INJURY SEVERITY IN SIDE IMPACTS - IMPLICATIONS FOR SIDE IMPACT AIRBAG

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ABSTRACT

One of the recent additions to the array of secondary safety systems in modern vehicles is the side impact airbag. The sensor for such airbags needs to be located at an optimum location since deployment needs to take place within an extremely short time. A study was conducted using real world side impact accident data from a sample of 444 cars in which at least one struck side front seat occupant received an AIS ≥ 2 injury. The analysis was performed for two groups of impacts, (i) AIS 2 only injuries and (ii) AIS ≥ 3 injuries. The optimum location for an electronic or pyrotechnical sensor was found to be the rear bottom quadrant of the front door. Significant differences in the distribution of ETS and type of injuries for the two groups were found.

A SENSOR FOR A SIDE IMPACT AIRBAG needs to trigger the deployment of the bag within a very short time interval after the onset of an impact. Therefore the optimisation of sensor location is critical since this also will directly affect deployment time. The location of one such sensor has been addressed in a previous study (Hassan et al, 1994). The best location for a pyrotechnical sensor which is activated by crushing of the door was found to be the lower left-hand quadrant of the front door. Positioned thus, it was established from analysing real world data, that 88% of AIS ≥ 3 injuries and 91% of AIS ≥ 4 injuries would be covered by airbag deployment. The results from that study together with the results from previous laboratory work (Haland, 1993) demonstrated that a significant degree of injury mitigation could be achieved. AIS ≥ 3 and AIS ≥ 4 injuries mostly occur due to occupant contact with the door when there is intrusion due to a direct impact on the door. This generally occurs within 20ms of initial contact (Haland and Pipkorn, 1993) in a 50 km/h side impact.

However, some injuries occur due to contact with the door in the absence of intrusion. These occur after a greater time lag (40 - 50 ms) than is the case when door intrusion occurs. The consequence of this is that a crush sensor will not detect an impact and so there is no airbag deployment. Hence a supplementary impact sensing system is appropriate to consider. One such sensor which can overcome this drawback is an acceleration based sensor. Such a sensor relies on sensing speed change rather than crush to effect deployment. Inherent in this design is the fact that sensor location is not so critical, unlike the crush-based sensor, since the time-lag between impact and airbag deployment can be somewhat longer in cases of no intrusion.

METHODOLOGY

We examined our in-depth crash investigation database containing information on 4231 vehicles in which there were 7092 occupants involved in traffic crashes. The data form part of an ongoing study (the Co-operative Crash Injury Study, CCIS) into vehicle crash performance and occupant injury undertaken between November 1983 and August 1991 (Mackay et al, 1985). The cars were examined at garages within a few days of the collision to explain the causes of occupant injuries. Injury data were obtained from hospital medical records and injury severities by body regions were rated according to the Abbreviated Injury Scale (AIS), (1985 revision). The specific contacts within the vehicles and the mechanisms of the injuries are thus documented.

CASE SELECTION CRITERIA

Vehicles suitable for inclusion in this study were selected according to the following criteria;
(i) The occupant saw an impact between the A and the C Pillars on the struck side.
(ii) The vehicle received a direct impact to the sides with a principle direction of force between 1 and 5 o'clock to the right side and 7 to 11 o'clock to the left side. Rollovers were excluded from the study.
(iii) Only occupants with an injury rated as AIS 2 or greater were included in the study.
(iv) Only vehicles receiving a maximum crush of over 50mm were included.

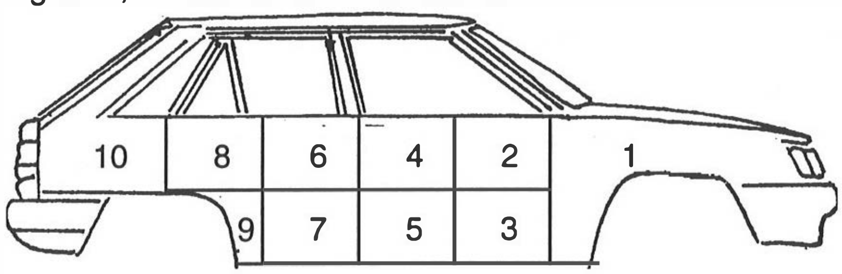
LOCATION OF DAMAGE - The damage location was recorded in terms of particular areas of the vehicle sides damaged rather than in absolute quantitative terms due to the procedure used for identifying areas of damage. The sectors of the side struck for recording the damage are shown in figure 1. The location of the damage is identified after consulting the case records and viewing the photographs of the cars. The damaged areas were identified as being in one or more of the pre-defined sectors of the vehicle side as shown in figure 1. The sides of the vehicle were divided as follows:

