INJURY RESPONSE IN BELTED AND UNBELTED CAR OCCUPANTS RELATED TO THE CAR CRASH ENERGY IN 458 ACCIDENTS
A study of all fatal automobile accidents in Sweden 1975

by

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Introduction

Injuries to automobile crash victims are common and costly to society. In order to reduce the severeness of the injuries and to save lives, seat belt use has been legislated in many countries. The effectiveness of the seat belts in reducing injuries to car occupants has been shown by many investigators (1,2,3,4). The protective effects of seat belts are undoubtely dependent on such factors as the type of accident, the type of car, the age of the car occupant etc. Studies on injury patterns in those immediately killed are important for further improvement of safety measures. In order to get a conception if the number of fatal casualties can be reduced by improved emergency medical care, studies of those cases who survive for some time is necessary.

The choice of the crash injury sample for such a study is of crucial importance. Contrary to other investigations, this investigation has been based on a one year selection of all fatal automobile accidents in a country with high medical standards.

Material and Methods

In all 458 automobile accidents with fatal outcome occurred in Sweden 1975. In these accidents 1366 persons were involved, 560 of which were killed. A person who survives the accident but dies within 1 year is considered killed. In the present investigation the killed car occupants as well as the surviving occupants are included. In all of these cases, data have been collected from police reports, autopsy records, case sheets, photographs from the scene of accident and the damaged cars, and from day-to-day reports supplied by the Swedish Road Traffic Safety Authority. Only 14 persons killed in automobile traffic accidents this year were not subjected to autopsy and the cause of death in these cases have been taken from the death certificates.

Since 1975 seat belt use is mandatory in Sweden for front seat occupants. The seat belt use by the back seat passengers is quite low, and in order to get test groups of comparable sizes only the front seat occupants, i.e. the drivers and the front seat passengers have been included in the evaluation of the injury reducing effectiveness of the seat belts.

In the analysis some cases have been excluded: occupants in cars underdriving lorries have not been studied more closely and persons thrown out of the car have been analysed as a special group.

The body injuries have been registered as to the type (eg. aortic rupture, lung contusion etc.), the location (eg. head, neck, thorax, abdomen, pelvis and extremities) and the severeness. In evaluating the severeness the Abbreviated Injury Scale (AIS 1976 revision) has been used. The AIS range from 0 to 6, where 0 indicate no injury and 6 fatal untreatable lesions.

When for a given person, the overall injury has been evaluated the Injury Severity Scale (ISS) proposed by Baker et al (5) has been applied. The ISS is the sum of the squares of the highest AIS codes in each of the three most severely injured body regions. The persons studied may have additional lesser injuries in other body regions but these are not considered in determining the ISS. In her work Baker recommended that injuries scoring 6 according to AIS should be omitted or valued 5 since they were not considered to be frequent. In the present material maximal AIS rating is at hand in a considerable number of cases and therefore the calculation of the ISS has been based on the original AIS score.

In order to get a comprehension of the impact energy, the accidents were studied as to the deformation of different zones of the car (cf. fig. 1). The car was subdivided into 8 zones. In addition the degree of intrusion of the steering wheel and the deformation of the dashboard was recorded, and these interior parts of the car were included as separate deformation zones.

The deformation (D) of each zone was scored from 0 to 3, where 0 indicate no deformation and 3 a fully deformed zone. In order to get an estimate of the impact energy (IE) for the different cars involved the deformation score was squared and summed up for all deformation zones:

$$IE=D(1)^2+D(2)^2+....D(10)^2$$

The value of IE then reflects the impact energy and should offer a qualitative tool for the selection of comparable accidents.

In order to determine actual differences in the present material statistical methods were employed. In the tests for significance the parameters studied were assumed to be normal with an average and a standard deviation or with a frequency. A two-tail test was always performed.

