AN EVALUATION OF AIRBAG BENEFITS/DISBENEFITS IN EUROPEAN VEHICLES – A COMBINED STATISTICAL AND CASE STUDY APPROACH

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ABSTRACT

Any restraint system carries a certain risk of injury from the system itself. It is therefore vital to know the balance of that risk compared to the overall benefits of the system. The objectives of this study were to address those questions by a thorough case review of in-depth real world cases to find problems associated with airbag deployment followed by examining the nature, frequency and mechanisms of AIS ≥ 2 head/face and chest injuries in European vehicles, with and without airbags. Belted and unbelted drivers were examined separately. The analysis considered only frontal impacts.

KEYWORDS: Airbags, Injury Severity, Head, Thorax, Restraint Injury

PREVIOUS EVALUATIONS OF FRONTAL CRASH INJURY protection from European airbags identified substantial benefits for the head and face, but little effect on chest protection (Lenard et al, 1998, Frampton et al, 2000). Those studies were directed to assessing overall population benefits. This work utilises the most recent data to assessing overall population benefits for the head and chest and a major individual case review of UK in-depth crash injury cases to identify injuries that may have been caused by airbag deployment. In this paper data are presented concerning drivers, both belted and unbelted, in frontal impacts. Extending analysis to unbelted drivers gives new insights and has relevance for countries with low levels of belt use.

To comprehensively determine the overall benefits of airbags, analysis of a large database is required but individual case review is needed to identify potential problems.
Overall statistical analysis will only be able to answer general questions by filtering the data enough to control for crash parameters. It is therefore, for example, very difficult to study the effect of airbags in rollover accidents. This is where extensive case review is then appropriate. By combining these two approaches the effectiveness of airbag equipped vehicles in the crashes that they were designed for, and whether injury patterns are different, can be investigated. Then the question 'are airbags causing injuries in other types of accident' can be answered, by knowing that all the relevant cases have been reviewed individually.

METHODOLOGY – Overall benefit Analysis

The in-depth data was collected within the UK Co-operative Crash Injury Study (CCIS), the analysis here covering cases investigated from 1996 to 2001. CCIS is a stratified sample that includes nearly all fatal accidents, 80-90% of the serious accidents (admission to hospital) and 20-30% of slight accidents from selected regions of the UK. For a crash to be investigated at least one of the vehicles must be 7 years old or younger, towed from the scene and have at least one injured occupant. Injury outcome is assessed using the Abbreviated Injury Scale (AAAM, 1990). As this analysis involved comparison between two samples of the database no weighting was carried out on the data. As CCIS is biased towards serious injury only inferences of relative injury risk can be made about the UK population as a whole. Drivers sit on the right in the UK.

This analysis utilises in-depth crash injury data to evaluate the injury reduction effectiveness of airbag equipped vehicles. A statistical analysis was used to examine the aggregate effects within the complete sample. Review of individual cases was used to identify cases with adverse effects.

The overall benefit for AIS ≥ 2 head and chest injury has been examined, using rates of injury and injury risk curves. Head injury rates for short stature drivers have been investigated along with the crash conditions for which AIS ≥ 2 head injury still occurs in airbag equipped vehicles.

DATA SELECTION: For the analysis of overall benefit, cases were selected if a frontal impact was the most severe impact in terms of injury severity. Impacts were considered to be frontal from –60 degrees (10 o'clock) to +60 degrees (2 o'clock) from the forward facing longitudinal axis of the vehicle and with a general location CDC code of F. Crashes with any element of rollover were excluded.

In all statistical tests performed a significance level p=0.05 is used for acceptance or rejection of statistical significance. All chi-square tests have 1 degree of freedom.

RESULTS

NUMBER OF CASES: For the analysis of overall benefit over 1000 cases were available with belted drivers in airbag equipped vehicles. A much lower number of data are available concerning unbelted drivers.

Driver's Airbag	Belted n=1942	Unbelted n=253
Non equipped	926 48%	140 55%
Equipped - Not Deployed	234 12%	28 11%
Equipped - Deployed	782 40%	85 34%

Table 1 – Number of Cases

COMPARABILITY OF SAMPLES: This analysis compared two independent driver samples, those in vehicles without frontal driver airbags and those with airbag equipped vehicles, for both belted and unbelted driver groups. Therefore it was important to ensure that crash parameters were similar.

<u>Direction of Impact:</u> The proportion of crashes with a 12 o'clock impact, as the most severe impact, was comparable between the non-equipped and equipped groups for both belted (χ^2=0.538, p=0.463) and unbelted (χ^2=0.346, p=0.557) samples, although in the unbelted sample there is some shift towards 11 o'clock impacts in the non-equipped group.

Direction of Force	Belted Drivers n=926		Unbelted Driver n=253	
	Non equipped	Equipped	Non equipped	Equipped
10 o'clock	2%	2%	1%	1%
11 o'clock	11%	11%	15%	10%
12 o'clock	73%	72%	73%	76%
1 o'clock	11%	13%	11%	12%
2 o'clock	2%	1%	-	1%
Total	100% (926)	100% (1016)	100% (140)	100% (113)

Table 2 – Direction of Impact

Collision Partner: The distributions of collision partners in the belted group were similar for both samples, especially for the largest category, impact to a car/car derivate (χ^2=1.161, p=0.281), although drivers in equipped vehicles tended to have more impacts with wide roadside objects and pole/narrow objects, but the difference is not large. The unbelted drivers in equipped vehicles tended to have proportionally more impacts with wide objects, MPV/LGVs and poles and less with cars, although the difference for car impacts was not statistically significant (χ^2=1.979, p=0.160).