The front wing was considered as one sector. Similarly, the back part of the car from the rear vertical edge of the rear door frame to the rear of the car was considered as another section. In hatchbacks, this sector was considered as being from a vertical line passing through the apex of the rear wheel arch to the rear of the car. The front and rear doors were considered as being made up of four equal sectors. These sectors covered the areas of the doors between the bottom edge of the window and the bottom edge of the door. In hatchbacks, the rear panel was substituted for the absence of the rear door. This area extended from the vertical edge of the front door frame to a vertical line through the apex of the rear wheel arch. The damage to the B pillar was assigned as damage to areas 4, 5, 6 or 7 on an individual case basis.

Damage to the vehicle was recorded as being direct or induced. Direct damage was damage to the vehicle considered to be damage received during contact with the bullet vehicle or object struck. Induced damage was damage to the vehicle side occurring indirectly as a consequence of the direct damage. This information was then computerised to allow cross-file analysis of the data.

The above selection process resulted in a sample of 444 cars which were suitable for inclusion in the analysis. The analysis was mainly performed by comparing the group of cars with only AIS 2 injuries to those with AIS ≥ 3 injuries. Nearly 97% of the cars in the latter group containing an AIS ≥ 3 injuries also included AIS 2 injuries. It was decided to adopt such an approach for the analysis since preliminary analyses indicated that there were possibly substantial differences in factors such as ETS and type of injuries between the two groups.

Figure 1; Vehicle Sector Classification



RESULTS AND DISCUSSION

The frequency of 'direct', 'induced' and 'no damage' to each of the sectors is shown in figure 2a. It was observed that over 78% of the direct contact damage is located to the front door area (sectors 2, 3, 4 and 5). The frequency of 'hits' to each of the sectors is similar. However, if the object struck is taken into account (table 1), then sectors 3 and 5 will experience more hits than sectors 2 and 4 since the majority of the collisions are likely to be with other cars. Table 1 shows that over half of the cases were car-to-car or car-to-light goods vehicle collisions compared to collisions with large objects such as trucks, poles, trees etc. The justification for selecting sector 5 as an optimum location for a crush sensor has already been described in the previous study (Hassan et al, 1994). Similarly, it is also observed in this study that the direct and indirect hits to sector 5 result in 84% and 7% respectively, in total 91%, of the AIS 2 only and AIS ≥ 3 severity of injuries (Figure 2a).

The deployment of an airbag using an electronic sensor is not dependent on the amount of crush. Therefore further analysis was performed to determine the incidence of hits to various sectors when direct impacts to sector 5 (and 4) are excluded from the analysis (Figure 2b). If collisions with direct impacts to sector 5 are excluded then a subsample of 71 cars was available. It was observed that 72% of the direct and induced damage occurred to sector 1, while 57-59 % of the direct and induced damage occurred to sector 2 to sector 3 areas of the car when these sectors received a direct hit.

