Head Injuries in Lateral Impact Collisions

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Abstract

Individual AIS 2+ injuries to the head that occurred to restrained and unrestrained drivers and front seat passengers on the struck side of impacted vehicles were examined. Injury type, injury combination, collision severity in relation to type of injury as well as contact sources were assessed.
47.6% of injuries were AIS 2 level. The most common type of injury was the diffuse brain injury, typically marked by a short period of unconsciousness, which occurred in collisions of lower severity than focal brain and skull fracture injuries.
105 out of 216 (48.6%) of contact sources for all injury types originated from outside the vehicle and such exterior sources were more likely to result in higher level AIS injuries. The most frequent vehicle interior contact source was the side window glass. 30.1% of injuries resulted from head contacts with other vehicles. Diffuse injuries tended to occur independently of other injury types and were more likely to originate from an interior rather than exterior contact. Preventative measures for head injury reduction in lateral collisions are discussed.

Introduction

Head injuries in car accidents have been and continue to be a major problem. Bradford et al (1986) observed that there is an agreement among car crash and injury researchers that such injuries are both the most damaging frequent injury and the most difficult to mitigate by vehicle design.
The problem of head injuries in side impacts alone has been addressed by several researchers. Such a problem exists fundamentally because the occupant on the struck side is travelling with the head positioned closely to side structures such as the 'A' and 'B' pillars, side window glass and side door. Mackay (1987) noted that in the case of car-to-car impacts, the direct loading of the occupants occurs from shoulder level downwards but the head may well flex laterally through the side window aperture to strike the bullet car. With a truck the head is more exposed to severe direct loads and in the case of poles and trees, when there is intrusion, the head is the body region most frequently injured.
Lister & Neilson (1969) noted that in an unbelted population of car users, side impacts accounted for 13% of all accidents involving cars which resulted in serious or fatal injuries. They also noted that head injuries were particularly few in car-to-car impacts but were more apparent in car-to-fixed object collisions.

Only half of the occupants escaped moderate, severe or fatal head injuries. Serious injury was equally likely to occur to those on either the near or the far side from the point of impact, though other injuries were more likely for occupants on the side of the impact.
Fan (1987) found that in vehicle crashes, approximately 27-30% of occupant casualties were attributable to side impact accidents. He noted that problem areas in side impacts were (1) thorax-to-side interior impacts, (2) head impacts with A-pillar/roof rail components and (3) occupant ejection through side windows.
Tarriere (1987) noted that the risk of brain and/or neck injury was slightly higher in side impacts than in frontal impacts. He studied belted front seat occupants and found that the risk of sustaining AIS $\leq$ 5 was 27.5% in frontal impacts and 31.3% in side impacts.
Gloyns and Rattenbury (1989) studied 85 vehicles containing 91 occupants and found that side impact fatalities , both struck side and non-struck side, accounted for 29.2% of all car occupant fatalities. They also found that nearly two thirds of struck side fatalities had some degree of head injury and of these, 50% had life threatening head injuries.
Fildes and Vulcan (1990) reviewing case studies of drivers involved in side impacts found that the most frequent body regions injured were the abdomen (90%), the chest (70%), the head (63%) and the upper extremity (63%). For severe injuries (>AIS 2), the most frequent body regions injured were the chest (47%), the abdomen (30%) and the head (17%). They also noted that drivers had a slightly higher risk of head injury than front seat passengers.
Contact sources in side impacts have been examined; Mackay (1983) examining sources of injury to fatally injured occupants (>AIS 3) found that the most frequent contact source was an exterior object such as another vehicle or pole or tree (42%), the side header (19%) and via ejection (6%). He also noted that sources of injury to seriously injured struck side occupants were the side header (20%), side glass (16%), A-pillar (12%) and via ejection (10%).
Huelke and Compton (1992) examined 62 unrestrained drivers with AIS 3-6 head injuries and found the most common contacts to be A-pillar, side roof rail or objects exterior to the vehicle.

Lateral Impact Regulations

Generally lateral impacts are second only to frontal impacts as a cause of fatalities. Frontal impacts account for about 60% and side impacts for about 30% of fatalities. Yet despite this, research into providing better crash protection in lateral impacts is a relatively recent development.
Strother et al (1984) noted that as the work of reducing injuries in frontal impacts progressed in the 1970's, more serious interest in side impacts developed. They noted that it had become clear that the side impact problem would not lend itself to the same solutions applied to frontal collisions.
By the late 1980's, proposals were being developed in Europe and the USA for test procedures for side impacts. European proposals differed slightly to those in America basically due to differences in the characteristics of vehicles between the two continents.

