AIS 3+ HEAD INJURY MECHANISMS AND CRASH CHARACTERISTICS - A REVIEW OF AIRBAG DEPLOYED CRASHES

Ruth Welsh, Steven Reed, Andrew Morris
VSRC, Loughborough University, UK

ABSTRACT

Previous studies have shown steering hub airbags to be effective in reducing the rate of serious head and facial injuries for drivers of passenger cars involved in frontal impacts. However, real world accident data shows that approximately 3% (50 out of 1680) of drivers in a sample of crashes received an AIS 3+ head injury despite a steering hub airbag having deployed. For struck-side occupants with deployed head protection 12% had an AIS 3+ head injury. This paper examines the nature and mechanism of the specific head injuries together with the surrounding crash characteristics in order to identify further occupant protection requirements beyond the scope and capability of the airbag. The in-depth case review has revealed that, among cases within the CCIS database, only 0.5% of those with deployed frontal head protection but 12% of those with deployed struck-side head protection show potential for improvement in occupant head protection.

Keywords: Airbag, Injuries, Head, Frontal impacts, Side impacts

IN EUROPE, AIRBAGS are predominantly seen as Supplementary Restraint Systems (SRS's) to be used in conjunction with the wearing of the seat belt. In general, the seat belt is designed to prevent the occupant from having harsh contacts with interior surfaces of the vehicle whilst the airbag has positive internal pressures which can exert distributed restraining forces over the head and face. Furthermore, the airbag can act on a wider body area including the chest and head, thus minimising the body articulations, which cause injury.

In Europe, the ECE R94 for frontal impact legislation focuses on the airbag as a supplementary restraint system to be deployed in conjunction with a seat belted occupant. Thus in general, deployment thresholds are higher and airbag volumes lower in these 'Supplementary Restraint Systems' compared to the 'Passive Restraint Systems' found in the United States.

In general, deployment of the airbag is completed within 20ms from the initiation by the sensor and the airbag has begun deflating at that stage. The airbag generates a positive force, which acts to absorb the forward momentum of the occupant during the impact phase of the crash; this is obviously more effective if the occupant is restrained.

Many studies have examined the effectiveness of frontal crash airbag systems. Previous evaluations of frontal crash injury protection from European airbags have identified substantial benefits for the head and face but little overall effect on chest protection (Lenard et al, 1998; Frampton et al, 2000; Morris et al 2005). Kirk et al (2002) also found a significant head injury reduction effect in frontal crashes for both belted and unbelted drivers although the benefits for chest injury reduction were less clear.

Side airbags obviously have different design and deployment characteristics since the airbag has to be inflated rapidly following the onset of the collision in order to have any overall effect. In terms of side airbag crash protection, there has been some published work looking at the general effectiveness of side airbags (.e.g. Braver and Kyrychenko, 2004, Page et al, 2006) and some field studies have also been conducted (Baur et al 2000; Roselt at al 2002; Kirk and Morris, 2003; Morris et al 2005;, Yoganandan et al, 2005, 2006) but the numbers of field deployments are still low. However a number of new cases are available allowing a further case review to be undertaken.

This study examines injury outcomes in airbag deployed vehicles to look initially at differences in crash circumstances for occupants who sustain AIS3+ head injuries compared to those who do not. The study examines such outcomes in vehicles in which the driver's frontal airbag was deployed. The study then uses an in-depth case review methodology to look at the nature and circumstances of the crashes in which AIS 3+ head injuries occurred in both frontal and struck-side airbag deployed crashes.

METHOD

DATA SELECTION**:** The data used for this study were selected from the UK in-depth accident data which is collected by the Co-operative Crash Injury Study (CCIS). Data from the accident years 1998 to present were analysed. The CCIS data collected during these accident years employs the following sampling criteria;

- Case vehicles are passenger cars which are 7 years old or younger at the time of the accident.
- At least one occupant within the case vehicle must have been injured.
- The case vehicle must have been towed away from the accident scene.
- The data are collected within defined geographical regions within the UK.

Additionally, the data are biased towards fatal and serious injury outcome. Typically all cases where fatal injury occurs, around 80% of serious injury cases and around 20% of cases where slight injury occurs are investigated. Thus, the data are not representative of the true injury rates within the UK. The sampling does not however affect the results in this study due to the nature of the analyses undertaken. Injuries are coded in the data according to the Abbreviated Injury Scale AIS90 version.

Single frontal and single struck-side impacts were selected. Frontal impacts were defined as having an impact location to the front of the vehicle and a direction of force of 11, 12, or 1 o'clock. Struck-side impacts required the presence of a front occupant on the impact side (either left or right) and a direction of force of 1, 2, 3, 4, 5, 7, 8, 9, 10 or 11 o'clock.