Figure 2a Frequency of damage Types to each Sector

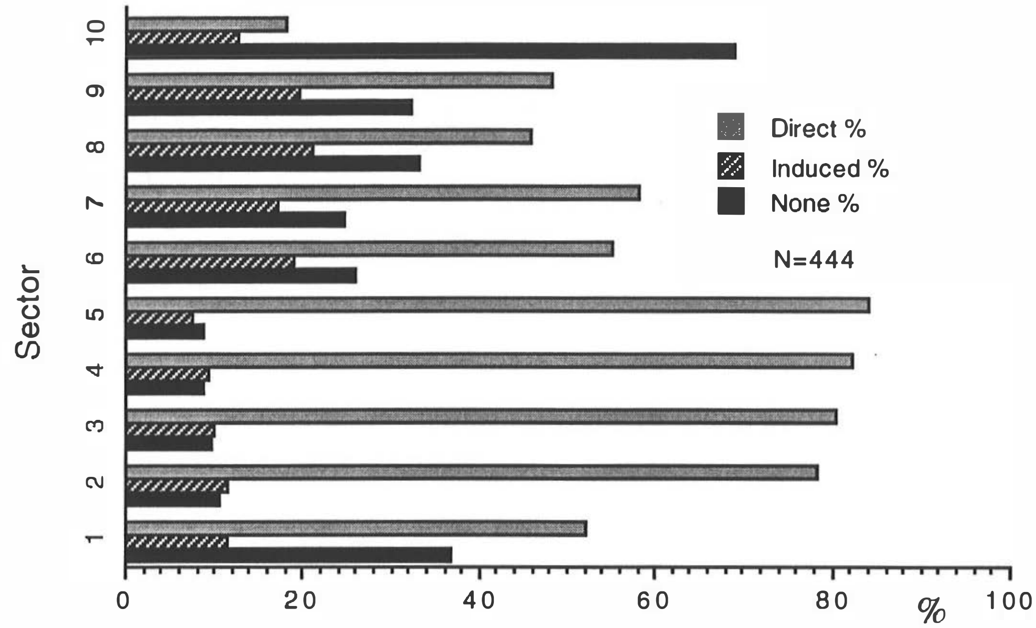
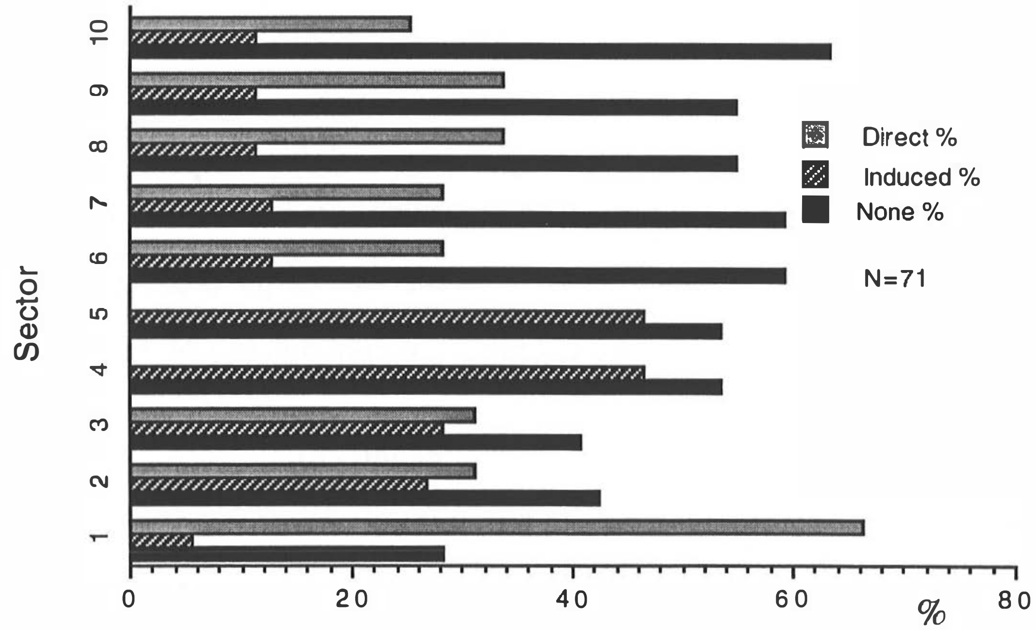


Figure 2b Frequency of Damage Types to Each Sector When No Direct Impact to Sector 5



A supplementary electronic sensor is meant to trigger the side airbag for impacts with no intrusion at the occupant, when there is mainly a risk of AIS 2 injury. This sensor reacts for the acceleration of the car body and can be located at an undeformed part of the car, since the time available for triggering the bag is relatively long. The bag must be fully inflated after 30 - 40 ms in a 50 km/h side impact with no intrusion at the struck side occupant compared with typically 12 ms when there is intrusion at the occupant level (Haland and Pipkorn, 1993). The data in figure 2b indicates that a supplementary electronic sensor should be located in the front half of the car, preferably inside sector 3 (with highest incidence of direct damage) and centrally. One sensor (an accelerometer) could then cover impacts to both sides of the vehicle.