Collision Partner	Belted Drivers n=926		Unbelted Driver n=253	
	Non equipped	Equipped	Non equipped	Equipped
Car / car-derivative	67%	65%	59%	50%
Two-wheeled vehicle	1%	1%	-	1%
MPV / LGV	6%	6%	5%	9%
HGV / PSV	12%	10%	8%	5%
Pole / narrow object <41cm	5%	6%	12%	15%
Wide roadside object >41cm	7%	11%	14%	20%
Other / Not known	4%	1%	2%	-
Total	100% (926)	100% (1016)	100% (140)	100% (113)

Table 3 – Collision Partner

CRASH SEVERITY ETS: Both delta v and Equivalent Test Speed (ETS) are calculated for the CCIS using CRASH3, but due to the number of measurements needed for delta v, ETS values are much more common in the data.

		Mean ETS (kph)	Inter-quartile range (kph)
Belted	Non equipped n=648	32.9	22 - 40
	Equipped n=756	29.2	20 -36
Un-Belted	Non equipped n=109	30.9	21.5 – 34.5
	Equipped n=92	29.6	21.25 - 34

Table 4 – ETS

Table 4 shows that values of crash severity were broadly similar between the non-equipped and equipped samples within the belted and unbelted groups. For belted drivers a shift towards higher crash severity is observed for the non-equipped sample, of 3 kph. This was in fact statistically significant according to the Mann-Whitney means test (u=209366, p=0.000) but within the accuracy of the CRASH3 program this was thought not to be significant in terms of injury severity. For unbelted drivers any difference was not statistically significant (Mann-Whitney u=4877, p=0.739).

Occupant Characteristics: The largest difference between the samples for belted drivers was the lower proportion of female drivers in the equipped group, 33% compared to 39% in the non-equipped group (χ^2=10.143, p=0.001). Mean age was very similar, 36.1 years in the non-equipped sample, 35.5 years in the equipped sample.

In the unbelted group the proportions of female drivers were more similar, 26% in non-equipped vehicles, 23% in equipped (χ^2=0.247, p=0.619). The proportion of female drivers is lower overall than in the belted samples. Mean age was again very similar, 39.8 years in the non-equipped sample, 40.6 years in the equipped sample.

Vehicle Parameters: The population of vehicles not equipped with airbags were older then those with airbags. Coincident with airbag fitment, newer vehicles contain improved seat belt systems as well as changes to bodyshell structures. These differences were noted and taken into consideration by the expert group conducting individual case evaluations. It is no surprise considering the changes in vehicle design that the mean mass of the equipped vehicles is 135kg higher at 1239kg for belted drivers compared to non-equipped vehicles, and for unbelted drivers 120kg higher at 1265kg.

INJURY BENEFIT ANALYSIS

WHOLE BODY INJURY SEVERITY: The maximum AIS (MAIS) of each occupant was used to compare overall injury severity between the non-equipped and equipped drivers samples, in both the belted and unbelted driver groups. Overall the drivers in the non-equipped samples had higher severity injuries than the drivers in the equipped samples. In the belted group, 32% of non-equipped drivers had a MAIS ≥ 2, but only 24% of equipped drivers had a MAIS ≥ 2. The difference is much smaller for unbelted drivers (from 40% to 37%). The decrease for the belted group was statistically valid (χ^2=14.467, p=0.000) but was not for the unbelted group (χ^2=0.211, p=0.646).

	Belted Drivers n=926		Unbelted Driver n=253	
MAIS	Non equipped	Equipped	Non equipped	Equipped
0 – No injury	13%	13%	9%	11%
1 - Minor	55%	63%	51%	52%
2 - Moderate	20%	15%	21%	18%
3 - Serious	7%	5%	12%	12%
4 - Severe	3%	2%	3%	4%
5 - Critical	1%	1%	4%	2%
6 - Maximum	1%	1%	-	2%
Total (n)	100% (926)	100% (1016)	100% (140)	100% (113)

Table 5 – MAIS Distribution

HEAD REGION: Belted drivers had a strong improvement in the rate of AIS ≥ 2 head injuries, from 12% in the non-equipped group to 5% in the equipped, a 58% benefit. According to the chi-squared test this was a statistically significant improvement (χ^2=29.721, p=0.000). As shown in figure 1 the rate of AIS ≥ 2 head injury rate was higher in the airbag equipped group, increasing from 7% to 10%, for pole impacts. Although this was not a statistically significant increase (χ^2=0.297, p=0.586) it was very different to all other results for the head.

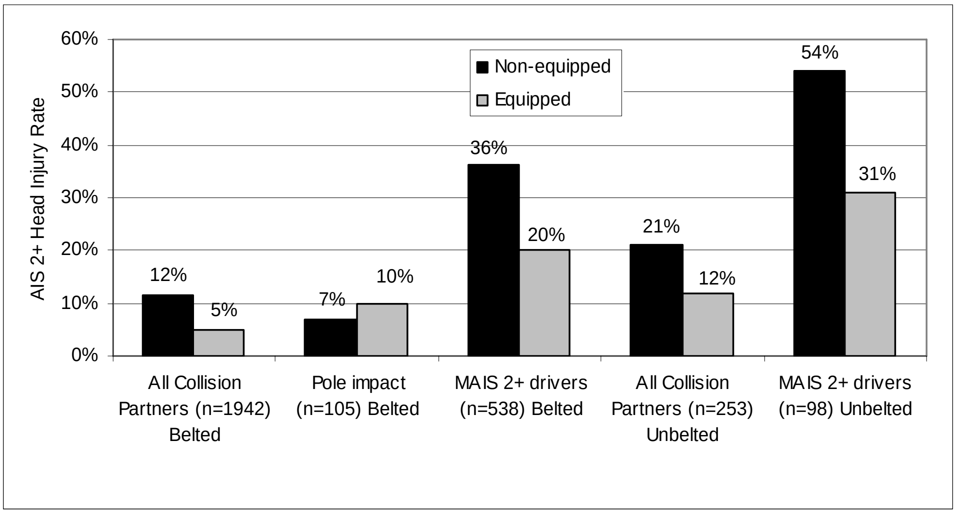

Figure 1 – Rates of AIS ≥ 2 Head Injury

Selecting drivers who had an overall MAIS ≥ 2 showed an improvement in the rate of AIS ≥ 2 head injury from 36% for non-equipped drivers to 20% for drivers equipped with an airbag (χ^2=17.234, p=0.000).

