be better known. Already in 1959, Haddon and Bradeness found that fatally injured drivers differed from drivers in general, particularly regarding alcohol. In northern (Paper II) and in southern Sweden (cf Krantz 1979), as in the U.S.A. (cf National Highway Traffic Safety Administration 1991), alcohol plays a large role among passenger car fatalities, particularly in single vehicle crashes. Often these victims are alcoholics, but the real extent of alcoholism in this group is still unknown (cf Kilje 1990). Several chemical analyses indicating chronic alcohol abuse in vivo are available for example, gamma-glutamyl transferase and carbohydrate-deficient transferrin. The reliability of these tests in autopsy has not yet been evaluated. Alcohol analyses in post mortem blood are reliable, but the BAC detects of course only recent (ab)use of alcohol. A BAC of 1.5 o/oo or above while driving has been used, however, as a criterium of alcohol abuse (cf Birrell 1965, Waller and Türkei 1966). Even if a large fraction of the chronic abusers is included by this criterium, 1/3 of heavy alcohol consumers die without alcohol detectable in their blood (Karhunen
and Penttilä 1990). Thus, it is not reliable to investigate chronic alcohol abuse among traffic fatalities only by toxicological analyses.

There is a strong correlation between fatty liver and heavy alcohol consumption (Sørensen et al 1984, Karhunen and Penttilä 1990). In Paper II, the relation between the presence of fatty liver and an increased BAC was shown (see Fig. 2 in Paper II) and the majority of the victims with a BAC of 1.5 o/oo or more also had fatty liver, indicating chronic abuse. These results indicate that judgement of the liver morphology complement the investigation of chronic alcohol abuse among traffic fatalities.

**Prevention of alcohol inebriation in traffic.** Different strategies can be used to reduce alcohol-related injuries in traffic.

*Behavioural changes*

**Intervention and treatment programs.** Such programs have little effect on drinkers (cf Nichols et al 1987, Nichols 1990), and researchers recommend that these approaches should not be used as a substitute for traditional sanctions (e.g. Peck et al 1985, Tashima and Peck 1986, Nichols and Ross 1988). Instead, treatment programs should be imposed on drunken driver offenders in addition to license sanctions (cf Nichols 1990). However in Sweden, compulsory treatment programs for 3-6 months and certified sobriety after 6 and 18 months (chemical and anamnestic) by a specialized physician to keep the license valid have resulted in a reduction of second drunken driver offenders from 31% to 6% (Roos 1992).

**Consumption reduction.** Higher price on alcohol beverages reduces the consumption of alcohol, yielding fewer highway fatalities (Cook 1981, Saffer and Grossman 1987, Phelps 1988). In the U.S.A., a lowering of the minimum drinking age has been associated with an increase in the number of alcohol-related crashes among young drivers directly affected by the change in the law (Douglas et al 1974, Whitehead et al 1975, Cook and Tauchen 1984). In fact, each 1-year increase in the legal drinking age limit has been estimated to decrease the number of fatalities in the directly affected age group by about 11 percent (Saffer and Grossman 1987).
In Sweden, the drinking age is 20 years, alcohol beverages are only sold by state owned monopolies open daytime during weekdays, and high taxes apply to all types of liquor. However, it has been reported that the Swedish control of alcohol sales are of less importance compared to the Swedish law enforcement against alcohol (Votey 1975, 1984).

**Deterrence.** Sweden has had strict policies of the sale and use of alcohol in general and of alcohol in traffic in particular for several decades. The first Swedish per se law, criminalizing drunken driving was introduced in 1941, defining two levels of drunken driving, viz. exceeding blood alcohol concentrations of 0.8 o/oo and 1.5 o/oo. The lower level defined "impaired driving", the higher level "driving while intoxicated". In 1957, the lower level was reduced to 0.5 o/oo, and as of July 1, 1990, to 0.2 o/oo. Today, it is possible to penalize the drunken driver by breath analysis alone.

After lowering the legal limit for drunken driving to 0.2 o/oo, the proportion of drunken driver fatalities has decreased from 31% in 1989 to 24% in 1992 (T. Lekander, VTI, personal communication). This decrease is partly explained by a reduction among driver fatalities with low BAC (less than 0.5 o/oo), while the proportion of highly intoxicated drivers remains the same. Many victims with high BAC are probably alcoholics, and not influenced by the legal limit. Thus, other countermeasures have to be applied to this group.