All of the cases included in the analysis had both an activated steering hub airbag and a belted driver (n=1680) or an activated side airbag that offered head protection for a front occupant (n=85). There was no selection on belt use for the side impacts to keep the sample size as large as possible. It should be noted that the belt use rate is over 90% in the sample.

ANALYSIS**:** For both the frontal and the side airbag cases the data were categorised according to head injury outcome. Two groups were formed; those where the driver or struck-side occupant had a head injury outcome of AIS 0, 1 or 2 and those where the head injury outcome was more severe, AIS 3+.

Analysis results for frontal impacts are given in part 1 and results for struck-side impacts in part 2. The analysis for the frontal impacts comprises both a statistical analysis, considering impact and occupant characteristics, and comments based upon an in-depth case review. For the struck-side analysis the number of cases with AIS 3+ head injury outcome, though proportionally high, are few in number (10 out of 85 cases). For this reason a statistical analysis comparing cases with AIS 3+ outcome to those without is inappropriate. Therefore, each of the 10 cases with AIS 3+ head injury outcome is presented separately as a case summary in part 2.

Much of the analysis makes use of information recorded in the Collision Deformation Classification or CDC. In order to describe the damage pattern in a manner that is universally agreed upon and readily recognised, the Society of Automotive Engineers (SAE) has devised a descriptive coding method, which conveys the essential features of the collision damage in a seven-digit code. This method of coding is fully described in a booklet entitled 'SAE Recommended Practice J224b'. The code describes the nature and location of direct contact to the vehicle for each collision it sustains.

RESULTS

PART 1 FRONTAL IMPACTS
<u>Statistical Analysis</u>

Table 1 Head Injury Distribution

	N	%
AIS 0	1506	89.7
AIS 1	93	5.5
AIS 2	31	1.8
Total AIS 0-2	1630	97%
AIS 3	29	1.7
AIS 4	11	0.7
AIS 5	7	0.4
AIS 6	3	0.2
Total AIS 3-6	50	3%

The rate of AIS 3+ head injury among the drivers with a deployed hub airbag is 3% (table 1).

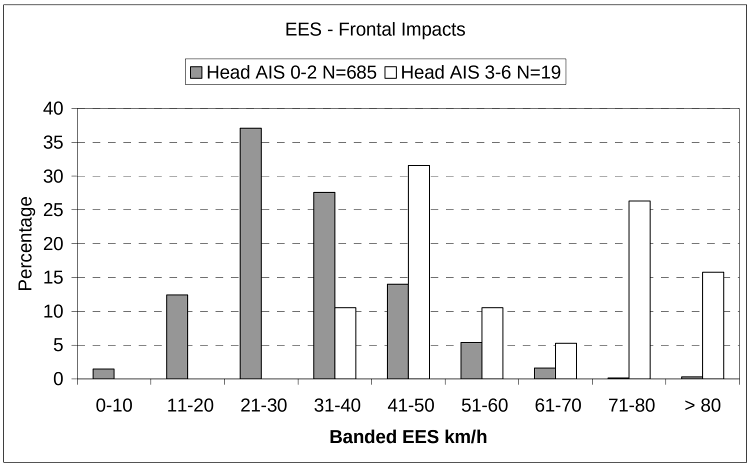

Figure 1 Crash Severity (EES) - Frontal Impacts

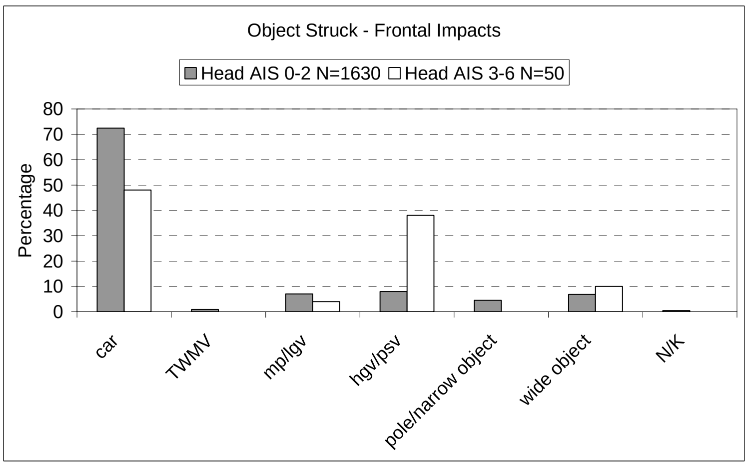

Figure 2 Impact Object - Frontal Impacts

Figure 1 shows the impact speed (approximated by Equivalent Energy Speed - EES) for those occupants with AIS 3+ head injury compared to those with AIS 0-2 head injury outcome. There is a clear shift towards higher severity crashes for the AIS 3+ cases.