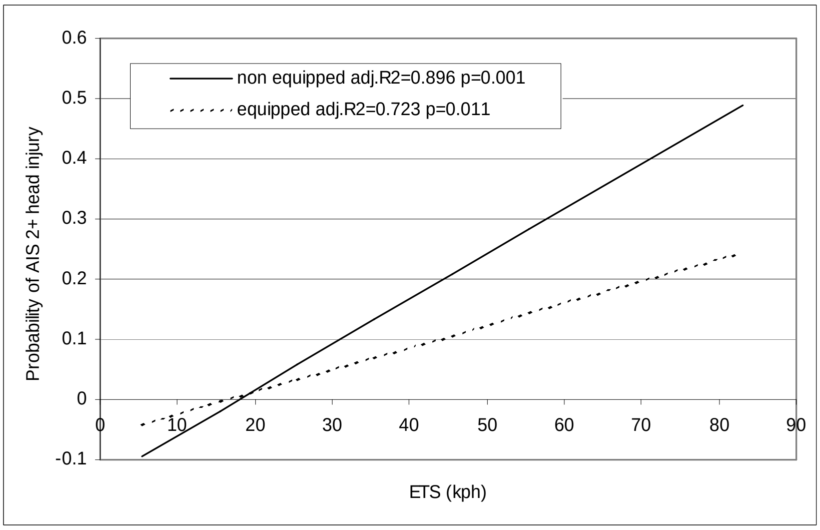

Figure 2 – Predictive Rates of AIS ≥ 2 Head Injury by Crash Severity for Belted Drivers

Putting the data into ETS bands it was possible to create linear regression models for the relationship between ETS and the rates of AIS ≥ 2 head injury to give predictive injury curves. The presented figure is for belted drivers. Both an obvious increase in injury risk for higher crash severity and the benefit for drivers in airbag equipped vehicles was evident.

A statistically significant improvement of 43% (χ^2=4.365, p=0.037) was found in the rate of AIS ≥ 2 head injury for unbelted drivers, figure 1. This is a smaller percentage benefit than for belted drivers and the same 12% injury rate for non-equipped belted drivers as for equipped unbelted drivers is notable (although crash parameters are not strictly comparable).
The improvement in AIS ≥ 2 head injury rate for unbelted MAIS ≥ 2 drivers was statistically significant (χ^2=4.986, p=0.026).

Direction of Impact: In the study increased rates of AIS ≥ 2 head injury were found for crashes with a 1 o'clock direction of impact, for belted drivers, along with a decrease in effectiveness compared to 12 o'clock impacts.

Direction of Impact	AIS ≥ 2 Head Injury Rate	
	Non equipped n=926	Equipped n=1016
10 o'clock	5%	0%
11 o'clock	9%	4%
12 o'clock	12%	5%
1 o'clock	15%	8%
2 o'clock	7%	0%

Table 6 – Rate of AIS ≥ 2 Head Injury by Direction of Impact

Driver Stature: Previous studies have identified an increased injury risk for short stature drivers as a consequence of interaction with a deploying airbag.

The data was split into 'short' and 'tall' groups, with the split at 1.73m (50%ile of the whole sample). For the 'short' group the rate of AIS ≥ 2 head injury was reduced from 12% to 6% in equipped vehicles (χ^2=6.254, p=0.012), and for the tall group the rate fell from 7.5% to 3.4% (χ^2=5.020, p=0.025).

Stature is correlated with gender and previous studies have found that generally female drivers sit closer to the steering wheel than male drivers (Parkin et al, 1993). This may increase the possibility of airbag interaction in the deployment phase and the risk of injury from the airbag. Selecting 'short' females (≤1650mm, the 50%ile of the crash data) there was an improvement in AIS ≥ 2 head injury rate, falling from 14% for non-equipped drivers to 6% for airbag equipped drivers and this was statistically valid, (χ^2=4.326, p=0.038). Further selection on 'short' females (≤1610mm, 50%ile Female, Bodyspace) found that there was an improvement in AIS ≥ 2 head injury rate (from 23.4% to 6.2%) and this was statistically valid although on the limit of cases required to run the test (χ^2=7.459, p=0.006).

Putting the data into height bands it was possible to create regression models for the relationship (in this case quadratic) between height and the rates of AIS ≥ 2 head injury to give predictive injury curves. The model for equipped vehicles was just outside significance (p=0.08) but in order to show trends it was thought that the model would be suitable. The presented figure is for belted drivers.