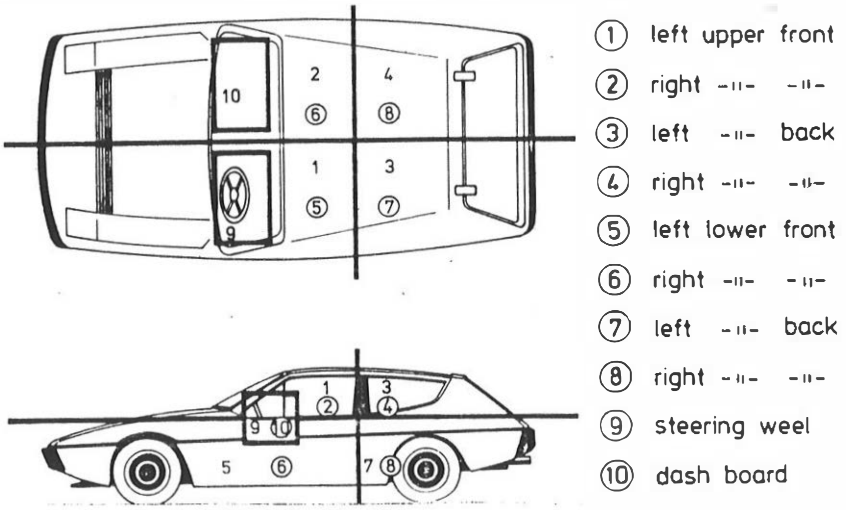
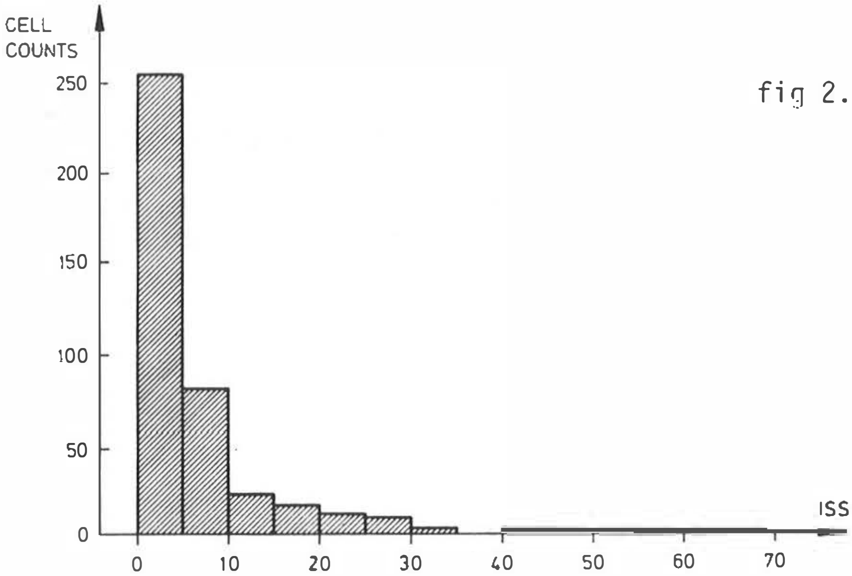


Fig 1. Definition of the deformation zones. 5-8 include hood and trunk.

ISS distribution in surviving and killed front seat occupants

Figg. 2 and 3 presents the distribution of the ISS in surviving and killed drivers and front seat passengers. According to fig. 3 there are some occupants with quite low ISS. Some of the deceased died from posttraumatic complications such as pneumonia and pulmonal fat or thrombo embolism. Four persons died from drowning in cars submersed in water. In 14 cases no autopsy was performed and in these cases an estimate of the ISS was made from the death certificates from which it is impossible to obtain a complete AIS scoring.



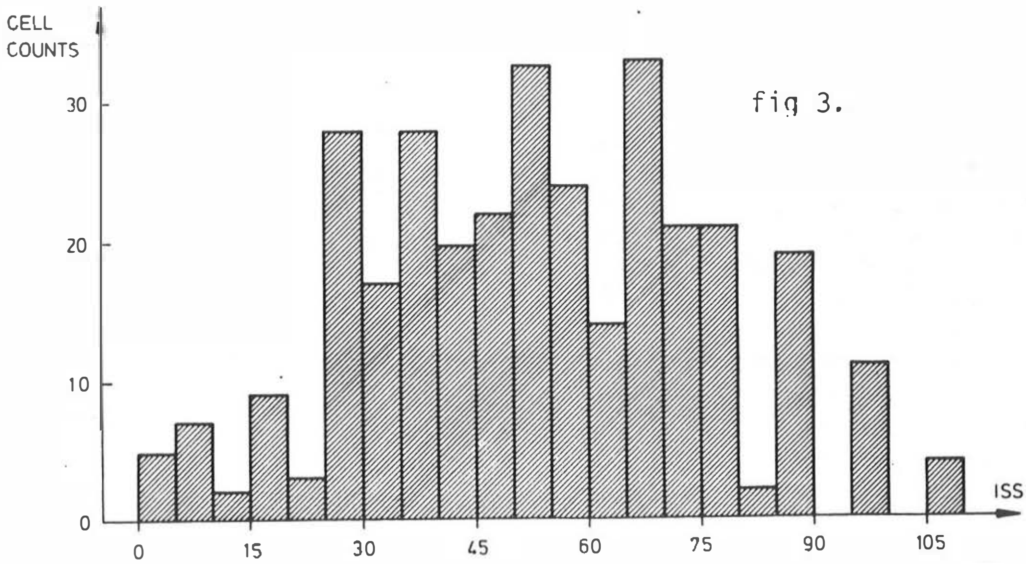


Fig 2 and 3. ISS distribution in surviving (2) and killed (3) occupants

An attempt to define a critical ISS level has been made such that there are as many deceased persons with an ISS value below this level as there are surviving with an ISS value exceeding this critical level. The so calculated critical level is ISS=25 and it corresponds to an AIS=5 value in one body region or to AIS=3 and AIS=2 for two body regions respectively.