Considering the impact object, figure 2 shows that there is a considerably higher proportion of impacts with large vehicles (HGV - Heavy Goods Vehicle / PSV - Public Service Vehicle) for cases with AIS 3+ head injury outcome compared to those with AIS 0-2 outcome.

The 'type' of impact according to the CDC classification is shown in figure 3. In accordance with the higher rate of impacts to large vehicles, cases with AIS 3+ head injury outcome show a higher prevalence of underrun type impacts compared to those with AIS 0-2 head injury outcome.

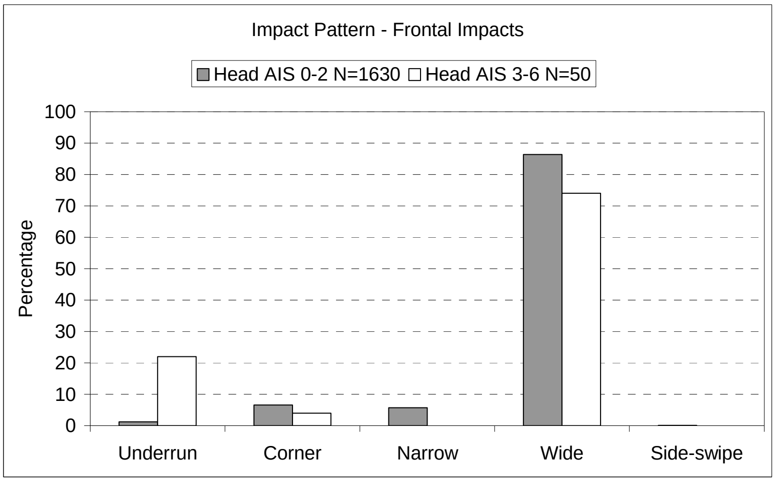

Figure 3 CDC Impact Pattern - Frontal Impacts

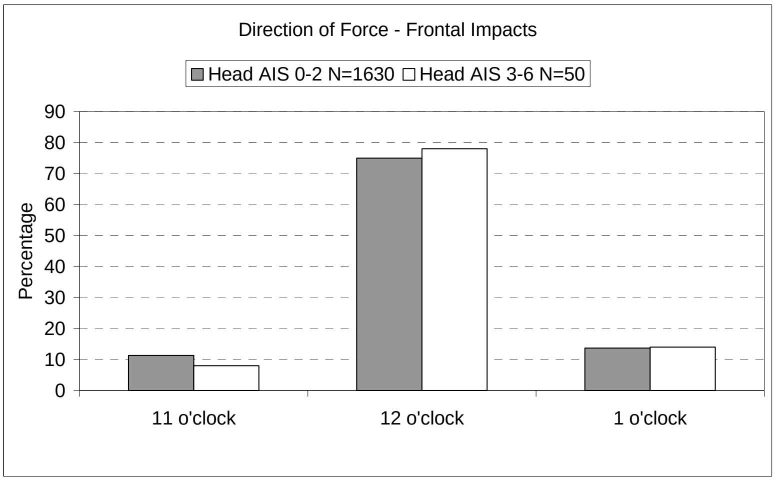

Figure 4 CDC Direction Of Force Of Impact - Frontal Impacts

Comparing the direction of force of the impact, figure 4 shows there to be little variation between those cases with AIS 3+ head injury outcome and those with AIS 0-2 head injury outcome.

Considering the CDC crush extent, figure 5 shows clearly that the AIS 3+ cases have a higher crush distribution than the AIS 0-2 cases.

Figure 6 (and associated diagram) shows the frontal intrusion into the passenger cell measured inwards from the joint between the A pillar and the bulkhead. It is apparent that greater intrusion is associated with the more serious head injury outcome group.