Current European proposals involve impacting the side of the vehicle with a Mobile Deformable Barrier (MDB) using an approach angle of 90 degrees and an approach speed of 50 +/- 2 kph. The European Side Impact Dummy (Eurosid) is installed wearing a seat belt in the driver's seat during the test. Instrumentation contained on the dummy is used to measure forces applied to the pelvis, abdomen, thorax and head.

This study examines the cause, incidence, nature and severity of head injuries in side impacts in real world accidents. Specifically, we aimed to address whether current European test proposals comprehensively represent the reality of actual side impact collisions.

Methodology

Interrogation was made of a database containing information on 4231 vehicles in which there were 7092 occupants. Overall, the database contains details of 22,722 individual injuries some 5813 (25.58%) of which are to the head and/or face.

The data used form part of a study into vehicle crash performance and occupant injury undertaken between November 1983 and August 1990. Each vehicle in the study was examined within a few days of the collision and only cars less than six years old at the time of the accident were considered. A more comprehensive overview of methodology involved in the Co-operative Crash Injury Study (CCIS) can be found in Mackay et al. (1985).

We selected injuries judged to be AIS 2 to 6 inclusive which occurred to restrained and unrestrained drivers and front seat passengers who were seated on the struck side during the collision.

In all, we analysed injury information on 145 occupants who sustained between them some 269 AIS 2+ injuries to the head and face.

Where possible, we classified each injury according to Gennarelli (1981). He observed that it is convenient in general terms to view head injuries in terms of focal brain injuries, diffuse brain injuries and skull fractures.

Focal brain injuries are defined as those in which a lesion large enough to be viewed with the naked eye has occurred. This type of injury generally results from primary localised tissue damage. The category includes injury types such as contusion, epidural haematoma, subdural haematoma and intracerebral haematoma.

Diffuse brain injuries are associated with a more global disruption of neurological function not normally associated with lesions visible to the naked eye. Such injuries cause widespread disruption of either brain structure or function. In this paper, the category includes injury types such as mild concussion (associated with symptoms such as lethargy, stuporousness or amnesia) and classical concussion (associated with temporary loss of consciousness). They also include injuries associated with considerable anatomical disruption of the brain structure of a diffuse nature together with prolonged loss of consciousness and often persistent neurological disability.

Three groupings of unconsciousness, namely minor, moderate and severe are used in this paper for occupants who were unconscious but showed no anatomical evidence of injury, according to the respective AIS injury ratings of 2,3 or 4+. Minor unconsciousness was typically for less than 1 hour in a patient who was awake on admission to hospital. Moderate cases typically were unconscious for between 1-6 hours or for less than 1 hour but who exhibited a subsequent associated neurological deficit. Severe cases involved occupants who were unconscious for 1-6 hours with a subsequent associated neurological deficit and those occupants who were unconscious for longer periods of time. Major injuries to the surface were not classified into any of these categories but were included in part of the analysis.

Where appropriate, we used vehicle Delta-V (computed by the CRASH3 programme) as a measure of collision severity. Whilst it is acknowledged that CRASH3 estimates of Delta-V in lateral impacts can never be taken as a true representation of actual Delta-V of the side-damaged vehicle, an acceptable degree of estimation can be attained. Smith and Noga (1982) compared true and predicted Delta-V values of 30 staged side collisions and found that the CRASH3 programme tends to produce an underestimate.

Results

Injury Types

We examined AIS levels, and individual injury types. AIS values are listed in Table 1.