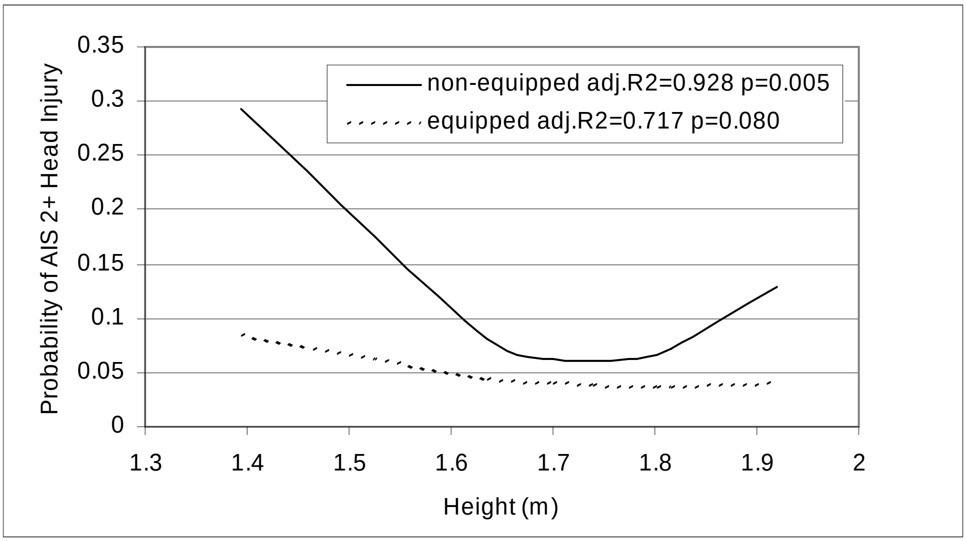

Figure 3 – Predictive Rate of AIS ≥ 2 Head Injury by Height for Belted Drivers

The trends of these models supported the results above, indicating a much-increased risk of injury in non-equipped vehicles towards shorter drivers, an increase mirrored in the equipped group but to a much lesser degree. An increase in injury risk was then apparent for taller drivers.

Limits of Airbag Effectiveness, AIS ≥ 2 Head Injury: During case review the question of 'what are the crash circumstances when AIS ≥ 2 head injury still occurs in airbag equipped vehicles', of which there are 49 drivers, was asked. A sub-sample of belted, equipped, drivers who received AIS ≥ 2 head injury was compared with the equipped sample who didn't receive a AIS ≥ 2 head injury.

Equipped n=967 AIS 0,1 Head Injury		Equipped n=49 AIS ≥ 2 Head Injury
28.4	Mean ETS	45.1
6%	Under-run	12%
35%	Car collision partner	67%
13%	1 o'clock Impacts	22%
1.74	Height (m)	1.72
76	Weight (kg)	76
68%	Gender Split (% male)	63%

Table 7 – Circumstances of AIS ≥ 2 Head Injury in Airbag Equipped Vehicles

It was found that the mean value of ETS was significantly higher (Mann-Whitney U=6743, p=0.000), more crashes involved under-run and more crashes involved interaction with heavier vehicles and narrow/poles, with only 35% of crashes to other cars compared to 67% for the AIS < 2 head injury group. Also more crashes had a direction of impact where the possibility of head injury was higher (1 o'clock). No large differences were found in the driver characteristics.

NECK INJURY: The neck was defined as including the cervical spine and cord, and the throat tissues. At the AIS ≥ 2 injury level there was no significant increase in the rate of neck injury for belted drivers in equipped vehicles compared to non-equipped drivers, the rate falls from 1.3% to 1.0% (χ^2=0.420, p=0.517). The same situation was evident when just selecting belted MAIS ≥ 2 drivers with the AIS ≥ 2 neck injury rate at 4.1% for both groups. For unbelted drivers there were no AIS ≥ 2 neck or cervical spine injuries.

<u>Neck Strain:</u> There was an observed, but not statistically significant (χ^2=1.861, p=0.173) increase in the rate of neck strain from 32% for non-equipped to 34% for equipped belted drivers. For unbelted drivers there was an improvement in the rate of neck strain from 27.9% to 17.7%, according to the chi-squared test for significance this is nearly a statistically significant difference (χ^2=3.608, p=0.057). Neck strain is an AIS 1 injury.

THORACIC INJURY: In the belted group an effectiveness of 29% was evident for the rate of AIS ≥ 2 thoracic injury. Although this shows a statistically significant (χ^2=7.038, p=0.008) benefit, the improvement is half that for head injury at the AIS ≥ 2 level (58% effectiveness) and in airbag equipped vehicles half as many drivers sustain AIS ≥ 2 head injuries (5%) as AIS ≥ 2 thoracic injuries (10%).

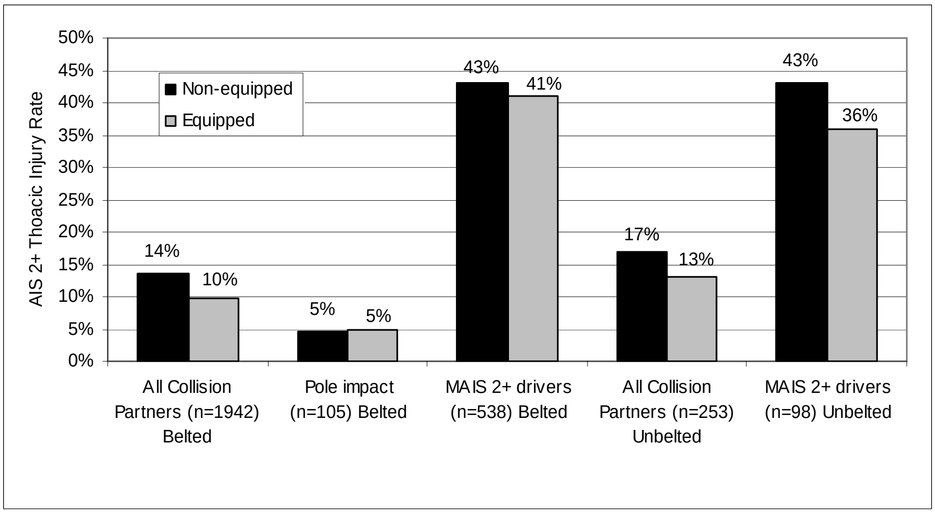

Figure 4 – Rates of AIS ≥ 2 Thoracic Injury

Controlling for driver MAIS or crash severity though revealed that the picture of improvements in AIS ≥ 2 thoracic injury rate was much less clear than for the head.
There was only a small observed improvement when selecting MAIS ≥ 2 drivers (figure 4), which was not statistically significant (χ^2, p=0.605), and this was mirrored in regression models formed against ETS (Figure 5).