A rough estimate to correlate this injury level to a relative collision speed of the vehicle has been made. Langwieder (6) has presented an injury material comprising 29.000 accidents: the severity of the injuries suffered by the deceased occupants in frontal collisions has been correlated to an equivalent test speed. Furthermore a corrective factor for the equivalent test speed in relation to the relative collision speed, i.e. the real speed at the moment of impact, is presented. The data presented by Langwieder are compared to the present material and calculations yield a relative collision speed of about 45 km/h corresponding to the above mentioned critical ISS level.

Type and frequency of the injuries suffered by belted and unbelted car occupants

The most frequent injuries suffered by belted and unbelted car occupants are listed in table 1, which also accounts for some injuries which differ in frequency in the belted and unbelted group.

Blunt trauma to the head with skull fractures and brain lesions is well known as frequent in traffic casualties. In the present material there is a *** significant difference regarding the cortical contusions and a ** significant

Type of injury	Frequency belted %	unbelted %	Significance level
Lung contusion	16.5	27.7	***
6-10 rib fractures	23.1	26.3	-
1- 5 rib fractures	21.3	23.6	-
Liver rupture	11.5	18.1	**
Pelvic fracture	16.5	18.5	-
Femur fracture	14.1	17.2	-
Face injuries(§)	14.5	17.1	-
Brain cortical contusion	9.0	16.2	***
Lung laceration	9.9	15.5	**
Commotio cerebri(§)	10.5	13.7	*
Spleen rupture	7.8	13.3	**
Cross fracture of the base of the skull	7.6	13.1	**
Impression fracture of the base of the skull	7.0	12.1	**
Aortic istmus rupture	7.8	11.0	**
Heart laceration	7.8	10.0	-
Disruption of many bridging veins	4.2	8.2	**
Fracture of iliac crest	2.6	0.9	*
Malleolar fracture	5.4	2.8	*

Table 1. Frequenly occuring injuries in surviving and killed belted (N=503) and unbelted (N=565) car occupants. (§) indicate surviving occupants only.

difference for various skull fractures, brain laceration, tentorial herniation and disruption of many bridging veins as can be seen in table 1.

Concerning neck injuries significant * difference is found for total disconnection of the occiput from the atlas, as well as cervical spine fractures including fractures of the odontoid process of the axis. Belted drivers tend to suffer from soft tissue injuries to the neck such as injuries to the carotids and the trachea more often than the unbelted do and this difference is evidently caused by the steering wheel.

In agreement with general experience injuries to the thorax with rib fractures and contusions and lacerations to the lungs is a very common finding. Although the number of rib fractures does not differ significantly between the belted and the unbelted group, there is a *** significant difference concerning the lung contusions and on the ** level concerning the lung lacerations.

Among other thorax injuries there is a significant difference ** found regarding rupture of the aorta at the istmus as well as in the ascending part just above the heart. These aortic ruptures are in many cases attributed to the shovel effect as suggested by Voigt (7).

Ruptures of the liver and the spleen occur more frequently in the unbelted group. There is a ** significant difference and it should be emphasized that rupture of the liver, often with intraabdominal bleeding, is seen in as much as 18 % of the unbelted. Concerning the drivers, the steering wheel was the causative agent in head-on collisions. The front seat passenger suffers from liver rupture in right side collisions.

Fractures of the pelvic girdle occur in comparably high frequency in the belted and unbelted group. However, although not very common, there is a higher incidence of fractures to the iliac crest in the belted group. The difference is significant on the * level and can be attributed to the lap belt.

Concerning injuries to the extremities, i.e. mainly different fractures, there is, apart from fracture of the femur, a slight overrepresentation in the belted group. A reasonable explanation for this difference is a pendulum effect which causes the freely movable extremities to move forward and hit the interior of the car while the trunk is restrained by the seat belts during the crash.

Injury pattern and causes of death in delayed fatalities

Out of the 560 fatalities in the accidents, 156 (28%) survived a varying amount of time. Of these, 20 cases (4% of all) died during the first hour and 52 cases (9% of all) within 3 hours. Seventy-eight cases (14% of all) were deceased within 24 hours and 114 cases (20% of all) within a week.