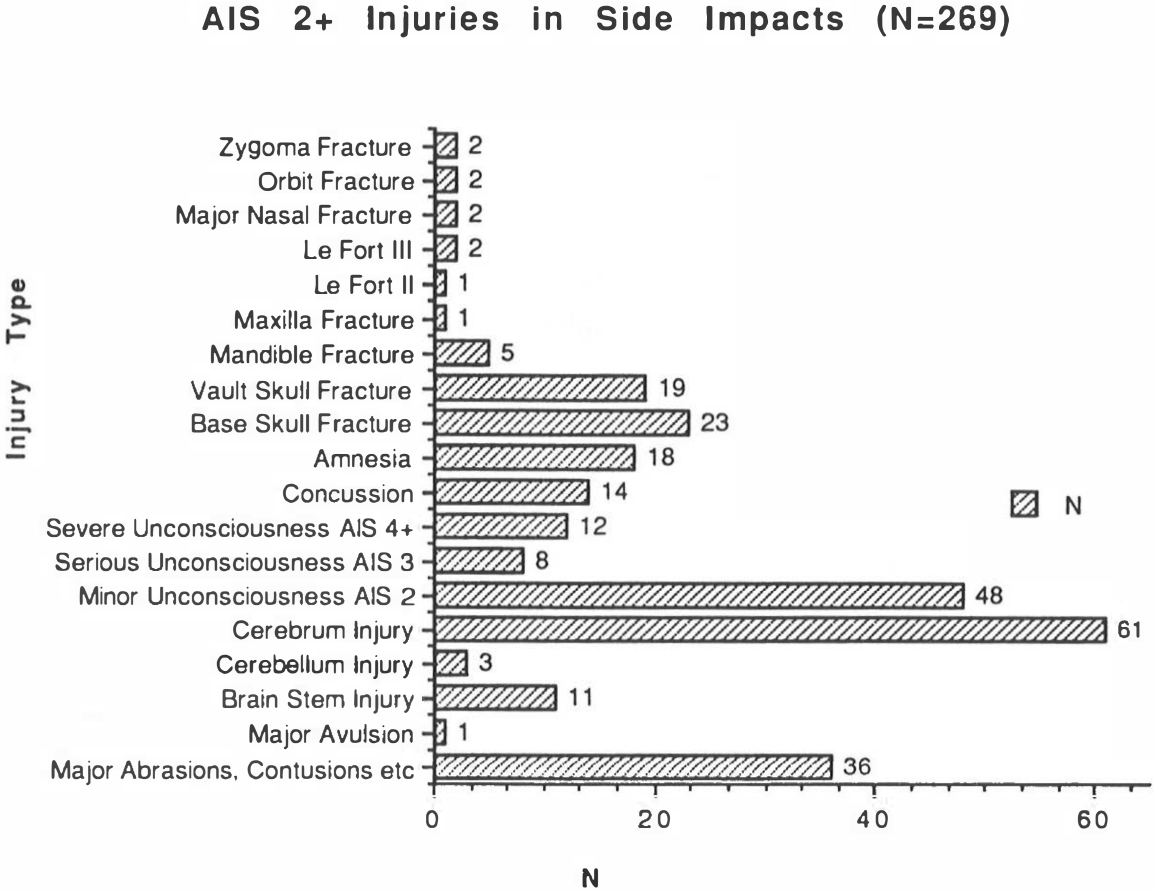
Table 1 AIS Injuries in Side Impacts(sustained by 145 Occupants)

AIS	N	%
2	128	47.6
3	81	30.1
4	43	16.0
5	11	4.1
6	6	2.2
Total	**269**	**100**

AIS 2 injuries comprised nearly half (48%) of the sample while approximately 23% of injuries were AIS 4-6 (severe to maximum). 38 injuries occurred to the head surface (14.1%), 55 to the head bony structures (20.4%) and 176 to the brain (65.4%). Types of injuries are shown in table 2.

The most frequent injury type was injury to the cerebrum (i.e. haemorrhage, haematoma, laceration and contusion) while unconsciousness of some description comprised 25.3% of the 269 injuries. 48 cases of unconsciousness were rated AIS 2, while 20 were rated AIS > 2 of which 4 involved subsequent associated neurological deficit.

Table 2



Injury Combinations

Of the 145 occupants in the study, 4 sustained injuries to the head surface only, these being lacerations and abrasions etc. 141 occupants sustained unconsciousness or an injury to the brain or to the skull only or a combination of these injuries to the head/face.
Table 3 shows the results of this analysis.
A diffuse injury was significantly more likely to occur than any other injury type. The most significantly frequent incidence of injury combination was focal injury and skull fracture compared to other combinations of 2 or more injuries. We also examined whether the focal injury and skull fracture combination occurred more frequently than either injury type occurring alone and found that there was a significant likelihood of the two injury types occurring together rather than either type occurring independently.