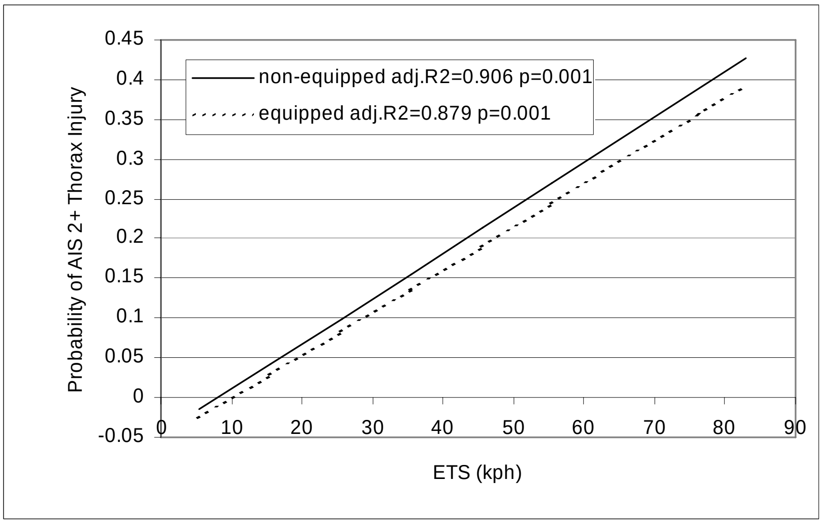

Figure 5 – Predictive Rate of AIS ≥ 2 Thoracic Injury by ETS for Belted Drivers

Figure 5 shows that whilst the injury risk was higher in non-equipped vehicles the difference is very small and compared to head injury the percentage benefit in injury reduction is not maintained at higher crash severity.

In the unbelted group (figure 4) an effectiveness of 22% was found for the rate of AIS ≥ 2 thoracic injury. This was not statistically valid (χ^2=0.718, p=0.397). As for belted drivers this improvement was half that for head injury at the AIS ≥ 2 level (46% effectiveness). Unlike the belted group the AIS ≥ 2 thoracic injury rate for equipped vehicles was comparable to the AIS ≥ 2 head injury rate of 11%. For MAIS ≥ 2 drivers (n=98) there was an observed but not statistically valid improvement in AIS ≥ 2 thoracic injury (χ^2=0.511, p=0.475).

BURNS, ABRASIONS AND CONTUSIONS: During case review, examples were found of burns, abrasions and contusions to the face and lower arm and hands, associated with airbag deployment, although serious head and chest injury was the focus of the review.

Statistically no increase was found in the rate of burns, abrasions or contusions to the face or neck for either belted or unbelted drivers in airbag equipped vehicles. For the lower arms and hands statistically significant increases were found in the rate of abrasions and burns, from 4.6% to 8.3% (χ^2=5.000, p=0.025) in equipped vehicles with belted drivers and for contusion injuries an increase from 7.6% to 12.5% (χ^2=6.159, p=0.013). These injuries were all AIS 1 on the database. For belted drivers there were no burns in the non-equipped sample and nine in the equipped sample (no fire occurred in any of these vehicles).

CASE REVIEW

The statistical analysis provided an overall estimate of changes in head and thoracic injury rates but it is possible for this to conceal instances where certain injury types have an increased risk. Individual case review was used to identify any such cases.

METHODOLOGY: Each case with airbag deployment and AIS ≥ 2 head/face or thoracic injuries was individually assessed to determine any causal relationship between the injuries and deploying airbag. This involved the review of some 220 CCIS cases. Cases were excluded if it was thought that intrusion was very high, a significant degree of under-run had occurred, the injury was from the seatbelt (many AIS 2 sternum and clavicle fractures were found) or injury was from heavy loading of the steering wheel. However in reality the first question to be asked was ‘do these injuries make sense looking at the circumstances of the crash and the characteristics of the occupants?’

A workshop was convened, where key cases were examined by a group of experts from the UK, France and Germany, in order to further qualify injury mechanisms.

Of all the cases reviewed five cases were found that associated serious (AIS ≥ 3) head or neck injury with airbag bag deployment. After workshop discussion it was felt that the fatal injuries in two cases could be directly associated with deployment of the drivers airbag with a high degree of certainty.

HEAD AND NECK INJURY CASE REVIEW

Case 1: This case provided a unique comparison in that it involved the same model of vehicle in a fully distributed frontal impact with female drivers of similar age, although vehicle 1 did roll after the initial impact. The driver of vehicle 1 was a 25 year old female, 1.60 m tall, wearing a seat belt that was pretensioned (MAIS 6, ISS 75). The driver of vehicle 2 was a 26 year old female, height and weight unknown, wearing a seat belt that was pretensioned (MAIS 3, ISS 10).

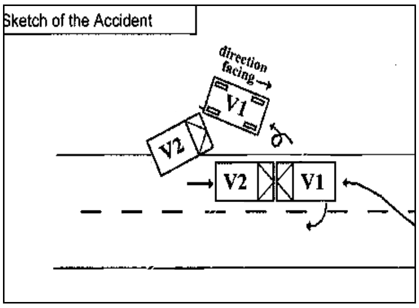

Figure 6 – Accident Sketch


Figure 7 – Both Vehicles (Vehicle 1 Left)


Figure 8 – Vehicle 1, Drivers Area

Vehicle 1	Vehicle 2
Full Frontal head on impact 100% direct damage with 0.50 rollover to nearside onto roof after impact CDC: 12FDEW5 Delta V = 89km/h ETS = 59 km/h Registration V 1999 Maximum crush 117 cm @ 49 cm height Rollover CDC: 00TPDO1	Full Frontal head on impact 100% direct damage CDC: 12FDEW5 Delta V = 82 km/h ETS 75 km/h Registration V 1999 Maximum crush 90 cm @ 48 cm height

Table 8– Vehicle details

The driver of vehicle 1 sustained a small amount of traumatic subdural and subarachnoid haemorrhage over the cerebral hemispheres (AIS 3 and 4), complete transection of cord at level of odontoid peg which also completely transected, with separation of atlas & axis and separation of skull away from cervical vertebral column (AIS 6) and tearing to oesophagus in its mid to lower section with haemorrhage into peri-oesophageal fat (AIS 3) also occurred. There was a large amount of haemorrhage into the soft tissues and muscles of the neck. Bruising and lacerations to the chin and lip area (all AIS 1) indicated likely contact with the airbag. Thoracic injuries were received from the belt webbing, generally bruising but also fracture of left 6th - 8th ribs in lateral position (AIS 2) and contusional damage to both lungs (AIS 4).