Forensic autopsy reports and hospital records offered a possibility to carefully penetrate the causes of death in these delayed 156 fatalities. In 67 cases (12% of all) the main cause of death were lacerations and contusions of the brain or brain stem and/or multiple disruptions of the parasagittal bridging veins. Many of these cases had no cerebral function at the arrival to the hospital. Lacerations of the heart or of large vessels accounted for 15 (3% of all) of the casualties. A delayed bursting of an incomplete rupture of the aorta was often seen in these cases. Multiple rib fractures with flail chest and/or contusions or lacerations of the lungs and diaphragm were seen in 23 cases (2% of all). Because of the severe pulmonal injuries in many of these cases, it was impossible to maintain the lung function despite of the fact that they survived for some time and were given intensive medical care. Rupture of the liver, spleen or the gut was regarded as the cause of death in 13 cases (2% of all). Most of these had a total or incomplete laceration of the liver. Six cases (1% of all) were elderly with moderate injuries. Complications due to such moderate injuries, e.g. pneumonia or pulmonal embolism, were the main causes of death in 19 cases (3% of all). Nine cases (2% of all) developed a fat or microthrombotic syndrome. Misdiagnosed epidural haemorrage, isolated injuries to the extremities, pure aspiration and burn injuries did only account for one case each in this sample.

It is obvious that 72 % of all cases killed in the present material were beyond all medical care as they were immediately killed at the scene of the accident. To judge whether an improved accident medical care might have reduced the number of delayed fatalities is of course very difficult. However, a considerable reduction seems doubtful.

Category	Body region	AIS-rating 0	1	2	3	4	5	6	Total	$\frac{\Sigma AIS^3}{N}$
unbelted front seat passenger	I	44	3	25	5	5	7	14	103	44.24
	II	94	0	0	0	7	1	1	103	7.66
	III	52	0	5	15	5	11	15	103	52.23
	IV	68	0	0	2	12	20	1	103	34.35
	V	86	0	1	16	0	0	0	103	4.27
	VI	67	0	35	1	0	0	0	103	2.98
belted front seat passenger	I	87	3	24	4	5	7	16	146	33.93
	II	134	0	0	0	9	1	2	146	7.76
	III	78	0	16	21	8	10	13	146	36.06
	IV	112	0	2	4	13	15	0	146	19.39
	V	123	0	2	21	0	0	0	146	3.99
	VI	99	1	44	1	1	0	0	146	3.04
unbelted driver	I	90	5	23	12	6	16	29	185	49.63
	II	176	0	0	0	9	0	0	185	3.11
	III	89	0	9	17	12	19	39	185	65.39
	IV	121	0	1	1	26	33	3	185	34.98
	V	158	0	0	27	0	0	0	185	3.94
	VI	111	0	72	2	0	0	0	185	3.40
belted driver	I	144	17	56	5	6	28	41	297	44.92
	II	276	0	0	0	18	0	3	297	6.06
	III	156	0	31	35	15	28	32	297	42.30
	IV	222	0	4	7	31	33	0	297	21.31
	V	249	0	2	46	0	0	0	297	4.23
	VI	187	1	106	2	1	0	0	297	3.26

Table 2. AIS classified injuries for each body segment in front seat occupants. I: head, II: neck, III: thorax, IV: abdomen, V:pelvis, VI: extremities.

AIS rating of body injuries in drivers and front seat passengers

In order to get a comprehension of the injuries classified according to AIS, table 2 illustrates the highest AIS for each body segment. For comparison an average injury severity value has been evaluated for each body segment by using the expression $\Sigma AIS^3/N$, a method which alsohas been employed by Walfish et al (8). By using this parameter the head, thorax and abdomen exhibit the most severe injuries as can be expected; - the values being higher for the unbelted occupants. Furthermore, the drivers tend to score higher values. This fact is pronounced concerning the head injuries in the belted group and concerning the thorax injuries in the belted as well as in the unbelted group. These expected findings, also reported by Harris et al (9), Shanks et al (2) a.o., show that the steering wheel and the dashboard account for severe injuries in belted as well as in unbelted front seat occupants, ie. seat belts cannot restrain sufficiently from contact with the interior of the car.

Fig. 4 illustrates the frequency of mild (AIS=1-2), moderate (AIS=3-4) and severe or fatal (AIS=5-6) for the body segments head, thorax and abdomen respectively. Also in this representation the higher frequency for severe injuries is evident. Severe thorax and abdominal injuries are significantly lower (** level) in the belted group.

Seat belt use versus age

The seat belt use as a function of age is presented in fig 5. The material has been subdivided into three groups of the same size regarding the number of persons. Sixty-one per cent of the front seat occupants use seat belts and women more often than men (64% and 59% respectively). This difference is not significant. There is however a marked correlation between seat belt use and age. Group I (45.7% seat belt use) differs significantly from the average level, and so does group III (70.8% seat belt use). It should be noted that 9 persons under 15 are included in group I, and therefore were not under the seat belt law. Anyhow, significant difference is maintained when these persons are excluded.