**Imprisonment.** The drunken driver cannot recidive while he is in prison, but the effect in a long term perspective is doubtful with no reduction in recidivism after jail terms (Buikhuisen 1972, Blumenthal and Ross 1973, Homel 1981, Tashima and Peck 1986). In fact, during 1966-1985, at least 31% of Swedish drunken drivers who had served prison sentences recidived (Kristenson 1992). Driving while intoxicated (≥ 1.5 o/oo) can result in a prison sentence of up to one year (generally 1-2 months) in Sweden, and the BAC limit for driving while intoxicated is going to be lowered to 1.0 o/oo from January 1, 1994 (R. Pettersson, Dept of the Police, Umeå, personal communication).

**Fines.** In Sweden, driving while impaired (0.20-1.49 o/oo) results in a fine up to 120 days of income. Fines are not less effective than periods of imprisonment (Homel
1981) and substantial fines are reported to reduce recidivism of drunken driving and fatal crashes in Scandinavia (Votey and Shapiro 1983, 1985).

License suspensions and revocations. In addition to fines, driving while impaired results in license revocation for up to one year in Sweden. Driving while intoxicated (1.50 o/oo or more) results, in addition to jail, in a license revocation for more than one year (G. Johansson, Dept of the Police, Umeå, personal communication). To reclaim the license, a drunken driver with a BAC of 1.50 o/oo or above will need a proof of sobriety over a period of six months by psychological testing and at least two blood samples negative for alcohol abuse. A follow up is needed on two occasions: after six months and after one year after the proof of sobriety (TSVFS 1990:70). Sweden's license actions are reported to be closely associated with reductions in fatal crashes when compared to other sanctions, including jail (Votey and Shapiro 1983, 1985). Also in the U.S.A., studies have shown that license actions appear to be more effective than others (Klette 1985, Votey and Shapiro 1985, Zador et al 1988), with fewer alcohol-related crashes than after education or treatment programs (e.g. Popkin et al 1983, Sadler and Perrine 1984, Tashima and Peck 1986). Even if a large proportion of the drivers continue to drive without a valid license (e.g., Peck et al 1985, Ross and Gonzales 1988, Roos 1992), their crash and violation records during suspension are significantly better than those of nonsuspended drivers. Probably, they drive less and more cautiously (Nichols and Ross 1988). In addition, the low rate of crashes and violations are maintained after the license actions expire.

Sobriety checkpoints. Roadside sobriety checkpoints have frequently, but not always, resulted in a reduction of alcohol-related fatal crashes (Voas and Lacey 1988). It is estimated that a breath test law in the U.S.A. would reduce highway fatalities by nearly 5%, with greatest effect among young drivers and those driving at night (Saffer and Chaloupka 1989).

Interlock. An ignition interlock device prevents a driver from starting a vehicle unless an alcohol-detecting breath test is passed. In the U.S.A., the device is used primarily for second time offenders resulting in a re-arrest rate of less than 1% (Evans 1991).
The device is currently being tested in Sweden, but its effectiveness has not yet been evaluated.

**Smart card.** A smart card in conjunction with the driver's license is under development in Sweden (Goldberg 1993). The vehicle ignition system is combined with the smart card in a unit, possible to programme for up to 10 driver's licenses. Unauthorized drivers, for example, drunken drivers will have their licenses deleted in the system and thieves will not be able to start the car. The smart card is connected to the radio frequency, making it possible to delete a license instantly, for example, from a police station. For a drunken driver offender, the card can be programmed to be valid with an interlock system only, making it very hard for an offender to rent another vehicle without an interlock system.

**Passive protection**

Most efforts to prevent alcohol-related traffic injuries have focused on the effectiveness of behavioural changes. However, inebriated trafficants constitute a high-risk group, generally with low compliance to behavioural changes, particularly if the drunken driver is a chronic abuser. For example, drunken drivers have a lower frequency of belt usage than sober drivers (Perrine et al 1988). In addition, the addiction of the drunken driver is in many cases unknown to the society, making it hard or even impossible to prevent drunken driving and injuries related to drunken driving. Thus, it will probably be impossible to eliminate all drunken drivers and more efforts need to be directed into passive protection in the vehicle and in the environment to reduce the risk of a crash and to minimize the injuries if a crash occurs.