Table 3 Head and Face Injury Combinations in Side Impacts

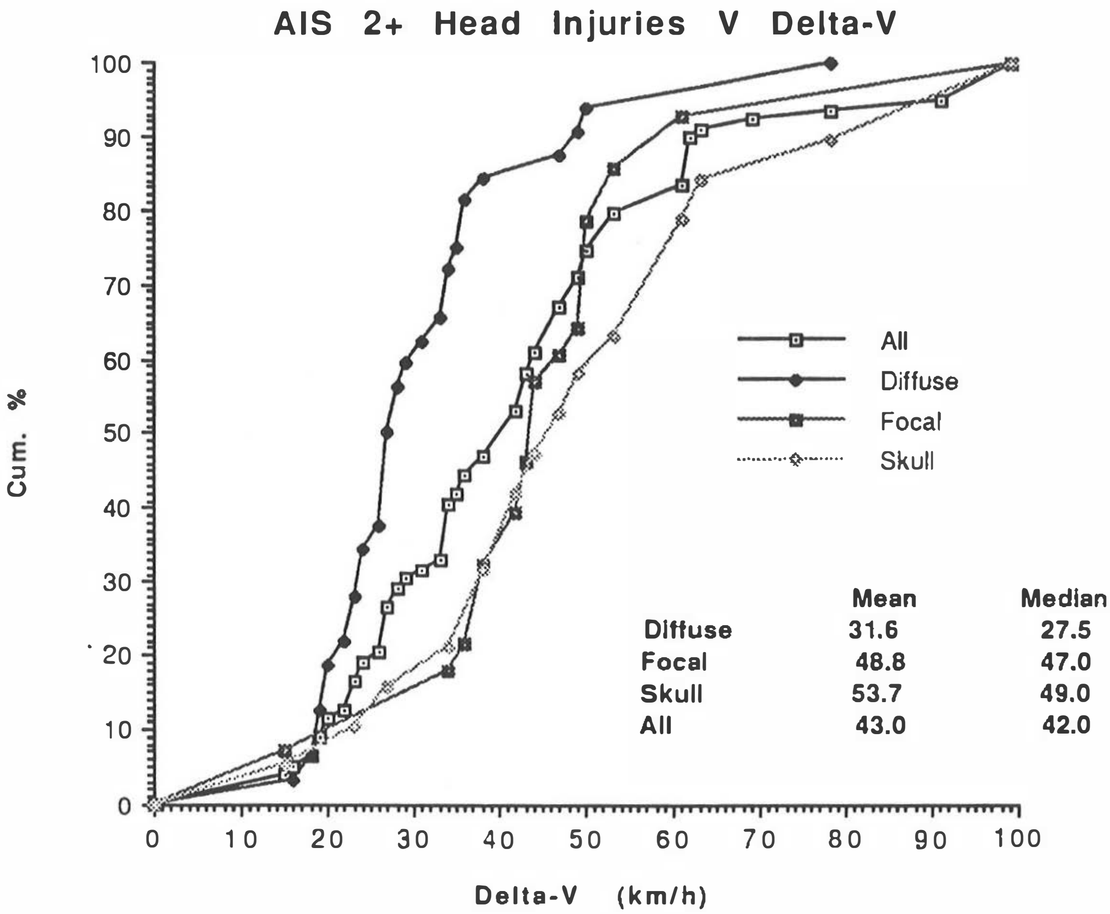
Injury Type	Number of Occupants		
	All Injuries	2 or more	Focal &/or Skull
Focal only	11		11
Skull only	9		9
Diffuse only	87		
Focal & Skull	21	21	21
Focal & Diffuse	3	3	
Diffuse & Skull	5	5	
All three	5	5	
Total	141	34	41
χ^2	269.62	24.81	6.04
d.f.	6	3	2
p	0.00001	0.001	0.02

The first column relates to injuries received by all occupants.
The second column states the number of occupants receiving two or more injuries.
The third column states the number of occupants receiving only skull and/or focal injuries.
The values in columns 2 and 3 are also presented in column 1.

(3a) Collision Severity (Delta-V) and Head Structure

We examined the distribution of Delta-V for injuries to the different types of head injury, i.e. diffuse brain injuries, focal brain injuries, and skull fractures. Tables 4a and 4b show cumulative frequency curves for AIS 2+ and AIS 3+ injuries to these body regions at different collision severities.
Mean and median Delta-V values are also included in the tables.