Table 1. Object Struck by 444 Vehicles

Type of Object Struck	Frequency	%
Car	230	51.8
Light Goods Vehicle	29	6.5
Truck	44	9.9
Public Service Vehicle	15	3.4
Other Vehicle	3	0.7
Motor Cycle	2	0.5
Lamp-post/pole	55	12.4
Wall	13	2.9
Crash Barrier	3	0.7
Tree	35	7.9
Fence	1	0.2
Other road furniture	9	2.0
Other	5	1.1
Total	444	100

The sensor that reacts to the crush of sector 5 must be installed in such a way that it will trigger a side airbag within 5 ms in a 50 km/h side impact (Haland and Lindqvist, 1994). In the absence of door intrusion at the struck side occupant, the supplementary sensor system must typically trigger within 25 ms. It basically senses the acceleration experienced by the target car and triggers for a certain integrated change in speed.

In this study, the ETS, determined using the CRASH3 programme, was considered to be equivalent to the closing speed (Noga and Oppenheim, 1981). It is appreciated that this method of determining closing speeds in side impacts is not wholly satisfactory but in the absence of any other suitable alternative for side impacts, it provides the best indication of severity for the struck car.

The distribution of ETS for impacts to sector 5 are analysed for belted and unbelted front seat occupants with AIS 2 only and AIS $\geq$ 3 injuries. The impacts to sector 5 include both direct and induced damage.

Figure 3: ETS distribution for AIS 2 only and AIS ≥ 3 injuries to belted occupants -Impacts to sector 5

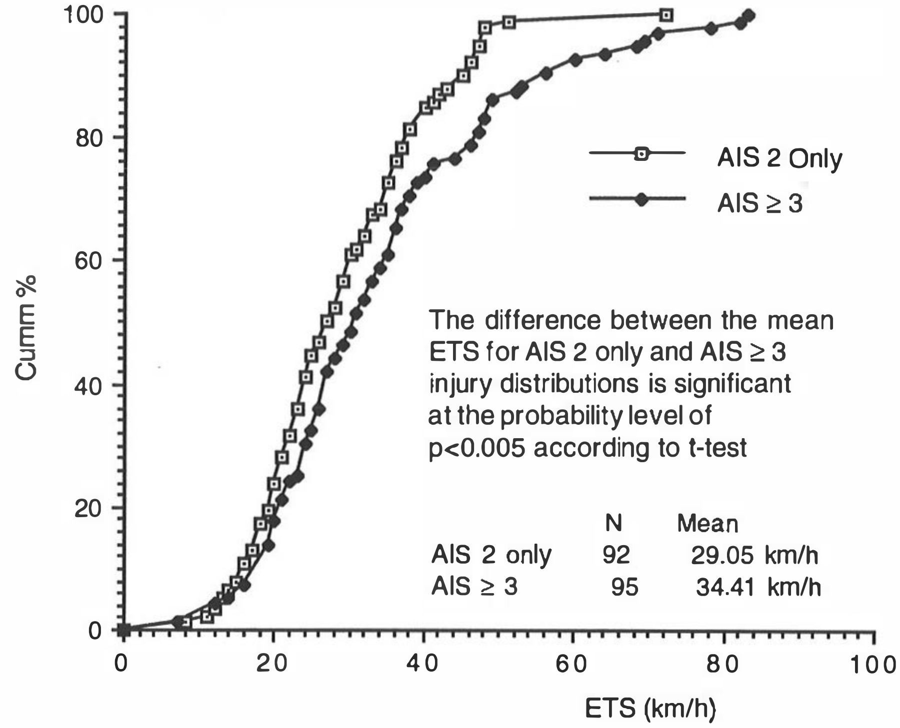
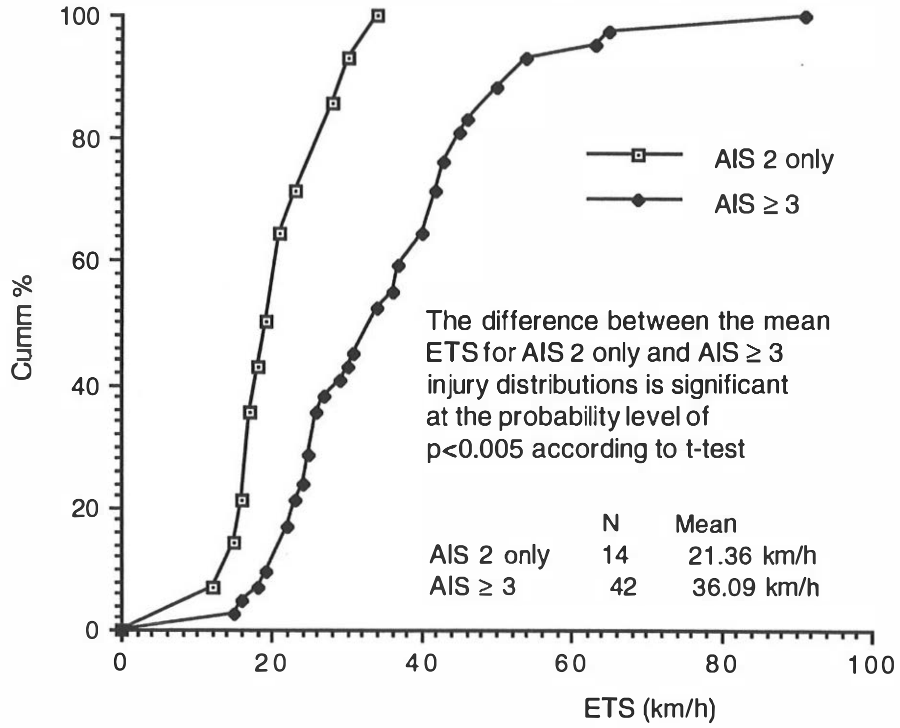