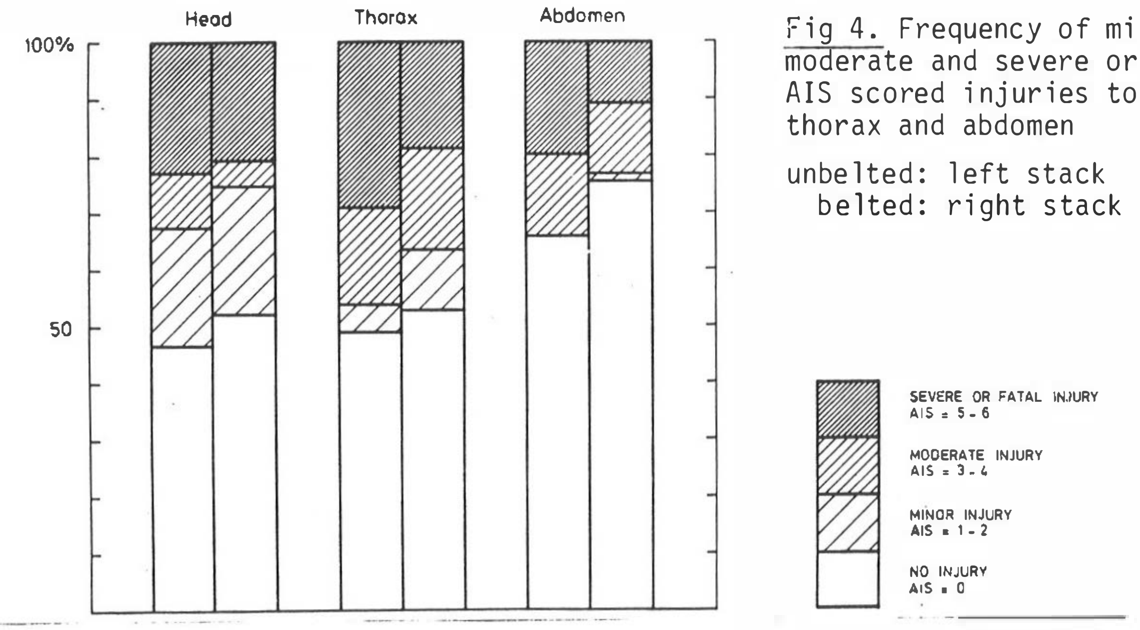


Fig 4. Frequency of mild, moderate and severe or fatal AIS scored injuries to head, thorax and abdomen

unbelted: left stack
belted: right stack

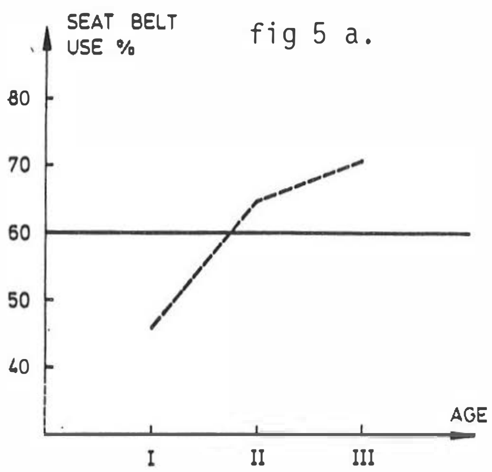
Average ISS for belted and unbelted front seat occupants versus age

It is a well known fact that biological material loses strength with age. Baker et al (10) has shown a positive correlation between ISS and age. This is readily illustrated in the present material too, cf table 3 and fig 5 b, where the average ISS is presented as a function of age for the belted and unbelted front seat occupants. Concerning the protective effects of the seat belts there is a significant reduction of the ISS, on the ** level in group II and on the * level in group III, while no significant difference can be detected in group I.

For the belted as well as for the unbelted front seat occupants there is a positive correlation between the ISS and the age. Concerning the seat belt users the ISS is significantly lower for group I and II compared to group III and for the unbelted there is a significant difference for group I compared to group II and III. The ISS versus age correlation is further confirmed by the fact that group I is involved in more violent accidents measured by the impact energy parameter used. The car damage is significantly higher (** level) in group I compared to group II, cf. table 3.

Age group	Average ISS belted N= 443	Average ISS unbelted N= 288	Average car damage N= 731
I	18.5	23.3	22.5
II	21.3	36.7	17.8
III	29.9	37.6	21.8

Table 3. Average ISS and average car damage for belted and unbelted front seat occupants correlated to age. I: age < 25 years, II: 25 years < age < 50 years, III: age >50 years.