**Vehicle.** A possible strategy to increase the interior protection of the vehicle is to supplement the seat belt with a passive dynamic padding system, such as an airbag and knee bars (cf Öström et al 1992). The bag should reduce injuries even if the occupant is unrestrained.

**Environment.** The elimination of injury risk factors close to the road such as ditches, pillars etc is of importance, especially in single vehicle crashes (Björnstig and
Lekander 1992). The deleterious effects of trucks and buses should also be considered Björnstig et al 1993).

**Helmet protection (Papers IV, V)**

In Sweden, in recent years bicyclists have accounted for about 12% of all traffic fatalities (Statistics Sweden 1989) and in northern Sweden an annual incidence of bicycle fatalities of 1.4 per 100 000 population was found (Öström et al 1993a). Head injuries is the main cause of death and is the main severe injury among bicyclists (cf Fife et al 1983, Björnstig and Näslund 1984, Ballham et al 1985, Öström et al 1993a) and in our material, about 1/3 of the clinical material sustained head/face injuries and six of ten bicycle fatalities died from head injuries without fatal injuries in other body regions (Paper IV).

Helmet use is an effective countermeasure to reduce head injuries among bicyclists (cf Worrell 1987, Thompson et al 1989) with substantial reduction of cost for hospital treatment and sickness benefit (cf Worrell 1987, Wasserman et al 1988, Thompson et al 1989). In Paper IV, about 2 of 5 bicycle fatalities and 1 of 5 in the clinical material might have benefited from a helmet. However, a helmet will of course not prevent all injuries. In 1/3 of the bicycle fatalities, the head injury was so severe that a helmet was considered to have no significant impact on the outcome. Thus, for further injury reduction among bicyclists, other countermeasures are also needed, such as separation of bicyclists from motor vehicles by building separate bicycle tracks (cf Öström et al 1993a).

**Helmet design.** The bicycle helmet testing procedures consider impact energy attenuation, penetration, and strength of the retention system (cf American National Starndards Institute 1984, Konsumentverket 1985, Standards Association of Australia 1982, 1990). In Paper IV, cases with head injuries without any external signs of impact on the head were found, indicating a rotation movement of the head (cf Genarelli 1984, Ommaya 1984, 1988). A hard shell helmet with less friction with the road surface would probably reduce the rotation movement. Insufficient protection by a soft helmet (cf Lereim 1984) also speaks in favour of a hard shell helmet.
The face is not protected by a conventional helmet (cf Paper IV) but a chin cover would probably reduce the face injuries. In only two cases (Paper IV), the fatal impact was located to the face. These results indicate that the protection of the face is of minor importance compared to protection of the head. In fact, the bony structures of the face may have a protective function, yielding an impact reduction of the brain.

In Paper IV, the trauma was blunt in almost all the victims, indicating that helmet designs against sharp trauma is not of great importance.

According to the Swedish Child Safety Council, at least five children (0-6 years) have been strangulated to death by the retention system of the helmet when playing with playground equipment. In comparison, during the same period, six children were killed in traffic (T. Lekander, personal communication). This shows that it is of great importance that the retention system automatically releases at a specific load to prevent such incidents.

Today, activities such as bicycling, riding and downhill skiing require different kinds of helmets. An allround helmet for all activities requiring helmets would probably increase helmet use and decrease the private cost. However, the injury mechanisms of other activities have to be further analyzed to construct a helmet, appropriate for allround purposes. However, if the injury mechanisms are about the same as in bicycling, an allround helmet preferably should reduce rotation and impact force, be made of a hard shell, have a chin cover, and an accurate retention system (Fig. 2).