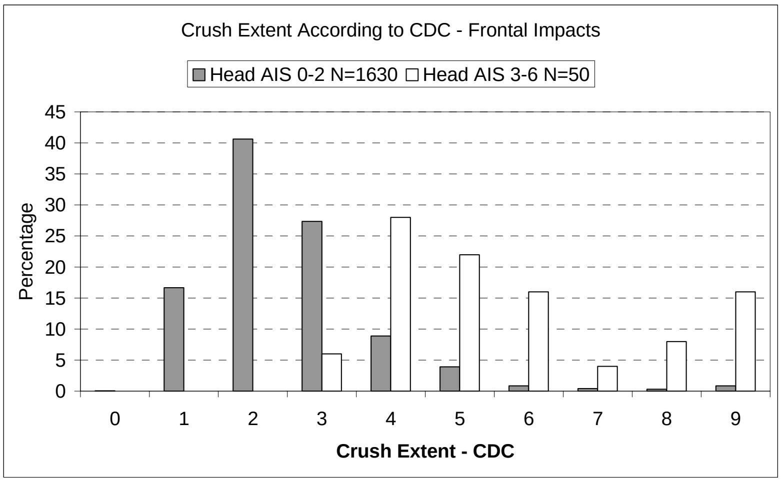

Figure 5 CDC Crush Extent - Frontal Impacts

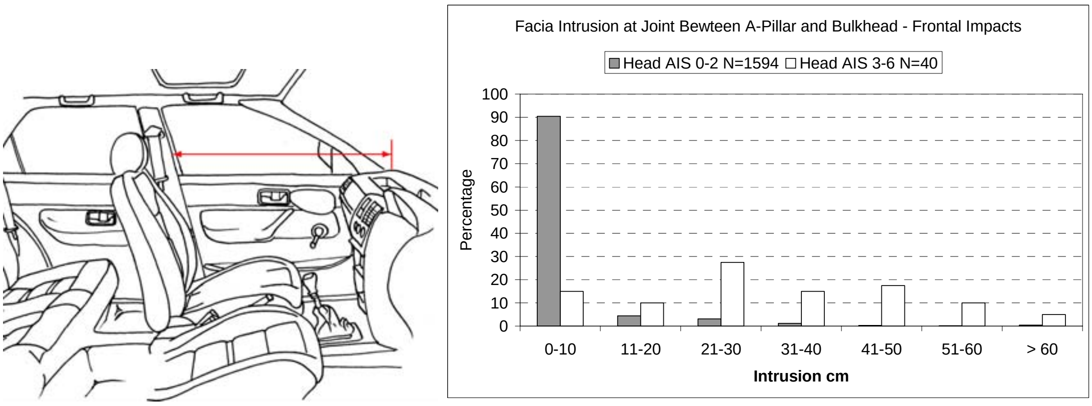

Figure 6 Intrusion - Frontal Impacts

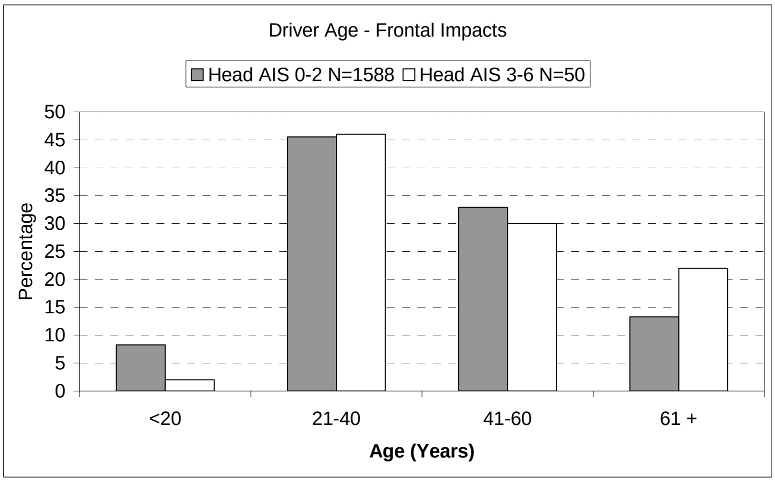

Figure 7 Occupant Age - Frontal Impacts

Figure 7 shows the age distribution for the AIS 3+ head injury cases and the AIS 0-2 head injury cases. Four age bands have been considered, <20, 21-40, 41-60 and 61+. There appears to be an over-representation of AIS 3-6 head injuries in the older age group.

Table 2 below shows that there is little variation in the gender distribution between the two head severity groupings.

Table 2 Occupant Gender - Frontal Impacts

	AIS 0-2	AIS 3-6
Male	65%	68%
Female	35%	32%
Total	100%	100%

IN-DEPTH CASE REVIEW - CASES WITH AIS 3+ HEAD INJURY: A brief review was made of the 50 cases with AIS 3+ head injury. Of these 11 were found to be gross underrun (defined as 'A' in the CDC damage pattern). Comments on cases with and without underrun are made below.

Cases With No Underrun: There were 39 cases with AIS 3+ head injury that were not underruns. Of these 24 exhibited signs of exceeding design and engineering capabilities (judged by a review of the photographic evidence, impact location and intrusion measures). Of the remaining 15 cases 8 had a severity recorded as fatal with the remaining 7 serious. The average age of the driver's involved in these cases was 47. Driver gender was biased towards male drivers with 12 of the 15 drivers being male. Of these 15 cases 9 had a comparatively low calculated crash severity (EES). The lowest calculated speed was 40kph with the highest just under the EuroNCAP test speed at 60kph, the mean being approximately 48kph. Of these 9 cases 6 have a fatal medical outcome with the remaining third classified as serious. However, all the cases exhibited high levels of crush and associated intrusion, the mean crush level was 79cm with a mean interior intrusion measure (recorded at the A-pillar to bulkhead joint) of 34cm. Typically no stiff structure engagement occurred thus resulting in high deformation associated with relatively low energy collisions. The AIS 3+ head injury was accompanied by severe chest injury in 3 of the 6 fatal cases.