Figure 4: ETS distribution for AIS 2 only and AIS ≥ 3 injuries to unbelted occupants - Impacts to sector 5



The cumulative frequency plots for ETS experienced by belted front seat occupants are shown in figure 3. It is observed that a significant difference exists in the mean ETS between AIS 2 only injuries and AIS $\geq$ 3 injuries. The AIS 2 only injuries occur at a lower mean ETS (29.05 km/h) compared to that for AIS $\geq$3 injuries mean ETS (34.41 km/h). The higher mean closing speeds in the case of AIS $\geq$ 3 injuries is to be expected, particularly as the AIS $\geq$ 3 injury cases have also door crush as a contributory factor.

During an impact without appreciable door crush, the occupant will experience a velocity change close to that of the car in which he is sitting. However, in the case of substantial door crush the occupant will experience a higher door contact speed since the contact with the door will occur relatively earlier, when the door is travelling at a speed closer to the over-the-road speed of the striking car. This may well be the main explanation for the difference between the two groups.

The distributions of ETS for unbelted front seat occupants are shown in figure 4. Interpretation of this data must be done cautiously because of small numbers of cases. A significant difference exists between the mean ETS for AIS 2 only (21.36 km/h) and AIS $\geq$ 3 (36.09 km/h) injuries. This again indicates that AIS 2 only injuries occur at lower impact speeds.

It is also suggested that seat belts influence the AIS 2 only ETS distributions but not the AIS $\geq$ 3 ETS distributions. Indeed comparison of the ETS distributions for belted and unbelted occupants indicate a significant ($p < 0.001$) difference between the mean ETS for belted (29.05 km/h) and unbelted (21.37 km/h) occupants receiving injuries of AIS 2 only severity.

The purpose of airbag deployment in side impacts is primarily to mitigate injuries to the thoracic region. The incidence of AIS 2 only and AIS $\geq$ 3 injury severities to this region experienced in side impacts by belted occupants in cars without side airbags are shown in table 2 for a direct contact impact to sector 5.

The values in tables 2, 3, 4 and 5 represent the proportion of occupants receiving injury to the particular body region for a particular injury severity group. The AIS $\geq$ 3 group are considered as two groups, namely AIS = 2 and AIS $\geq$ 3.

For belted occupants, the head is the most frequent body region (47%) for experiencing AIS 2 only injuries. The nature of these injuries tend to be incidences of simple concussion and brief episodes of unconsciousness sustained by occupants contacting the vehicle interior structures such as door glass, pillars, roof and the door itself (Morris et al, 1993). The other major body regions include the chest (21%), pelvis (28%) and upper limbs (28%). The AIS 2 only severity of injuries were found to be fractures to the rib-cage in all cases (table 5).

Table 2

All Front Seat Restrained Occupants - Body Regions Afflicted in Direct Contact Impacts to Sector 5 Only.