**Increase of helmet use**

Bicycle helmet campaigns are often aimed at children. The present helmet usage rate among adult bicyclists in Sweden is only 4%, which is considerably less compared to 33% among children below 10 years of age (Nolen 1992). However, the importance of helmet use is not less among adults. In fact, the risk of a fatal outcome from the same impact is higher among the elderly (Evans 1991) and in our district, elderly (50+ years) were twice as likely to die in a bicycle crash as those aged 5-14 years (Öström et al 1993a), indicating that helmet protection is of great importance not only for children, but also for adults, particularly the elderly.
With extensive bicycle helmet campaigns, usage rates of about 25-30% have been reported (Bader 1990, Nolen 1992), and with a law, rates of up to 90% (Leicester et al 1991). These findings clearly point out the limited value of campaigns as compared to compulsory laws. However, campaigns are sometimes needed to more ease the introduction of laws, leading to a rapid and very high usage frequency of bicycle helmets (cf Bader 1990, Leicester et al 1991). As a comparison, the Swedish law on helmet usage for motor cyclists was introduced in 1975 and resulted in a 39% reduction in the numbers of fatalities (see Björnstig et al 1985).

Figure 2. Suggestion of a design of an allround helmet. With emphasis on rotation- and impact reduction made by a hard shell, chin cover, and accurate retention system.
Effectiveness of a helmet law among different vehicle categories

A compulsory helmet law among bicyclists and motorcyclists should lead to an increased rate of use, yielding fewer head injuries. In Finland, a compulsory law regarding snowmobile helmets have been implemented. So far, no evaluation of this law has been performed. In Sweden, the frequency of helmet use among snowmobile riders is not known. However, only a minority of the fatally injured in Paper V had used a helmet. Due to the documented injury reduction of a helmet among bicyclists and motorcyclists, Swedish authorities are at present discussing the introduction of a compulsory helmet law regarding snowmobile riders.

In Paper V, we have analyzed the cohort before the introduction of a law. Fatal head injuries were less common among snowmobile riders (Paper V) than among motorcycle riders (cf Drysdale et al 1975, Björnstig et al 1985) and bicyclists (Öström et al 1993a, Paper IV); this difference was probably due to other crash mechanisms and the padding effect of snowy terrains. Actually, drownings was the most common cause of death among autopsied snowmobile riders (cf Eriksson and Björnstig 1982, Öström et al 1993c), in agreement with Canadian findings (McCullough 1991). In addition, there is a higher frequency of alcohol-related fatalities in the snowmobile group than in other vehicle categories (Eriksson and Björnstig 1982). The snowmobile riders also show a low compliance to compulsory countermeasures (cf Paper V).

In conclusion, it is probably harder to increase helmet use among snowmobile riders with a compulsory law than among bicyclists or motorcyclists. A helmet law for snowmobile riders would probably not have a significant impact on head injuries since the victims are in most cases alcohol inebriated and/or had violated other major traffic laws (cf Paper V). Floating clothing preventing drownings are probably more important than helmet use among snowmobile riders.

Airbags

Already in the 1930's, the air force in the United States experimented with the effects of airbag reduced injuries in crashes (Frey 1970). The first patent was made in the 1950's (Hetric 1952), and Ford Motor Company was the first to develop airbags for passenger car occupants in 1957 (Clark and Blechschmidt 1966). With the introduction in 1968 of the Federal Motor Vehicle Safety Standard 208 (FMVSS 208) (National
Highway Traffic Safety Administration 1968), and its limitation of maximal forces to the body in a collision, the research on airbags increased. This standard has been changed several times, but from 1990 onwards all passenger cars in the U.S.A. are required to have an automatic safety belt or an airbag for the driver (Jagger et al 1987). From 1994 onwards, similar regulations also apply to the passengers in a vehicle (Insurance Institute for Highway Safety 1991). As of 1998 models, all passenger cars in the United States should be equipped with airbags (Insurance Institute for Highway Safety 1991).

The safety belt has probably been one of the most effective devices in reducing injuries and costs of medical care (cf Orsay et al 1988). Already in 1975, a mandatory law requiring safety belt use was introduced in Sweden with a significant increase in belt use and a significant drop in traffic fatalities (Lacko and Nilsson 1986, Statistics Sweden 1992a). The combination with an airbag should additionally increase the safety (see below). In 1993, there is yet no law requiring airbags in vehicles in Sweden, which means that few cars in Sweden are equipped with an airbag. During recent years, car manufacturers have begun to introduce airbags in Sweden as an option, or as a standard feature in some more luxurious models.