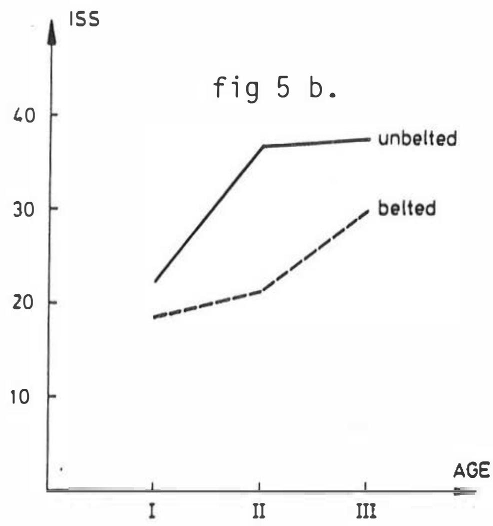


Fig 5 a, b. a) seat belt use correlated to age in front seat occupants; b) average ISS and average car damage for belted and unbelted front seat occupants correlated to age. I: age < 25 years, II: 25 years < age < 50 years, III: age > 50 years.

ISS and impact direction

The influence of the impact direction has been studied for the driver and the front seat passenger separately. Four main impact directions have been used: head-on, right and left side, and roll over. Impacts from behind are few and have not been studied. A roll over accident is considered as soon as the car has rolled on the side or top, irrespective of any initial clockwise direction. The frequency of the impact directions in the accidents studied are evident from fig 6.

The average ISS is presented in table 4. From the figures it is evident that seat belt use reduce the injury severity. In head-on collisions there is a significant difference for the driver and the passenger. In head-on collisions the average injury severity for belted drivers is somewhat higher compared to that for belted front seat passengers. This difference should be attributed to the steering column.

In side impacts significant difference is found concerning reduction of injuries to the opposite side occupant. No negative effects of seat belts could be found in side impact collisions. These results are in good agreement with those of Danner (11), who has studied the injury characteristics of belted occupants in side collisions.

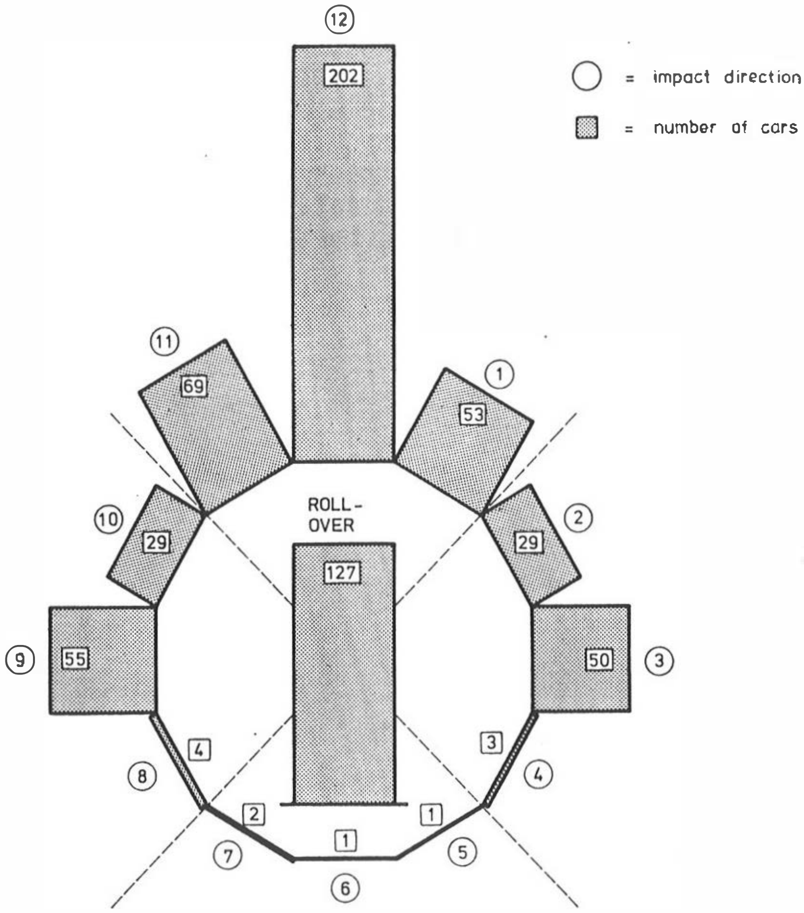


Fig 6. Frequency of accident impact direction

Impact direction	Driver belted Number	Driver belted ISS	Driver unbelted Number	Driver unbelted ISS	Significance level
11, 12, 1	168	22.0	93	29.5	*
2, 3, 4	45	19.1	22	25.5	*
8, 9, 10	47	44.1	25	51.8	-
roll over	34	21.4	44	32.1	-
Front seat passenger					
11, 12, 1	80	16.8	52	29.9	**
2, 3, 4	29	42.7	13	53.8	-
8, 9, 10	22	14.1	12	30.3	*
roll over	15	21.3	25	11.9	-

Table 4. Average ISS in belted and unbelted drivers and front seat passengers correlated to accident impact direction.