When considering the nature of the injuries and the coding of a corresponding Injury Causation Code (ICC) a number of common factors were highlighted. The most common of these injury causations was the apparent overloading of the frontal 'hub' airbag; this allows the drivers head to contact the stiff structures that make up the steering wheel; interestingly a number of these cases showed an equivalent test speed (ETS) not dissimilar to EuroNCAP testing speed (64kph). Steering wheel contacts are aggregated from 4 different codes describing certain components of the wheel assembly (Rim, Spoke, Hub, and Combination).A further common injury causation was contact with the A-pillar; this was most prevalent in cases with a 1 o'clock direction of force although a small number exist with a true longitudinal force of 12 o'clock. These A pillar contacts could be explained by the driver's head 'rolling off' the side of the airbag, possibly due to facia intrusion moving the orientations of the steering column.

Underrun Case Reviews: As mentioned in the statistical comparison of AIS 0-2 and AIS 3+ cases, there is a clear increase in underrun type accidents for the higher severity scores. An in-depth case review of all AIS 3+ underrun cases was conducted to determine the nature of these accidents and the associated types of injuries and causations. A total of 11 (22%) underrun cases exist in the 50 case AIS 3+ sample. For these 11 cases the bullet object was always another vehicle; 8 heavy goods vehicles (HGV), 2 public service vehicles (PSV) and 1 with a trailer detached from the towing vehicle. There was a roughly equal driver gender split with 6 male drivers and 5 female drivers. The average age of the drivers was 35.

Almost all of the cases exhibited very little stiff structure engagement with no direct contact to either longitudinal. Most cases did however show some degree of intrusion to the passenger compartment. This intrusion was normally associated with the A-Pillar to bulkhead measurement seen in Fig 6. Steering wheel movement was also much more prevalent in these underrun cases compared to the car to car non underrun impacts. This movement may not be directly associated with the frontal intrusion but could give an indication as to the severity and extent of the underrun as components of the larger vehicle may penetrate the passenger compartment.

A review of the ICCs associated with the head injuries revealed that in almost all of the cases (10) an external object had been coded as the injury cause; this can be directly associated with stiff components on the larger vehicle (Truck/Bus) and demonstrates the severity of these types of impacts on injury outcomes.

In summary, the cases with AIS 3+ head injury in airbag deployed frontal crashes all have some explanation for why a serious injury would have occurred. This is typically due to the damage pattern, the vehicle deformation and associated intrusion. None of the injuries observed are exceptional.

PART 2 STRUCK-SIDE IMPACTS

Table 3 Head Injury Distribution - Struck-Side Impacts

	N	%
AIS 0	52	61.2%
AIS 1	20	23.5%
AIS 2	3	3.5%
Total AIS 0-2	75	88.2%
AIS 3	4	4.7%
AIS 4	4	4.7%
AIS 5	1	1.2%
AIS 6	1	1.2%
Total AIS 3-6	10	11.8%

For occupants with deployed head protection, the rate of AIS 3+ head injury among struck-side occupants is much higher than for the drivers in frontal impacts, 12% compared with 3% (table 3).

The 10 cases with AIS 3+ head injury outcome are presented below.

Case 1 - Fatal	
CDC	03RYAW4
Impact Object	Coach
EES	43 km/h
Maximum Crush	460 mm
Relevant lateral intrusion	300mm from base of window down to sill
Belt Use	Belted
Airbags	Hub - Activated Knee bolster - Activated Seat back thorax - Activated Curtain - Activated
Occupant Age	57 years
Occupant Gender	Male
Head Injuries and sources	
# Skull AIS 3 - External object	
Subdural bleed AIS 4 - External object	
Other injuries	
Multiple fractured ribs with hemothorax AIS 5	
Liver lacerations AIS 2	
Cause of Death	
Multiple injuries	
Comments	
The head injuries are attributed to contact with an external object, there is evidence of hair and skin tissue at the base of window of the coach. Due to the nature of the impact the resultant deformation may give the impression of a higher energy impact than that calculated. The calculated value is believed to be representative. The side curtain has deployed. The side curtain would have been expected to have provided head protection to mitigate this kind of injury.	