Injury reduction
Airbags deploy mainly in frontal collisions with a speed of the vehicle of about 15 km/h and above, protecting mainly the head and face (Johansson et al 1989). Recently, airbags protecting in nonfrontal collision have been introduced (cf Olsson and Skötte 1989, Håland and Pipkornm 1991, Warner et al 1991).

In Paper VI, two cases where the airbag probably saved the life of the driver are presented. The fatality-reducing effectiveness of the airbag versus safety belt is shown in Table 5.

If airbags had been used in all passenger cars in Sweden during 1986 through 1988, the mean annual reduction is estimated to be 88 fatalities and 762 injured persons (Andersson et al 1991). Injury reduction of the airbag is strongly correlated to the proportion of safety belt users (Viano 1988). It is estimated that a stop in safety belt usage in combination with use of an airbag can result in a 41% increase in risk of death in a collision (Evans 1990a). Thus, a safety belt has to be used in combination
with an airbag (National Highway Traffic Safety Administration 1984, Viano 1991). It is possible that occupants in a car equipped with an airbag feel safe and do not use the safety belt. However, experiences from the U.S.A. show that the rate of safety belt users did not decrease among persons in vehicles equipped with an airbag (Williams et al 1990).

*Table 5.* Comparison of estimates of fatality reducing effectiveness between safety belt and airbag. Lap belt effectiveness is for rear seat only, whereas other results are mainly for front seat occupants.

<table>
<thead>
<tr>
<th>Occupant protection device</th>
<th>ref A</th>
<th>ref B</th>
<th>ref C</th>
<th>ref D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airbag + lap/shoulder belt</td>
<td>46± 4</td>
<td>45-55</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lap/shoulder belt</td>
<td>41± 4</td>
<td>40-50</td>
<td>31</td>
<td>32</td>
</tr>
<tr>
<td>Airbag + lap belt</td>
<td>-</td>
<td>40-50</td>
<td>29</td>
<td>34</td>
</tr>
<tr>
<td>Shoulder belt</td>
<td>29± 8</td>
<td>-</td>
<td>-</td>
<td>28</td>
</tr>
<tr>
<td>Lap belt</td>
<td>18± 9</td>
<td>30-40</td>
<td>17</td>
<td>13</td>
</tr>
<tr>
<td>Airbag only</td>
<td>17± 4</td>
<td>20-40</td>
<td>18</td>
<td>25</td>
</tr>
</tbody>
</table>

ref A = Evans 1991  
ref B = National Highway Traffic Safety Administration 1984  
ref C = Wilson and Savage 1973  
ref D = Huelke et al 1979.

*Injuries due to an airbag deployment*

Of the 50,000 airbag deployments in real-world crashes up to 1990, 197 injuries associated with the airbag have been reported (Insurance Institute for Highway Safety 1991). Injuries include reversible hearing impairment (Allen et al 1970, Nixon 1972), injuries to the skin (Ziperman and Smith 1975, Shebar and Laurenzano 1991), and injuries to the eyes (Ingraham et al 1991, Larkin 1991, Rosenblatt et al 1991). In the
field study (Paper VI), a spectrum of injuries are presented. While most of these injuries are minor, some occurred in minor crashes where resulting injuries to the belted driver without the airbag would have been minimal or nonexistent. It must be of interest to minimize these types of injuries to get the airbag accepted among the public. The experimental airbag study (Paper VII), was focused on skin abrasions since this is the most common adverse effect of an airbag deployment. The study showed that abrasions may occur within a distance of 350 mm and that a significant reducing effect was obtained using reverse fold and tethering. However, these minor injuries are negligible compared with the great injury reducing capacity of the airbag.

Cost benefit ratio

It is estimated that for every US dollar invested in airbag installations, 6 US dollars are saved by fewer and less severe injuries (National Highway Traffic Safety Administration 1974). The annual economic savings are estimated in the United States to be 5,000-8,000 million dollars (National Highway Traffic Safety Administration 1984, Robertson 1989). In Finland, the cost of an airbag was about 2,300 USD in 1989 and it was estimated that this price must drop to about 1/5 before driver airbags can become cost-beneficial (Sleet and Kallberg 1991).