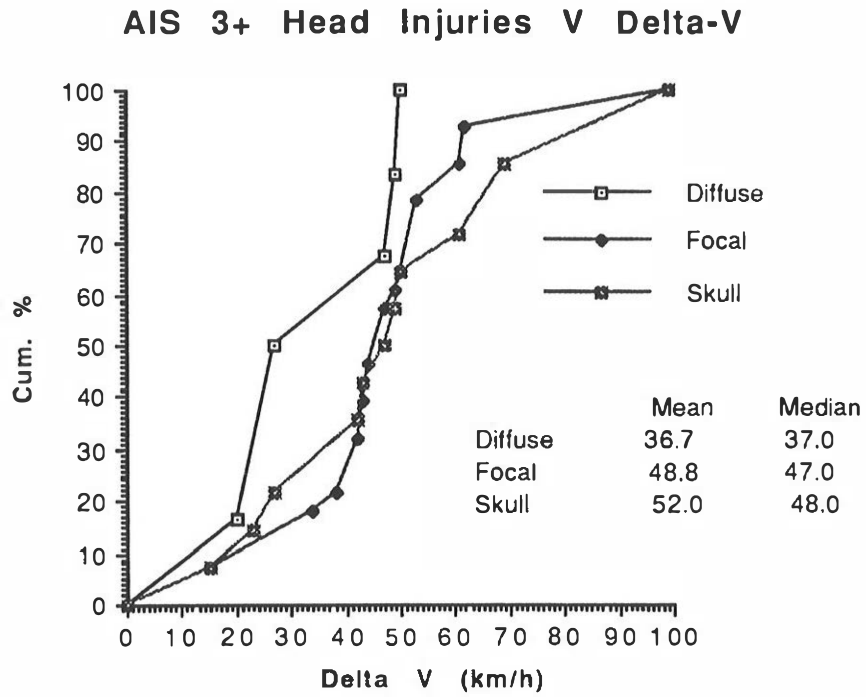
Table 4a



As can be seen from table 4a, diffuse type injuries occur at lower collision severities than either focal injuries or skull fractures.
Diffuse injuries occur at a significantly lower median Delta-V than focal injuries (χ2 = 21.56 d.f. = 1, p=0.0001). Diffuse injuries also occur at a significantly lower median Delta-V than skull fractures (χ2 = 12.3597 d.f. = 1, p=0.0004).
Approximately 85% of diffuse injuries occurred in vehicles whose collision Delta-V was calculated to be <40km/h (25mph). Conversely, over 50% of both focal and/or skull fractures occurred in vehicles for which the collision Delta-V exceeded that value. While the absolute value of Delta-V may be approximate when calculated using side impact damage details, these results indicate an important transition in the nature of head injuries at crash severity levels corresponding to CRASH3 Delta-V values of around 40km/h.
No significant differences in the median delta-V were observed between focal injuries and skull fractures (χ2 = 0.1305 d.f. = 1, p= ns) thus focal injuries and skull fractures were equally likely to occur.

Further analysis suggests that the significant difference in the median delta-V between diffuse injuries and either focal injuries or skull fractures are due to the contribution of concussive type injuries (AIS 2) which are diffuse injuries. This is observed in table 4b which shows the cumulative frequency distribution of delta-V for head injuries of AIS 3+ severity. The differences in median delta-V's for diffuse, focal and skull fractures are not statistically significant as indicated by the median test ($\chi 2 = 0.4958$, d.f. = 2, p=ns) for AIS 3+ injuries which substantially exclude concussive type injuries (AIS 2).