Case 2 - Fatal	
CDC	09LPEW4
Impact Object	Citroen Van
EES	32 km/h
Maximum Crush	590 mm
Relevant lateral intrusion	550 mm base window/mid door
Belt Use	Belted
Airbags	Facia - Not Activated Seat back head and thorax- Activated
Occupant Age	20 years
Occupant Gender	Male
Head Injuries and sources	
# Skull AIS 2 - External object	
Subarachnoid Hematoma AIS 3 - External object	
Cerebral Oedema AIS 3 - External object	
Other injuries	
# Ribs with Hemothorax AIS 4 , Diaphragm tear AIS3, Spleen injury AIS 2, # Pelvis AIS 2	
Cause of Death	
Multiple injuries	
Comments	
The head injuries are attributed to contact with an external object, the striking vehicle. It is possible that the calculated EES value is a slight underestimate. The seat back head/thorax bag has deployed. The side bag would have been expected to have provided head protection to mitigate this kind of injury.	

Case 3 - Fatal	
CDC	03RPAW5
Impact Object	Tree
EES	n/k
Maximum Crush	910 mm
Relevant lateral intrusion	550 mm at cant rail
Belt Use	Belted
Airbags	Hub - Not activated Seat back thorax - Not activated Curtain - Activated
Occupant Age	47 years
Occupant Gender	Male
Head Injuries and sources	
Extensive regions of disruption to brain stem AIS 5 - B Pillar	
Extensive regions of disruption to the cerebellum AIS 3 - B Pillar	
Extensive regions of disruption to both cerebral hemispheres AIS 3 - B Pillar	
Complicated fracture base and vault of skull AIS 4 - B Pillar	
Other injuries	
# Pelvis AIS 2, Liver Lacerations AIS 4, # Arm AIS 2	
Cause of Death	
Head Injuries	
Comments	
Given the crush extent the crash severity is likely to be high but no reliable calculation could be made due to the nature of the damage. Though the head injuries have been attributed to the B pillar in this case, it is also likely that some external contact was made with the tree given the location of the impact and the perpendicular direction of force. The curtain might have been expected to offer better head protection.	

Case 4 - Fatal	
CDC	01RYAW3
Impact Object	Vauxhall Van
EES	44 km/h
Maximum Crush	560 mm
Relevant lateral intrusion	340 mm at base of door
Belt Use	Belted
Airbags	Hub - Activated Seat back thorax - Activated Curtain - Activated
Occupant Age	73 years
Occupant Gender	Male
Head Injuries and sources	
Subdural haemorrhage AIS 4 - Own side nfs	
Subarachnoid haemorrhage AIS 3 - Own side nfs	
Brain swelling AIS 3 - Own side nfs	
Contusions in cortex AIS 3 - Own side nfs	
Other injuries	
# leg, # thoracic spine, # ribs with hemothorax, lung contusions, ruptured atrium, liver and kidney lacerations	
Cause of Death	
Multiple injuries	
Comments	
Due to the nature of the impact, the resultant deformation may give the impression of a higher energy impact than that calculated. The calculated value is however believed to be representative. This elderly occupant has received a fatal injury to the heart. Given the extent of the vehicle damage and the deployed side airbags, the head injuries are surprising.	

Case 5 - Fatal	
CDC	02RPAW3
Impact Object	Tree
EES	33 km/h
Maximum Crush	320 mm
Relevant lateral intrusion	180 mm from cant rail down to mid door level
Belt Use	Belted
Airbags	Hub - Activated Seat back head and thorax - Activated
Occupant Age	63 years
Occupant Gender	Female
Head Injuries and sources	
# Base of skull AIS 3 - external contact with tree	
Subarachnoid haemorrhage AIS 3 - tree	
Intraventricular haemorrhage AIS 4 - tree	
Other injuries	
Pleural haemorrhage AIS 3	
Cause of Death	
Multiple injuries	
Comments	
The calculated EES is believed to be representative of the impact. This is a convertible. The side head airbag is relatively small. The non perpendicular impact could have resulted in occupant kinematics such that the head missed both the hub and the side airbag during the impact phase. If a larger airbag had been present then the contact with the tree may have been avoided.	