Body Region	AIS 2 Only		AIS ≥ 3			
			AIS = 2		AIS ≥ 3	
	N	%	N	%	N	%
Head	55	47.0	39	32.2	70	42.2
Cervical Spine	1	0.8	9	7.4	8	4.8
Face	5	4.3	26	21.5	10	6.1
Neck	0	0.0	1	0.8	0	0.0
Chest	24	20.5	42	34.7	97	58.8
Thoracic Spine	1	0.8	4	3.3	4	2.4
Abdomen	4	3.4	37	32.2	45	27.3
Lumbar Spine	2	1.7	5	4.1	0	0.0
Pelvis	33	28.2	36	29.7	30	18.2
Upper Limbs	33	28.2	49	40.5	19	11.5
Lower Limbs	8	6.8	28	23.1	52	31.5
Total Occupants	117		121		165	

The AIS = 2 and AIS ≥ 3 injury groups follow slightly different distributions. The upper limbs (41%) are the most frequently injured regions for the AIS = 2 group followed by the chest (35%), head (32%), abdomen (32%) and pelvis (30%) regions. Well over half (59%) of the occupants in the AIS ≥ 3 group received injuries to the chest followed by injuries to the head (42%) and the abdomen (27%). The injuries to the head occur mostly due to contacts with external objects (24%) such as other vehicles, fixed objects and the ground as found in an earlier study which considered injuries of AIS ≥ 2 experienced in lateral impacts (Morris et al, 1993). Injuries to the chest are mainly due to contact with the door (table 4).

The distributions of injury producing contacts for lateral impacts are shown in table 3. It can be seen that the door and door structure are by far the most frequent source of injury. This contact source was found to be responsible for injuries to 54% of the occupants in the AIS 2 only category of injuries. Similarly, 62% of the occupants in the AIS = 2 category and 75% of the occupants in the AIS ≥ 3 category received injuries due to contact with the door. External contacts account for a substantial proportion of injury contacts in the AIS ≥ 3 category (24% for AIS = 2 and 27% for AIS ≥ 3). External objects include other vehicles, narrow, wide and other external objects (such as poles, trees etc.), penetrating object and the ground.

Table 3

Contact Sources by AIS for Restrained Front Seat Occupants for Direct Hits to Sector 5

Contact	AIS 2 Only		AIS ≥ 3			
			AIS = 2		AIS ≥ 3	
	N	%	N	%	N	%
Windscreen	0	0.0	1	0.8	1	0.6
Facia	1	0.8	2	1.6	4	2.4
Transmission Console	1	0.8	0	0.0	1	0.6
Footwell	3	2.6	13	10.7	5	3.0
Steering Wheel	2	1.7	1	0.8	5	3.0
A Pillar	3	2.6	7	5.8	7	4.2
B Pillar	10	8.5	8	6.6	8	4.8
Side Header	0	0.0	2	1.6	1	0.6
Door	63	53.8	75	62.0	124	75.1
Door Glass	18	15.4	5	4.1	1	0.6
Rear Panel	0	0.0	1	0.8	1	0.6
Roof	3	2.6	4	3.3	3	1.8
Seat Belt Swivel	1	0.8	1	0.8	0	0.0
Seat Belt Webbing	3	2.6	8	6.6	5	3.0
Deceleration	2	1.7	2	1.6	1	0.6
Self	1	0.8	0	0.0	0	0.0
Other Occupant	5	4.3	3	2.5	3	1.8
Flying Glass	0	0.0	3	2.5	0	0.0
Other Vehicle	1	0.8	20	16.5	27	16.4
Narrow Object	2	1.7	4	3.3	11	6.7
Wide Object	0	0.0	0	0.0	1	0.6
Other External Object	1	0.8	1	0.8	0	0.0
Penetrating Object	1	0.8	2	1.6	3	1.8
Ground	0	0.0	2	1.6	2	1.2
Crush	0	0.0	1	0.8	1	0.6
Seat	1	0.8	1	0.8	2	1.2
Not Known	22	18.8	31	25.6	23	13.9
Total Occupants	117		121		165	

The incidence of injuries to the chest increases with an increase in the severity of injuries. The role of the door as an injury source increases with increase in injury severity. Thus, an airbag should be designed primarily to mitigate serious thoracic injuries.