Both drivers sustained a fracture of the right femoral supracondyle (AIS 3). The only head, neck or thoracic injury that the driver of vehicle 2 received was a bruise to the right of the chin (AIS 1).

Case 2: The vehicle (1) lost control on a left hand bend, crossed the carriageway and was struck at the nearside rear (10LZAW4, maximum crush 33cm) by another car. The delta v was calculated as 27 kph. The male driver was 37 years old (height 1.85 m, weight 90 kg) wearing a seat belt which was not pretensioned.

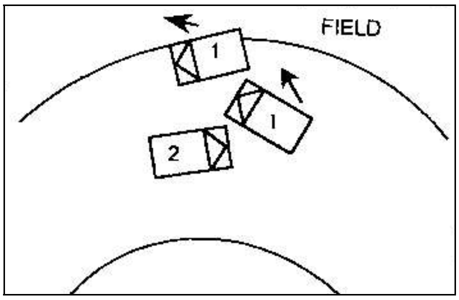

Figure 9 – Accident Sketch


Figure 10 – Area of Impact

The driver sustained AIS 1 contusions over both hands, the chest and left shin (indicating a good level of post mortem detail). The fatal head injury was described as, complicated fracture at base of skull forming ring fracture passing through basilar part of sphenoid bone, the petrous temple bones on both sides and the squamous parts of the occipital bones (AIS 4). The brain was mildly diffusely swollen with severe haemorrhagic contusions around base of brain and the lower brain stem (AIS 3 and 5 injuries).

Base of Skull Fracture: In April 1999 a coroners court in the UK submitted the verdict that a female died from airbag related injuries due to close proximity to the airbag at the time of deployment. The fatal injury was a ring fracture of the base of the skull. This was geographically not a CCIS case but received a large amount of media coverage (The Times, 1999). A blow to the stronger mandible bone, occipital bone at the rear, or even the facial bones can cause transmitted forces that fracture the relatively fragile bony structure of the base of the skull. Such a blow may be caused if the head is in close proximity to the airbag and meets it as it is rapidly deploying. It is noteworthy that this kind of injury would not be identified in crash tests using current test dummies.

During case review four base of skull fractures were identified as a possible airbag injury (including case 2) although during the workshop it was felt that it was difficult to be confident that the airbag was associated with deployment in three of the cases.

For belted drivers the rate of base of skull fractures decreased from 1.4% (13) in non-equipped vehicles to 0.6% (6) in airbag equipped vehicles, this difference being just outside statistical significance (χ^2=3.308, p=0.069).

THORACIC INJURY CASE REVIEW: During the work it was felt that it was very difficult to separate seat belt loading, steering wheel interaction and airbag deployment when considering thoracic injuries that may have been caused by airbag deployment. This was evident in some of the cases brought to the workshop, where certain injuries had been coded to the seatbelt, airbag and intrusion.

Two cases have been identified that illustrate the effect of the chest being in very close proximity to, if not resting against, the steering wheel at the time of airbag deployment.

Case 3: This case involved the unbelted driver of an airbag equipped vehicle who, due to dazzling sunlight, mounted a central reservation and collided with a bollard. The area of impact was to the centre of the vehicle front, (CDC :12FZEN1) and an ETS of 26 kph has been calculated. It is thought that the mounting of the kerb caused an initial forward movement of the driver and then a relatively slow crash pulse will have increased this forward movement. Evidence of this forward movement is a head strike to the windscreen (abrasion over scalp). It is surmised that at the time of deployment the drivers chest was directly over the airbag module and deployment caused fatal chest injuries. The main injuries to the 48 year old male driver were complete transection of the thoracic aorta (AIS 6) and multiple fractures of the ribs, right 2-7, left 2-6 (AIS 4).

Figure 11 – Frontal Impact Case 3

Figure 12 – Head Strike to Windscreen Case 3

Case 4: This case involved a 64 year old male who suffered a heart attack before his vehicle hit a bollard. The driver was unbelted and at the time of airbag deployment the driver's chest was slumped against or very close to the steering wheel. There was evidence of a headstrike to the windscreen. As in case 3 the driver sustained severe bilateral rib fractures, 1-6, (with plural blood effusions) (AIS 5) and severe damage to the heart, tearing to both the left atrium and aorta (AIS 5). The impact to the bollard was not severe and only involved interaction to the wheel and superficial wing damage. In comparison the 65 year old female passenger in the same impact received only AIS 1 lacerations and contusions to the face. It is impossible to say whether the death of the driver was due to a heart attack or the crash injuries, but the thoracic injuries would have been fatal anyway.

Figure 13 – Impact to Bollard

Figure 14 – Drivers Area Case 4

DISSCUSSION

HEAD AND NECK INJURY: Statistical analyses of a large European data has demonstrated the significant head injury reduction effect of airbags in frontal crashes, for both belted and unbelted drivers. Regression models have shown that protection is afforded towards higher crash severity (ETS) and across the range of driver height. In the models for both non-equipped and equipped samples the rate of injury is higher for shorter drivers and then starts to increase again for taller drivers, possibly indicating the optimisation of restraint performance for drivers at or around 1.7m in stature. There is no indication that the drivers' airbag is causing an overall greater head injury risk to shorter drivers. The injury risk is increased but not to the same extent as for shorter drivers in non-equipped vehicles.