ISS correlated to relative accident impact energy for drivers and front seat passengers

Bartz et al (12) have correlated the collision speed and the severity of occupant injury. For this purpose they recomend that preference should be given to the ISS system of grading injuries when classifying the severity of an accident. The collision speed is suitable when impact energy is to be calculated. However, in our case, as in many others, it is impossible to estimate the collision speed.This is why the deformation of the cars involved has been choosen for the calculation of a relative impact energy (IE). Fig. 7 presents the distribution of the relative impact energy in the accidents studied.

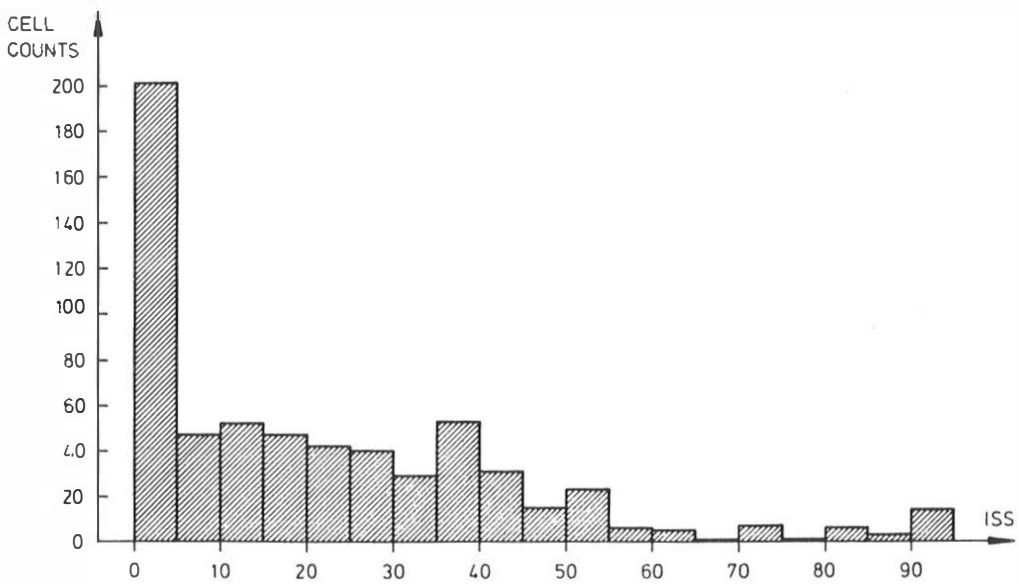


Fig 7. Distribution of car damage. N=625

In fig. 8 the variation of the ISS in relation to the impact energy is presented for belted and unbelted drivers and front seat passengers. A gliding average has been used to smoothen the ISS graph. In addition the number of belted and unbelted front seat occupants in relation to the impact energy is indicated too.

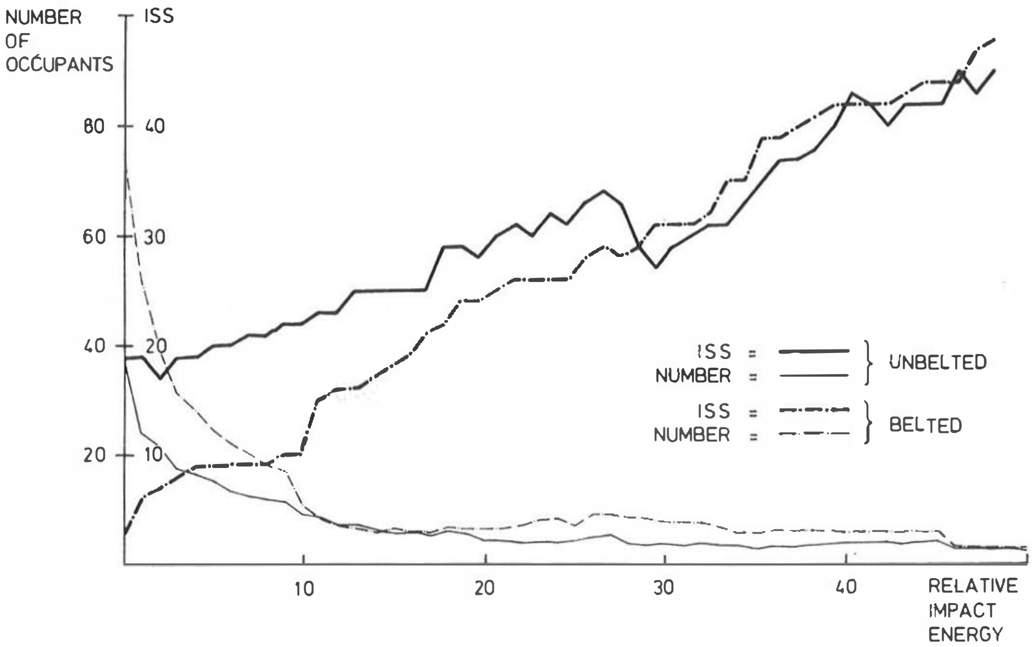


Fig 8. ISS in belted and unbelted front seat occupants correlated to relative impact energy.