Case 6 - Fatal	
CDC	10LZAW5
Impact Object	Truck
EES	Not Known
Maximum Crush	380 mm
Relevant lateral intrusion	710 mm at base of window
Belt Use	Belted
Airbags	Facia - Activated Seat back thorax - Activated Curtain - Activated
Occupant Age	52 years
Occupant Gender	Female
Head Injuries and sources	
Basal # Skull AIS 3 - External object	
Blood present in meninges AIS 3 – External object	
Bone shards present in brain stem AIS 6 – External object	
Other injuries	
Multiple rib # with bilateral haemopneumothorax AIS 5, Atlanto-axial subluxation with severed spinal cord AIS 6,# spine AIS 2, Bilateral acetabulum #' & multiple pelvic #s AIS 2	
Cause of Death	
Multiple injuries	
Comments	
The head injuries are attributable to an external object (Truck) and the extensive intrusion into the vehicles nearside would support this. Considering the level of intrusion the curtain bag could have provided a level of protection although overloading may be a possibility	

Case 7 - Serious	
CDC	01RYAW4
Impact Object	Truck
EES	45 km/h
Maximum Crush	400 mm
Relevant lateral intrusion	350 mm base of window / mid door
Belt Use	Belted
Airbags	Hub - Activated Seat back - Activated Curtain - Activated
Occupant Age	28 years
Occupant Gender	Male
Head Injuries and sources	
# Base of skull, CSF leak AIS 3 - External object	
Cerebral contusions AIS 3 - External object	
Subdural hematoma AIS 4 - External object	
Other injuries	
Internal chest injuries AIS 3	
Comments	
Due to the nature of the impact the resultant deformation may give the impression of a higher energy impact than that calculated. The calculated value is believed to be representative. The head injuries are attributed to contact with an external object though no inspection was made of the truck. The side curtain has deployed. The side curtain would have been expected to have provided head protection to mitigate this kind of injury.	

Case 8 - Serious	
CDC	09LPEW3
Impact Object	Car
EES	35 km/h
Maximum Crush	400 mm
Relevant lateral intrusion	200 mm at cant rail and mid door level
Belt Use	No evidence of belt use
Airbags	Facia - Activated Seat back thorax - Activated Curtain - Activated
Occupant Age	16 years
Occupant Gender	Male
Head Injuries and sources	
Small brain hematoma AIS 3 - Own side/B pillar	
Other injuries	
None	
Comments	
This vehicle has been substantially damaged by the emergency services giving the impression of a higher severity impact. The calculated EES is believed to be representative. The only injury to this occupant is the brain hematoma. The curtain would have been expected to mitigate this type of injury. There was no evidence of belt use. This was a perpendicular impact and therefore evidence of belt use is not necessarily expected.	

Case 9 - Serious	
CDC	11LYAW4
Impact Object	Transit Van
EES	31 km/h
Maximum Crush	400 mm
Relevant lateral intrusion	390 mm at base of door
Belt Use	Belted
Airbags	Facia - Activated Seat back head and thorax - Activated
Occupant Age	66 years
Occupant Gender	Female
Head Injuries and sources	
Inter cerebral contusion AIS 3 - External object	
Subarachnoid haemorrhage AIS 3 - External object	
Other injuries	
AIS 2/3 injuries to the upper extremity, pelvis and lower extremity	
Comments	
The nature of the collision was such that there was substantial soft structure damage (e.g. the wings) which gives the impression of a higher EES. The calculated EES is believed to be representative. This is a convertible. The side head airbag is relatively small. The non perpendicular impact could have resulted in occupant kinematics such that the head missed the side airbag during the impact phase.	

Case 10 - Serious	
CDC	00LDAW3
Impact Object	Ditch Side
EES	U/K
Maximum Crush	7mm
Belt Use	Belted
Relevant lateral intrusion	Nil
Airbags	Facia - Activated Seat back head and thorax - Activated
Occupant Age	22 years
Occupant Gender	Male
Head Injuries and sources	
# Skull AIS 2 - Roof	
Mild R subarachnoid haemorrhage AIS 3 – Roof	
Loss of consciousness AIS 2 - Roof	
Other injuries	
Abrasion with swelling L forehead AIS 1	
Comments	
The head injuries are attributable to a roof (internal cant rail area) contact due to the non horizontal impact with the ditch side. The seat back head and thorax bag has deployed and would be expected to mitigate these injuries.	

DISCUSSION

This study has examined the nature of and circumstances under which drivers and struck-side occupants sustain AIS 3+ head injuries despite the deployment of head airbag protection systems. The methodologies employed have included both data analysis and in-depth case review for frontal impacts and in-depth review only for struck-side impacts. Some interesting results have emerged, particularly with regard to struck-side impacts.

Given that the CCIS data are biased towards serious and fatal injury outcome, it is encouraging to see that the overwhelming majority of drivers in hub airbag deployed vehicles receive no head injury and only 3% sustain head injuries at AIS 3+.

With regard to the data analysis, there are clear differences in the nature and circumstances of the crash when comparing drivers with and without an AIS 3+ head injury in the frontal impacts. These differences may explain why these serious injuries occur. When an AIS 3+ head injury occurs the crash severity is clearly higher and the impacting object is more aggressive. Other significant differences include the higher proportion of underrun cases, the higher crush distribution and the increased amount of intrusion observed in cases where AIS 3+ head injury is apparent. A further possible contributing factor is driver age with drivers over 60 years old seemingly over represented in the more severe injury grouping.