In Sweden, the cost of an airbag in 1993 was about 600 USD. With installation of airbags in all passengers cars in Sweden, an annual reduction of 88 fatalities and 762 severely injured in Sweden (cf Andersson 1991) would reduce the annual cost by 895.5 million SEK (cf Persson 1992) corresponding to the cost of about 190,000 airbags. In comparison, 3,621,114 passenger cars were registered in Sweden in 1991 (Statistics Sweden 1992a). The reduction in the health care cost and reduced cost for the insurance companies could be used in lower taxes and insurance premiums to stimulate the use of airbags.
CONCLUSIONS

When estimating the vehicle-related fatalities in northern Sweden during 1980 through 1989 with regard to risk factors and injury reducing factors, the elimination of alcohol-related crashes was by far the main factor, with an estimated fatality reduction by 17% (Table 6). In comparison, the proportion of fatalities attributable to alcohol was 47% in the U.S.A. in 1987 (Evans 1990b). Most drunken drivers are at fault in the crash. Of drunken driver fatalities in northern Sweden, only 4 of 103 were judged not to be at fault (cf Öström et al 1993d).

With the present days' injury-reducing approach, the proportion of about 20% inebriated vehicle-related fatalities in northern Sweden is probably close to the lowest proportion in a society where alcohol is established. When education, information, and even law enforcement has limited injury reduction value, other countermeasures, for example, passive protection are needed. The traffic environment, which includes traffic signs, roads and the vehicles need to be designed such that even a drunken or otherwise impaired driver can cope with it (cf Hicks 1976). In addition, this would make it easier for other groups, such as the elderly, which also require a safer traffic environment (cf Sjögren et al 1993a).

The effectiveness of an airbag in preventing fatalities in the U.S.A. is estimated to be 18% for car drivers and 13% for right front passengers (Viano 1991). When this is applied to the fatalities in our material, we can estimate that a maximum of 8% of lives would have been saved if airbags had been equipped in all cars in the district investigated in the present study, and none of the victims had been using a safety belt. However, the figure is very approximate since the types of car crashes in northern Sweden compared to the U.S.A. are not necessarily similar, and the safety belt use was unknown.

The reduction of fatalities by bicycle helmet use was estimated to be 40% (Paper IV). However, the overall fraction of lives saved was only a few percent since the proportion of bicyclist fatalities is low. However, to avoid unnecessary head trauma and deaths, the use of bicycle helmets must increase. A compulsory law is the most effective way in rapidly reaching an acceptable usage frequency.
Among snowmobile riders, head injuries are not the main cause of death and the fraction of fatally injured snowmobile riders is low. Thus, one case per year would be saved if helmets were used by all snowmobile riders. In addition, it is believed that a compulsory helmet use law for snowmobile riders would not have any significant impact on the reduction of head injuries since most injured victims without helmets had broken other major traffic laws, indicating a low compliance to compulsory countermeasures.

In addition to the traumatic vehicle-related deaths, about 200 people in northern Sweden died of natural causes while driving during this decade. However, as cited in Paper I, these victims were seldom a risk for other persons in traffic and the property losses were low. In addition, a large proportion of these victims had no previous symptoms of major disease. Further restrictions in driving among people with, for example, heart diseases will probably not have any significant impact on injury reduction in traffic.

Table 6. Estimation of the number and percentages of saved lifes among 1,089 traumatic vehicle-related fatalities in northern Sweden during 1980 through 1989

<table>
<thead>
<tr>
<th></th>
<th>(n)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation of airbags in cars*</td>
<td>89</td>
<td>8</td>
</tr>
<tr>
<td>Elimination of drunken driving</td>
<td>189</td>
<td>17</td>
</tr>
<tr>
<td>Total use of bicycle helmets</td>
<td>37</td>
<td>3</td>
</tr>
<tr>
<td>Total use of snowmobile helmets</td>
<td>12</td>
<td>1</td>
</tr>
</tbody>
</table>

* Mortality reduction according to Viano 1991 if safety belt was not used.

In conclusion, human factors such as alcohol inebriation is probably the main cause of injuries in traffic. Behavioural changes such as compulsory laws for bicyclists can reduce injuries but in many cases, countermeasures regarding behavioural changes have a limited effect. For a significant reduction of vehicle-related injuries, further research on passive protection is stressed.
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