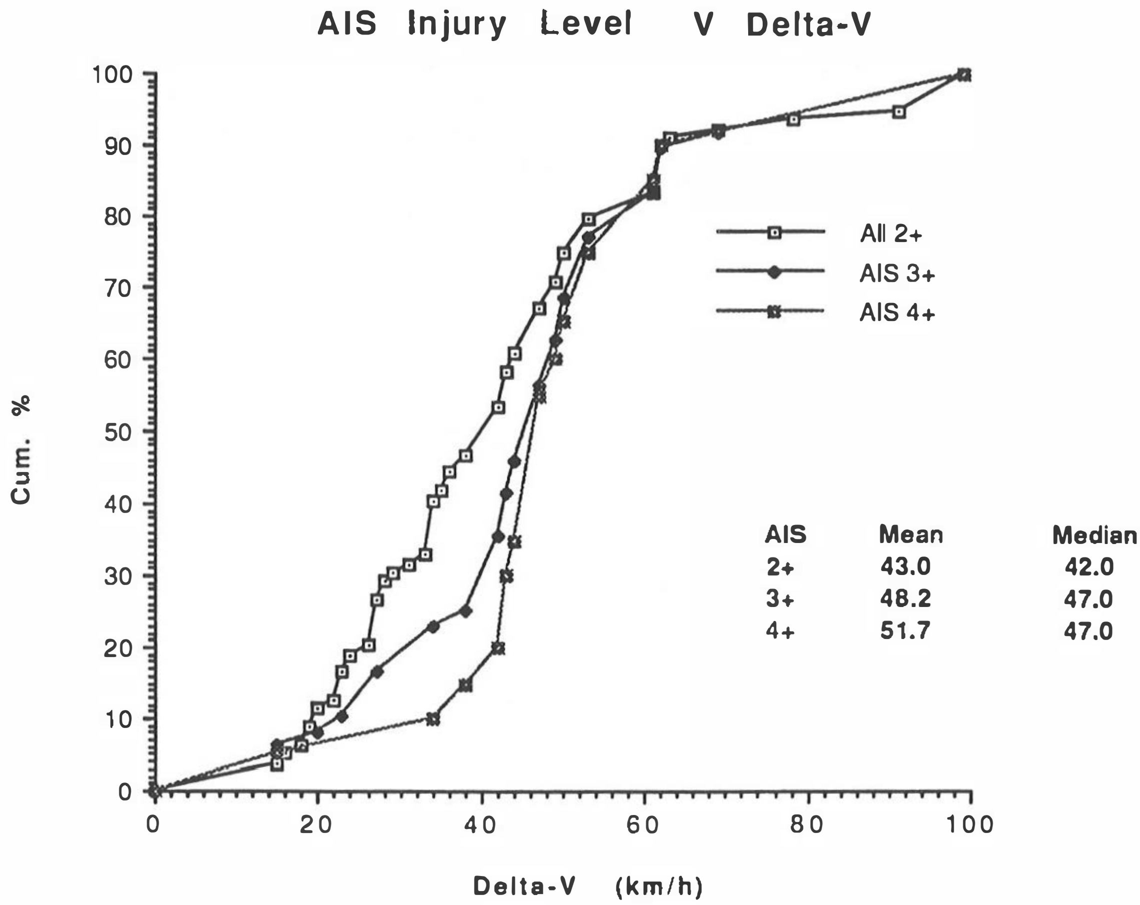
Table 4b



(3b) Collision Severity (Delta-V) and AIS

Delta-V was again used as a measure of collision severity to examine differences in speed change between AIS 2+, 3+ and 4+ injuries. There were 95 AIS 2+ injuries, 48 AIS 3+ injuries and 20 AIS 4+ injuries in collisions where the Delta-V calculations had been possible. The results are shown in table 5. Median and mean delta-V values for each AIS level are shown on the graph. Median AIS values were found to differ significantly ($\chi 2 = 25.25$ d.f. = 2, p=0.0001) i.e. higher AIS injuries are more likely in collisions with greater collision severity.

Table 5



Contact Sources

Contact sources were established for 216 injuries; 98 AIS 2 injuries, 70 AIS 3 injuries and 48 AIS 4+ injuries. These are shown in Table 6.

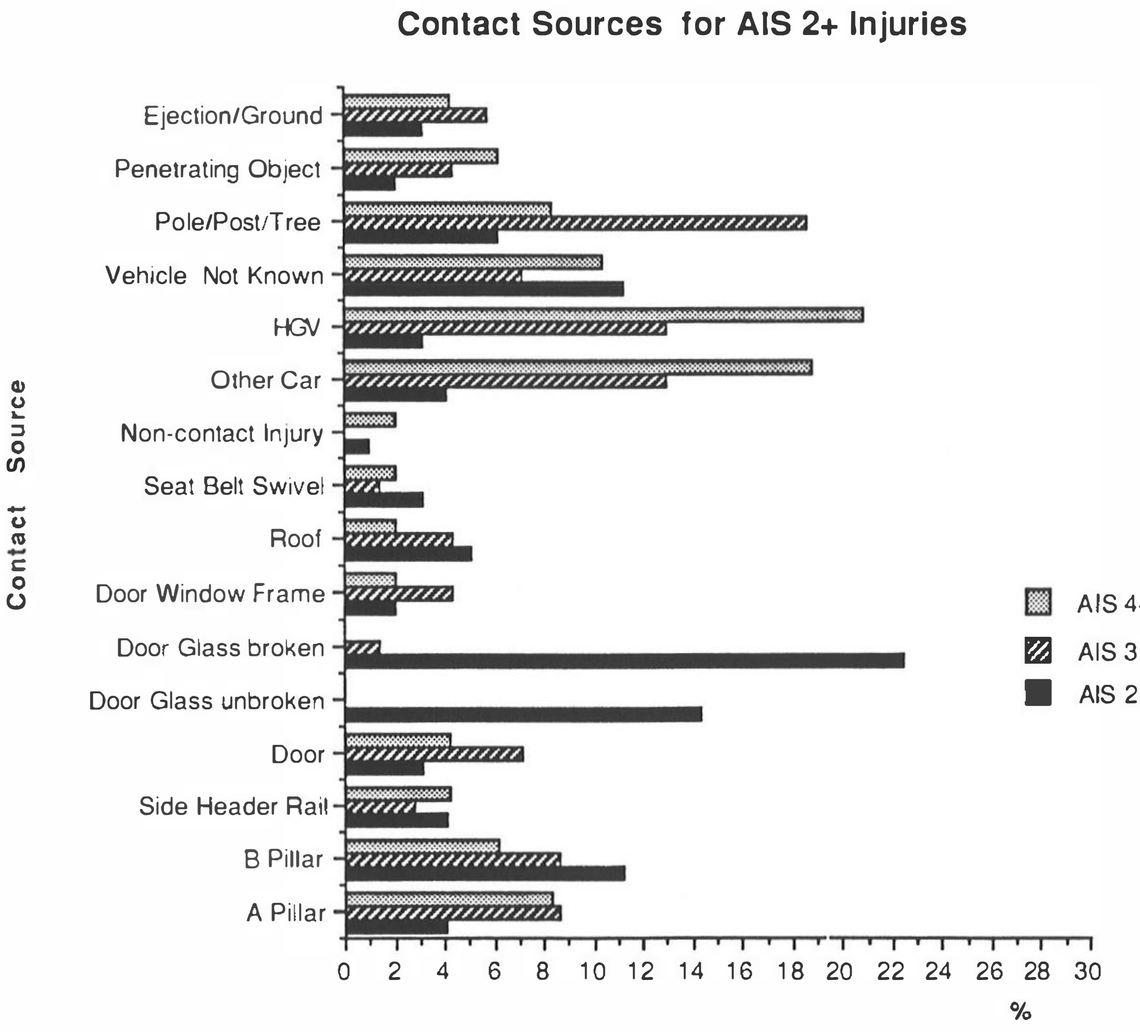
(70.4%) of AIS 2 injuries originated from a vehicle interior source while 29 (29.6%) occurred as a result of the occupant contacting an exterior source. The most frequent contact source (36.7% of 98 injuries) was the door glass. 18.3% of injuries originated from contacts with other vehicles. The most commonly occurring interior contact sources were pillars (15/98) and door glass (36/98).