Considering the in-depth case reviews of frontal impacts where an AIS 3+ head injury occurred, 18% had a relatively low crash severity and did not underrun the collision partner. It should be noted that this represents just 0.5% of all drivers in the data base with a deployed hub airbag. The mechanism by which serious injury occurs in these circumstances is unclear although all of the cases exhibited significant levels of intrusion. It could be that in these cases the crash pulse is such that the driver contacted the steering wheel just prior to the point of deployment. Alternatively an adverse head contact could occur due to occupant kinematics and bulkhead intrusion resulting in close proximity to the deploying airbag itself.

A further 22% of the AIS 3+ cases in frontal crashes occurred in association with an underrun type impact. The fitment of underun protection and the regulations on usage for trucks are based on a series of complex rules which take in to account the age of the vehicle or trailer and the type of vehicle or usage; for example a modern tractor unit can legally tow an unprotected trailer that was constructed before the underrun protection regulations. In this study it was not possible to determine the fitment of underrun protection on all vehicles; often the truck is relatively undamaged in the incident and is removed before an examination can be conducted. In these cases the AIS 3+ head injuries were almost exclusively caused by direct contact with the truck and a deployed hub bag would almost certainly have had no benefit. In the remaining 60% of the AIS 3+ head injury cases where a hub bag deployed, the severity of the crash was such that any potential benefit of secondary safety systems would be out-stretched.

For the struck-side impacts, the residual high rate of AIS 3+ head injury, despite head protection via the side airbag having deployed, is in itself a cause for concern. This is affirmed by the in-depth case review where the cases with AIS 3+ head injury would not be considered ‘’wipe-out’’ crashes given modern secondary safety systems. The majority of the cases indicated a head contact with an external object as the injury mechanism. Prevention of such contacts is however thought to be one of the main functions of the side airbag protection system. Though not the focus of this paper it should also be noted that in some of the cases there were significant chest injuries that contributed to a fatal outcome despite chest protection airbags also having deployed.

The time available in which to adequately deploy a side airbag to offer good protection for the head (and chest) is extremely limited in a struck-side impact due to the restricted space between the occupant and the impacting object. In most side airbag deployments, the side airbag has to be deployed within 20-30 milliseconds of the initial contact with the collision partner. If this is not achieved for any reason, then the protection capabilities of the side airbag as a whole could be compromised. In this study, due to the retrospective nature of the crash investigations, little insight could be gained about the efficacy of the deployment timing but particularly in higher speed impacts, it could be a significant issue.

Though it could be argued that the occupant age (and inherent frailty) could be a factor in some of the cases presented, the cases do indicate a need to further consider the timing of the airbag deployment in struck-side crashes. Furthermore, although the injury mechanism is given as contact with an external object, apart from those cases where evidence such as hair or skin tissue has been found on the bullet vehicle other options are possible. It is possible that there was an immediate head contact with an aggressive deploying airbag followed by a subsequent contact with the external object, or it is also possible that the airbag deployed too late in the crash phase to prevent a first contact with an external object. There is also potential for the airbag to be overloaded. Further exploration of the occupant kinematics in relation to the airbag deployment timing would be beneficial, possibly through the use of virtual simulation.

CONCLUSIONS

- Considering the CCIS data base, in crashes where head protection has deployed (hub/side airbag) 3% of drivers in frontal impacts and 12% of struck-side occupants in side impacts sustain an AIS 3+ head injury.
- Data analysis shows that factors that influence the occurrence of AIS 3+ head injury in airbag deployed frontal crashes are impact object, intrusion, crash severity and underrun. These results are not surprising.
- For frontal impacts in 82% of cases with AIS 3+ head injury and hub bag deployment the nature of the impact, in terms of crash severity and underrun occurrence, is such that the injury outcome is not unexpected.
- The AIS 3+ head injury mechanism is less clear in the remaining 18% of cases where the crash severity was relatively low and no underrun occurred.
- For struck-side occupants with deployed head protection a better head injury outcome could have been expected for all of the occupants with AIS 3+ head injury though the exact circumstances of each crash are difficult to assess retrospectively.
- The in-depth case review has revealed that, among cases within the CCIS database, 0.5% of those with deployed frontal head protection (hub bag) and 12% of those with deployed struck-side head protection (curtain or side bag) show possible potential for improvement in occupant protection.
- Further exploration of the occupant kinematics in relation to the airbag deployment timing would be beneficial, possibly through the use of virtual simulation that explores both perpendicular and oblique impacts and the variety of head protection available in different styles of car.
- A review of underrun protection with respect to improvement in vehicle to vehicle compatibility would be beneficial.

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