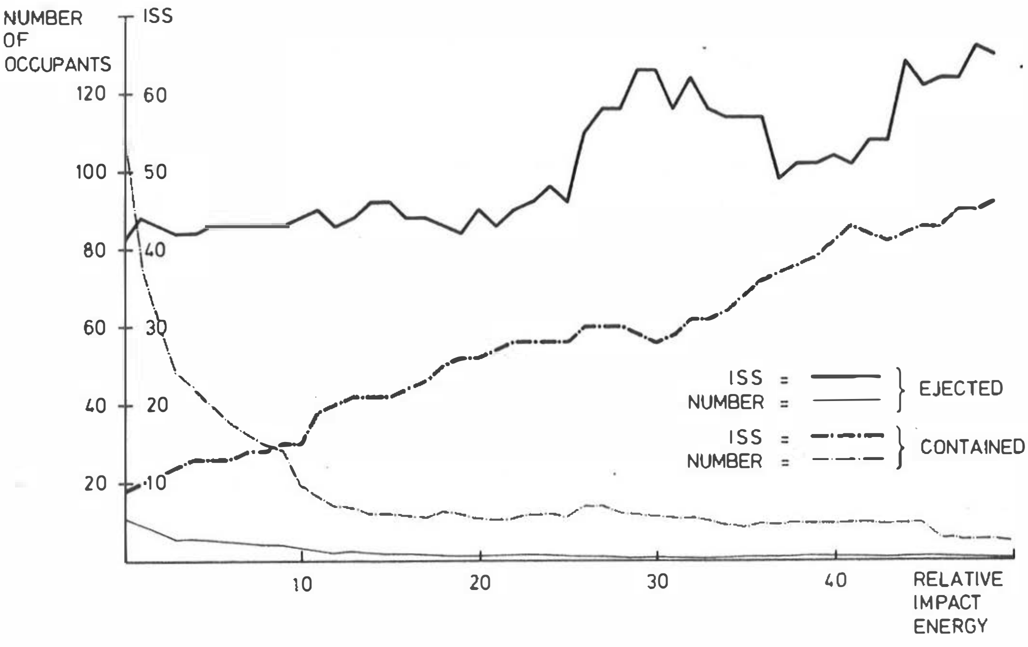


Fig 9. ISS in front seat occupants (belted and unbelted) confined in the car or ejected, correlated to relative impact energy.

For impact energy values below 11 units there is a ** significant difference between the injuries in the unbelted and the belted group. The average difference is about 10 ISS units which corresponds to an AIS value of three i.e. a severe, not life threatening injury in one body region, e.g. spinal injury involving C-4 and below, lung contusion, abdominal or organ contusion, comminuted and/or open fractures of long bones, pelvic fractures etc. or to an AIS value of two in three different body regions. For high energy accidents the difference of the ISS scored injuries suffered by belted and unbelted front seat occupants tend to diminish as can be expected. As the deformation of the car gradually becomes greater, the protective effects of the seatbelt will not longer be at hand.

Ejection from the car and the benefit of the seat belts to prevent ejection has been discussed by many authors. In fig. 9 the same ISS impact energy relation as the one used above is presented, but this time for front seat occupants confined in the car (belted and unbelted) in comparison to occupants ejected from the car during the accident. It is, of course, difficult to compare the pattern of injury in a group of ejected persons with a group of persons confined in the car, as the "environmental" factors are not comparable. However, by using the present representation it is possible to study the difference in injury severity for a person confined and a person ejected. In the present material nearly all of those ejected did not wear seat belts. Ejection almost always involves fatal injuries. From fig. 9 it is evident that a considerable reduction in injuries can be expected if the occupants are confined in the car. Thus, one of the most important effects of seat belt use is the prevention from ejection.

Conclusions

Results of this investigation indicate that:

Fatalities in accidents occur in spite of and not because of seat belt use. Seat belt use reduce the likelihood of severe injuries to occupants for most types of occupant or crash circumstances.

It is much better to remain in the car during the crash than to be thrown out. Notwithstanding seat belt use prevens ejection, this is true whether seat belts are used or not.

Steering columns and dashboards remain a threat to lives. Skull and brain injuries are not substantially reduced with seat belt use in front seat occupants.

Seat belts reduce severe and moderate injuries to a greater extent than they save lives.

Injury severity is strongly dependent of age.

It is doubtful whether improved emergency medical care can considerably reduce the number of fatalities.

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