Table 4

Chest Injury Contact Sources by AIS for Restrained Front Seat Occupants for Direct Hits to Sector 5.

Contact	AIS 2 Only		AIS ≥ 3			
			AIS = 2		AIS ≥ 3	
	N	%	N	%	N	%
Facia	-	-	1	2.3	1	1.0
Transmiss. Console	1	4.4	-	-	-	-
Steering Wheel	-	-	-	-	2	1.9
A Pillar	-	-	2	4.5	2	1.9
B Pillar	-	-	-	-	2	1.9
Door	17	73.9	26	59.1	73	70.1
Seat Belt Webbing	3	13.0	3	6.8	5	4.8
Other Occupant	-	-	-	-	2	1.9
Other Vehicle	-	-	6	13.6	5	4.8
Narrow Object	-	-	-	-	1	1.0
Penetrating Object	-	-	1	2.3	1	1.0
Ground	-	-	-	-	1	1.0
Seat	-	-	-	-	1	1.0
Not Known	2	8.7	5	11.4	8	7.7
Total Occupants	23		44		104	

Since the primary role of the airbag is to mitigate injuries to the chest, it is appropriate to identify the injury-producing contacts. Table 4 shows the distribution of contacts responsible for causing injury to the chest. It is seen that the door is the main source of injury for the chest in side impacts. Some 74% of AIS 2 only injuries result from contact with the door. Similarly, in the more severe injury category, 59% of the AIS = 2 injuries and 70% of the AIS ≥ 3 injuries are due to contact with the door. This further consolidates the view that the placement of an inflated airbag in the area between the chest and the door will prevent the occupant from contacting the door during a side impact collision.

Further analysis of the type of chest injuries is shown in table 5.

Table 5

Types of Chest Injuries Sustained

Injury Type	AIS 2 Only		AIS ≥ 3			
			AIS = 2		AIS ≥ 3	
	N	%	N	%	N	%
Skeletal (Rib Cage)	22	100.0	24	68.6	10	11.1
Organ Only	0	0.0	9	25.7	41	45.6
Skeletal and Organ	0	0.0	2	5.7	39	43.3
Total Occupants -	22		35		90	

The AIS 2 only injuries to the chest were all injuries to the rib cage. These injuries were all fractures of the ribs or sternum.

The AIS ≥ 3 injuries also included injuries to the organs and a combination of injuries to rib cage and an organ. The AIS = 2 injuries in this group are mostly (67%) of the skeletal type to the rib cage followed by injuries to the organs (27%) of the thoracic cavity (i.e. heart, lung, blood vessel, etc.). The incidence of injuries to the organs and the combination of injuries to the rib cage and organs increase with an increase in injury severity as shown by their incidence of AIS ≥ 3 injuries. The incidence of injuries to the organs only (47%) and to the combination of rib cage and organ (43%) is nearly the same in the AIS ≥ 3 injury group. These injuries are of importance since chest injuries are one of the most common causes of death in side impacts (Fields and Vulcan, 1990).

CONCLUSION

The findings from this study indicate that incorporating a supplementary electronic sensor will further help in mitigating injuries of AIS 2 only severity by initiating airbag deployment during collisions where there is no appreciable crush of the door area. Such a sensor addresses a significant number of cases in which a crush related sensor would not be activated and therefore such a sensor extends the utility of the side impact airbag concept. This study has not addressed the second order effects of early lateral acceleration of the occupant by the airbag in terms of diminishing the frequency and severity of head impacts in particular. The data does suggest however that side airbags are likely to diminish the frequency of serious thoracic injury given that the mean ETS for AIS ≥ 3 injuries is 34.4 km/h, a condition close to the proposed European side impact test (Commission of the European Communities, 1994).

The results relating to belt use for struck side occupants are of interest. Even for such occupants belts have a significant benefit, probably by diminishing the lateral excursion of the head in oblique side impacts under the crash conditions of AIS 2 only cases. The AIS ≥ 3 sample demonstrates no benefits of seat belts for the struck side occupants.

It is also worth reiterating that the car/mobile barrier type of crash specified in the proposed European side impact directive only represents some 68% of our side impact sample. Narrower objects such as trees and poles represent at least 25% of the striking objects. For such collisions, a side impact airbag is likely to be more effective than static structure and padding.

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