For belted drivers improvements in the rates of AIS ≥ 2 head injury in airbag equipped vehicles were evident across a range of different driver heights. There was no indication from the analysis that airbags were increasing the severity of head injuries to shorter drivers. In fact airbags would appear to be most beneficial for smaller drivers, compared to smaller drivers in non-equipped vehicles. Generally the impression is that there is no large increased risk of AIS ≥ 2 head injury for 'shorter' drivers in airbag equipped vehicles and in fact, in this data, short non-equipped drivers have such a high risk that the percentage benefit of airbags for short drivers is very high.

Limitations of Protection: A lack of improvement in AIS ≥ 2 head injury rate for pole impacts was noted. The rate of deployment for pole impacts was lower at 64% than for any other collision partner, especially other cars at 80%, which may indicate that airbag systems may have a degree of difficulty in sensing impacts to narrow objects, especially if interaction with the stiff structures is not immediate. Also in these circumstances the crash pulse may begin with a low level of deceleration where the driver may move forward more than usual before airbag triggering takes place. This may increase interaction with a still deploying airbag or increase the possibility of travelling through the airbag and loading the steering wheel. Case 3 involved an impact to a bollard with no interaction with the longitudinals of the vehicle, which is likely to have increased driver forward excursion before triggering. In the study increased rates of AIS ≥ 2 head injury were also found for crashes with a 1 o'clock direction of impact, for belted drivers, indicating a continuing need for further A-pillar protection and that airbag protection for these impacts may be more limited.

The crash conditions under which AIS ≥ 2 head injury still occurs in airbag equipped vehicles show that on average the crash conditions are more severe, with higher ETS, more under-run crashes, more oblique impacts and more collisions with heavier vehicles and narrow objects. This indicates that there are reasons for increased head injury risk and starts to explore the limits of airbag protection, having implications for crash test specifications.

Case Review: Case reviews revealed individual cases with airbag induced injuries to the head and neck. In case 1 it is suggested that the severe head and neck injuries were a result of the chin meeting the airbag as it was still deploying, either due to late deployment of the airbag or close proximity of the head. Bruising and lacerations to the chin and lip area indicate contact with the airbag. Overall this was a very high energy head and neck injury and very severe compared to the bruised chin of the other driver. In case 2 the driver was in a vehicle registered in 1994 and it was considered that this was an early airbag system with a sensing system that may have deployed the airbag quite late in the crash sequence. It was surmised that the driver's head had moved into the airbag deployment zone during deployment causing the severe fracture and brain injury.

Due to the injury mechanism of a strong blow to the front of the head, base of skull fractures have been identified as an injury that may be caused by the head being in close proximity to the airbag and meets it as it is rapidly deploying. In the UK a case of this injury was reported in a coroners court and during case review four base of skull fractures were identified as a possible airbag injury (including case 2) although during the workshop it was felt that it was difficult to be confident that the airbag was associated with deployment in three of the cases. For belted drivers in frontal collisions the rate of base of skull fractures decreased in airbag equipped vehicles.

During case review it was felt that to investigate airbag induced injury the level of medical information has to be high and in some cases solid conclusions could not be made. Certainly a good degree of confidence is needed in the medical data on head contacts as this can associate head injury to hard contact within the vehicle (for instance contact with the B pillar) or with the airbag. The CCIS data does not give any data on faulty performance of restraint systems and any affect this may have on injury outcome. It is hoped that in the future interrogation of the vehicles' restraint systems' electronics modules will be possible and these will indicate faulty performance, an element that could be taken into account during case review.

Neck Injury: Previous studies (Otte, 1995, Morris et al, 1996) have concluded that cervical spine strain injury rates do not benefit from airbag deployment. Insurance data studies by Langweider et al (1997), have suggested that, in severe crashes airbags are beneficial, reducing serious and critical injuries to the head and trunk of drivers. In this study no significant increase in the rate of AIS ≥ 2 neck injury was found for belted drivers and the rate of neck strain increased by a small, but not significant amount. The nearly significant improvement for unbelted drivers for neck strain was notable.

THORACIC INJURY: The benefit in AIS ≥ 2 thoracic injury rate was less clear than for the head. Whilst a benefit was found for the belted sample overall, controlling for ETS or overall driver severity gave small improvements that were not significant (unlike head injury).

During case review case 3 and 4 showed very clearly the effect of airbag deployment with the chest in very close proximity to the steering wheel and the possibility of injury. In both cases the drivers sustained multiple fractures of the ribs on both sides and critical injuries to the aorta. Airbag loading tests using both Hybrid III and anaesthetised swine were conducted by Horsch at al (1990). The airbag module was placed opposite the sternum and severe to critical injuries were seen in all the tests. These injuries included heart contusions and perforations, similar critical injuries to those seen in cases 3 and 4. Other than these cases though it was found to be difficult in case review to give any degree of confidence to thoracic injuries with heavy seat belt loading and damage to the steering wheel. In fact during the study as a whole it was evident that in many cases driver loading of the steering wheel was still taking place even though airbag deployment had occurred.

SEATBELT USE: Whilst any direct comparison between the belted and unbelted groups should be take into consideration the differences in distribution of crash types and driver characteristics the advantages of belt use are made clear in this work. There is a benefit to unbelted drivers associated with airbag fitment, but only that the protection they are afforded is the same as that for belted drivers without an airbag, under the crash conditions investigated here. Case review has identified cases where the lack of seat belt use has allowed drivers to move forward into the deployment zone of the airbag. A study in the US of airbag effectiveness presented results on unbelted drivers (Crandall et al, 1994) and found a higher possibility of receiving a brain (AIS ≥ 2) or facial injury if restrained only by an airbag.