27 (38.6%) of AIS 3 injuries originated from a vehicle interior source while 43 (61.4%) of injuries were as a result of contact with an exterior vehicle source. The most frequent sources of contact for AIS 3 injuries were other vehicles with 23/70 (32.9%). The most commonly occurring interior contact sources were pillars (12/70) and door /window frame (8/70).

15 (31.3%) of AIS 4+ injuries originated from an interior vehicle source while 33 (68.7%) originated from contacts exterior to the vehicle. The most frequent source of contact in this category again proved to be contacts with other vehicles which accounted for half (24/48) of the injuries in the category. The most commonly occurring interior contact source were the pillars (7/48).

Overall 111 out of 216 (51.4%) of contact sources originated within the vehicle while 105/216 (48.6%) of contact sources originated from outside the vehicle. The most frequent source of contacts for AIS 2+ injuries proved to be other vehicles with this contact accounting for 30.1% of injuries (65/216). The second most frequent contact source proved to be door glass which accounted for 37 out of 216 injuries (17.1%).

Table 6



Note HGV equals Large Truck or Bus

(4a) AIS Severity and Contact Sources

We investigated the relationship between interior and exterior contact sources using the chi-square test. The results are shown in table 7.

Table 7 AIS v Contact Source

		AIS			
		AIS 2	AIS 3	AIS 4+	Total
Contact Source	Interior	69 (50.4)	27 (36.0)	15 (24.7)	111
	Exterior	29 (47.6)	43 (34.0)	33 (23.3)	105
	Total	98	70	48	216

Values in parentheses are expected frequencies for the chi-square statistic
$\chi 2= 26.5872$ d.f. = 2 $P<0.000001$

We thus found that occupants are significantly more likely to sustain both AIS 3 and AIS 4+ injuries from exterior source and are less likely to sustain injuries at this level if they contact an interior vehicle component. Conversely, occupants are significantly less likely to sustain AIS 2 injuries from an exterior source and are more likely to sustain injuries from an interior vehicle source.

(4b) Injury Type v Contact Sources

We also investigated the relationship between contact source and injury type. Specifically, we wished to examine if the head injury type (i.e. diffuse, focal or skeletal) was related to whether the contact source originated external or internal to the vehicle.

Table 8 shows the results of this analysis.

As can be seen from table 8, diffuse head injuries are significantly more likely to originate from interior contact sources while both focal and skeletal type head injuries are significantly more likely to originate from a contact source exterior to the vehicle.

Table 8 Injury Type v Contact Source

		Injury Type			
		Diffuse	Focal	Skeletal	Total
Contact Source	Interior	57 (36.9)	24 (33.2)	17 (27.9)	98
	Exterior	13 (33.1)	39 (29.8)	36 (25.1)	88
	Total	70	63	53	186

Values in parentheses are expected frequencies for the chi-square statistic
$\chi 2= 37.611$ d.f. = 2 $P<0.00001$

Discussion

Head injuries in side impacts are of major concern. While such injuries are of equal importance to thoracic injuries in terms of threat to life, in many respects, they carry much greater importance because of problems associated with long term disability, quality of life, etc.

Such injuries are also among the more difficult to mitigate by vehicle design alone because of the fundamental problem of the driver or passenger positioned so close to the striking object in a collision scenario.