The two drivers in case 3 and 4 were not using the seat belt. In case 3, with a relatively small impact, it was concluded that it was the lack of seat belt restraint that led the driver to move forward into the deployment zone and receive fatal injuries. In case 4, if the seat belt had been worn, the driver may not have been able to slump over the wheel if the belt had tightened due to the forward movement of the driver.

ABRASIONS, BURNS AND CONTUSIONS: Significant increases in the rates of abrasions and burns, and contusions, to the hands and arms were seen for belted drivers in airbag equipped vehicles. Sodium azide burns extremely rapidly to provide the nitrogen gas that inflates the airbag, so it is not surprising that as the hot gases vent from the airbag burns can be caused. Also as the airbag material comes into contact with the skin the movement across the surface can cause abrasion, whilst as the airbag strikes the skin contusion may be caused. These were all AIS 1 injuries so should be balanced with the benefit of airbags to AIS ≥ 2 head injury.

LIMITATIONS OF THE STUDY: The types of crash that each sample, non-equipped and equipped, experience were shown to be similar for direction of impact, object struck and crash severity (ETS), within the belted and unbelted groups. Any differences in crash parameters didn't undermine the validity of the results. Concerning vehicle parameters the increase in mass for equipped vehicles was a large difference and these increases were likely to have been beneficial to occupant protection (Thomas et al, 1999). A lower proportion of belted female drivers were found in the equipped sample and this may benefit injury reduction in the equipped sample. Female front seat occupants have been found to be more venerable to skeletal chest, and soft tissue neck injury in the CCIS (Lenard et al. 2001). As more vehicles in the fleet are airbag equipped and driven by females any benefits seen here for chest or neck injury may be reduced.

CONCLUSIONS

- The MAIS ≥ 2 rate was reduced from 32% to 24% for belted drivers in airbag equipped vehicles in frontal crashes. For unbelted drivers this improvement was smaller, from 40% to 37%.
- There was a strong improvement in the severity of head injuries for both belted and unbelted drivers. The effectiveness for belted drivers at the AIS ≥ 2 level was 58% and unbelted drivers 43%.
- Extensive case review has revealed that airbags can cause serious head, neck and chest injuries but these cases are not common.
- Controlling for ETS and overall driver injury severity no significant benefit was apparent for thoracic injury.
- Airbags are more effective in preventing injury when worn in conjunction with the seatbelt, even though benefit for head severity is evident. Cases have been reviewed where lack of seatbelt use has allowed forward excursion into the airbag deployment zone.
- No significant difference was found in the rate of neck strain between non-equipped and airbag equipped belted drivers.
- For belted drivers there was a significant increase in the rate of burn and abrasion injuries to the arms or hands in equipped vehicles, although on the database these are all minor, AIS 1, injuries.
- There are situations in which frontal airbags are less effective for head injury reduction, such as 1 o'clock impacts and pole impacts.

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Further information on CCIS can be found at http://www.ukccis.com/

REFERENCES

Association for the Advancement of Automotive Medicine. The Abbreviated Injury Scale 1990 Revision, 1990

Crandall, J. R., Kuhlman, T. P., Martin, P. G., et al. Differing Patterns of Head and Facial Injury with Airbag and/or Belt Restrained Drivers in Frontal Collisions- Advances in Occupant Restraint Technologies, Joint Procs AAAM/IRCOBI Conf, Lyon, 1994

Frampton, R. J., Sferco, R, Welsh, R, et al. Effectiveness of Airbag Restraints in Frontal Crashes- What European Field Studies Tell Us. Procedures. IRCOBI conference on the Biomechanics of Impact, Montpellier, France, 2000, pp 425-438.

Hassan, A.M., Hill, J.R., Parkin, S., Mackay, G.M. Secondary Safety Developments: Some Applications of Field Data. Autotech 1995, Birmingham, U.K. London: IMechE, 1995.

Horsch J, Lau I, Andrzejak D, Melvin J, Pearson J, Cok D, Miller G. Assessment of air bag deployment loads. Proc 34th Stapp Car Crash Conference. SAE 902324, pp 267-288, 1990.

Langweider, K., Hummel, T. H., Mueller, C. H. R. Performance of Front Airbags in Collisions: Safety and Problem Areas - Experience from Accident Research. Procs VDI Conf on Innovative Occupant Protection and Vehicle Compatibility, Berlin, Germany, 1997

Lenard, J., Frampton, R. J., Thomas, P. The Influence of European Airbags on Crash Injury Outcomes. Procs 16th ESV Conf, Windsor, Canada, 1998.

Lenard, J., Welsh, R. A Comparison of Injury Risk and Pattern of Injury for Male and Female Occupants of Modern European Passenger Cars. Procedures. IRCOBI conference on the Biomechanics of Impact, Isle of Man, United Kingdom, pp 15-26, 2001.

Mackay, G. M., Galer. M. D., Ashton, S. J., et al. The Methodology of In-depth Studies of Car Crashes in Britain. SAE Technical Paper Number 850556, Society of Automotive Engineers, Warrendale, PA, 1985

Morris, A. P., Thomas, P., Brett, M. A Review of Driver Airbag Performance in Europe and Japan to date. Procs 15th ESV Conf, Melbourne, 1996

Otte, D. Review Of Airbag Effectiveness in Real Life Accidents – Demands for Positioning and Optimal Deployment of Airbag Systems. Procs 39th Stapp Conference, Coronada, 1995

Parkin, S., Mackay, G.M. & Cooper, A. How Drivers Sit in cars. Procs 39th AAAM Conference pp 375-388, 1993.

Pheasant, S., Bodyspace, Taylor & Francis, 1986.

Thomas, P. & Frampton, R. J. Large and Small Cars in Real-World Crashes – Patterns of Use, Collison Types and Injury Outcomes. Procs 43rd AAAM Conference pp 101-118, 1993.

The Times, Liverpool Echo and Guardian newspapers, UK, 15th April, 1999.