We have found that approximately half (47.6%) to be AIS 2. This category includes patients who were awake on admission to hospital and had been unconscious for less than one hour, patients exhibiting lethargy or amnesia and those exhibiting injuries to the head surface. Injuries at this level can lead to long-lasting symptoms and disabilities. Such injuries appear to have their origins within the vehicle rather than from some exterior vehicle source and as such may be the easier type of injury to mitigate by vehicle design. Any steps taken to reduce such injuries would therefore be well worthwhile. Such measures could involve the inclusion of design features such as laminated side window glazing with appropriate bonding and frame support, side air-bags and perhaps shoulder spacers and padding. Laminated side window glazing may well be beneficial for the prevention of partial head ejection but would be of less use in collisions which involve large intrusion or pole/truck impacts at the window level. The retention properties of laminated glass, already proven in the case of windscreen contacts, may well help reduce higher AIS injuries. Side airbags may offer potential for keeping the head away from intruding objects as well as maintaining retention properties of their own, however without available field data, it is difficult to assess their feasibility. They may also prevent head contacts on side glass but again the benefits may diminish in collisions where there is large amounts of intrusion. Shoulder spacers may alleviate violent head contacts by directing the head away from the door or striking object in the collision. Such design suggestions have obvious implications for the overall width of cars.

When considering the problem of higher level AIS injuries (i.e. AIS 3+) the problem is more difficult to address by alternative vehicle design. This is because the injuries tend to have their origins outside the vehicle. When contact with an exterior object is made, then it is likely that the occupant will receive both a high AIS level injury, and that the injury will be either focal brain injury or skull fracture or a combination of both. The long term consequences of such injuries are likely to be much more serious than lower level injuries given that the occupant survives. One problem with current lateral impact test proposals is that, as Mackay (1989) notes, by requiring a severe test i.e. a heavy and relatively rigid Mobile Deformable Barrier (MDB) travelling at high speed into the test vehicle will encourage designs which are optimal for such a condition. We have shown in our study that 48.6% of AIS 3 injuries and 49.9% of AIS 4+ injuries originate from a direct contact with an external source <u>other</u> than a car, such as a large truck or other vehicle type or a narrow object such as a lamppost or tree. 12.9% of AIS 3 injuries and 18.8% of AIS 4+ injuries were from contact with the bullet car. The issue of contact with exterior objects other than cars is not included in any of the current test proposals yet would appear to be a major problem. We acknowledge that it is difficult to reduce the aggressivity of these dangerous contacts. For vehicular impacts with a narrow rigid object the problem arises because the fixed object cannot be induced to absorb any significant portion of the crash energy. Kahane (1982) observes that one method of injury reduction in this collision scenario is that included in Federal Motor Vehicle Safety Standard (FMVSS) 214. This involves the inclusion of longitudinal reinforcement beams inside car doors so that when the collision with the rigid object occurs, the vehicle can partially deflect the striking object resulting in a more glancing collision trajectory spreading the damage, reducing the damage depth and maintaining door integrity. Kahane notes that the benefits of such a design feature includes a reduction in head injuries. However opinions differ as to how successful a solution to the problem door beams will be. Again there is little field data to allow firm conclusions to be drawn. Future work could examine head injuries in collisions involving current vehicles fitted with side impact beams to assess if benefits in this respect can be derived. Certainly as Thomas et al (1986) propose, the future incorporation of a car-to-pole test in lateral impact test requirements has the potential for injury reduction.

With regard to mitigating head injuries that arise through vehicle collisions with large trucks, buses and other such vehicles there is a possibility that the redesign of the front structures of such vehicles to ensure compatibility with car side structures could be of some benefit. In this collision scenario, if the striking object is designed to protrude forward at the level of the front under-run bumper or its equivalent (as suggested by Breen et al, 1990) such that the impact is directed at or below the pelvis, then other design features such as laminated side glass suitably mounted, side airbags and shoulder padding in the target car could prevent the head contacting the exterior object in a proportion of such cases.

With regard to actual collision severity, it is apparent that diffuse brain injuries are more likely to occur in collisions of significantly lower median collision severity (Delta-V) than focal and/or skull fractures. Such differences should be borne in mind when agreement is reached on actual test requirements. Perhaps inclusion of head-form tests may also contribute to informative results which would assist in the formulation of appropriate legislation. Lower AIS level diffuse injuries are themselves worthy of consideration because of possible long term consequences. Higher AIS level diffuse injuries are almost certain to result in long term neurological deficit in the survivor. Future work which examines outcomes of these injury types would be of some interest.

Much development work is needed by both the vehicle designer and the highway engineer in addressing this important class of collisions generating major brain injury and disability. Issues of vehicle compatibility are apparent, a recognition of the populations of people exposed, the range of crash severities and the likely benefits and disadvantages of various alternative designs need to be evaluated by using real world crash data as is illustrated in this paper. No simple solutions stand out and each design change will have disadvantages but the data discussed in this paper illustrate the importance and complexity of head injury in side impacts. The results suggest that the current whole system test of FMVSS 214 and its still to be agreed European counterpart, will not adequately address the head injury problems illustrated here, just by specifying an HIC requirement on a 50%ile dummy in a single Mobile Deformable Barrier crash test.

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