EFFECTIVENESS OF AIRBAG RESTRAINTS IN FRONTAL CRASHES – WHAT EUROPEAN FIELD STUDIES TELL US

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ABSTRACT

UK and German field accident data show that European airbag systems provide a 32% and 55% reduction in AIS 2+ injury to the cranium and face when belted drivers sustain MAIS 2+ injury in frontal crashes. The greatest benefits of airbags were seen in crashes exceeding 30 km/h delta v. Airbags do not appear to affect a reduction in chest injuries and they exert a neutral influence on the incidence of cervical spine strain. Drivers in airbag vehicles sustained proportionately more AIS 2+ upper limb injuries than those in vehicles without airbags. That difference was largely the result of a higher proportion of clavicle fractures. Overall, deployment thresholds correlate well to the onset of moderate/serious head injury but there appear to be some unnecessary deployments at low crash severities.

Keywords: Accident Analysis, Airbags, Epidemiology, Frontal Impacts, Injury Probability.

EXTENSIVE STUDIES OF AIRBAG EFFECTIVENESS in the US have shown effectiveness in reducing fatality by 31% in frontal crashes (NHTSA, 1996). Studies have also examined effectiveness related specifically to airbag and belt combinations, belt only and airbag only. They show that drivers have a higher probability of receiving an AIS 2+ brain injury or a facial injury if they are restrained by only an airbag compared with only a seat belt (Crandall et al, 1994). Concerning overall injury reduction, for serious injury, the combined airbag plus lap-shoulder belt provides a 60% reduction in injury risk, automatic belts alone a 37% effectiveness and the airbag alone a 7% effectiveness (NHTSA, 1996).

Traditionally, the US has concentrated on airbag systems which protect belted as well as unbelted occupants, resulting in the need for large, high powered airbags which, in rare instances have caused injury, especially to small drivers, children and out of position occupants (Phen et al, 1998, Winston and Reed, 1996, NHTSA, 1996). The development of airbag systems to meet new criteria for FMVSS 208 frontal crash protection will encourage the development of smaller capacity, less aggressive airbag systems which will be more closely aligned to those used in Europe.

European airbags, optimised to protect the belted occupant, are generally less powerful and deployed at higher crash severity thresholds but few in-depth accident studies have been conducted to assess the effectiveness of these systems. Current findings, based on small data samples show, that injured drivers with deployed airbags, incur proportionally fewer head injuries and proportionally more arm injuries than those drivers from non-airbag vehicles (Lenard et al, 1998). Both a German study (Otte, 1995) and a combined European / Japanese investigation (Morris et al, 1996) 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.

Real World crash injury data provides invaluable information on the crash performance of new vehicle designs as well as providing a focus for future priorities in occupant protection. However, when major changes in design occur, data is initially sparse, so it is important to continually monitor the field situation as more data becomes available. This current study utilises the most up to date and largest in-depth crash injury data in Europe to assess the benefits of airbags for belted occupants. The benefits of this large dataset offer the opportunity to verify or refute previously reported trends with a greater degree of confidence, and to carry out additional work previously hampered by the numbers of available data.

METHODOLOGY

This European study is based on in-depth crash injury data from the UK Co-operative Crash Injury Study (CCIS) and the Medical University of Hannover (MHH). CCIS data was available from calendar years 1992-2000 and MHH data from 1996-99. The result is one of the largest, currently available European sources of in-depth crash injury information with airbag equipped vehicles. Both studies select cases for investigation using a random sampling procedure based on injury severity and in both studies there are many common variables. For a comprehensive description of CCIS, the reader is referred to Mackay et al, 1985 and for MHH to Otte, 1994. For the purposes of this study front seat occupants in passenger cars involved in a frontal crash were selected. For CCIS, a frontal crash was selected if it was considered to be the most severe impact to a vehicle in terms of injury outcome. For MHH, a frontal crash was selected if it was the most severe impact in terms of vehicle delta v.

Injury outcome was assessed in both studies using the Abbreviated Injury Scale (AAAM, 1990). When skull is referred to in the text, it is taken to mean the whole skeletal structure of the head, including the cranial bones and those of the face.

Two measures of crash severity have been used. Delta v and the Equivalent test Speed (ETS). ETS is the vehicle delta v, calculated on the assumption that deformation was caused by impact with a rigid barrier. The calculation assumes the force was directed through the centre of the crush area. It does not assume the vehicle was brought to rest. ETS is different to the Equivalent Energy Speed (EES) used in other in-depth studies because the EES calculation assumes the force to be through the vehicle centre of mass and that the vehicle was brought to rest. ETS is therefore always less than or equal to EES. There are a number of factors which affect the accuracy of ETS so it is best used to place crashes into groups of similar severity rather than to compare individual crashes.

Where results have been statistically tested, the test level has been set at $p=0.05$ for acceptance or rejection of statistical significance.

In the preceding analyses, sample sizes vary from the original data selection due to availability of valid information for certain variables.

RESULTS

Study Data: Table 1 shows the number of occupants in the study by airbag fitment and deployment. It should be noted that the airbags represented here are a mixture of European and US systems, although the majority are European and the majority of the occupants were proven to be belted (73% in CCIS and 81% in MHH).

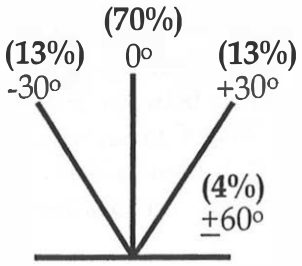
Table 1: Occupant Seat Position and Airbag Status – Frontal Crashes – CCIS/MHH Data

	MHH			CCIS		
	Total	Driver	Pass.	Total	Driver	Pass.
Deployed	158	132	26	542	512	30
Not Deployed	248	212	36	212	200	12
Not Fitted	1334	1075	259	4461	3215	1246
Total	1740	1419	321	5215	3927	1288

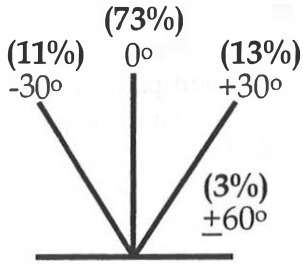
CRASH INPUT PARAMETERS: The introduction of airbags into European cars generally coincided with changes to other vehicle restraint systems and to vehicle front structures. In this study, only the effectiveness of the airbag was considered. No attempt was made to evaluate other changes in vehicle design. Therefore, injury outcomes in cars without airbags were compared to those where an airbag was fitted. It was considered essential to initially verify that comparisons were not being undertaken between groups of occupants with different types of frontal crash. Figure 1 shows the primary impact angle for belted drivers with no airbag fitted and for those in airbag equipped cars.

The distribution of impact angles between no airbag fitted and airbag equipped cases was comparable in CCIS for injury severities of MAIS 0-6. This was also the case for MHH data. In both datasets, the majority of impacts were head-on, or 0°. This is the condition where the occupant's kinematics are more likely to produce a stable head contact on the airbag. In CCIS, very oblique impacts of ± 60 ° were rare but impact angles of ± 30 ° accounted for about a quarter of crashes, which may influence the nature of head to airbag interaction.

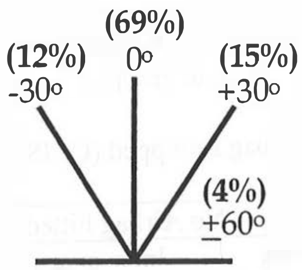
Very oblique impacts of ± 60 ° were more common in the German dataset compared to the UK. Considering injury severities of MAIS 2+, the distribution of impact angles for the airbag/no airbag groups in CCIS were still comparable.



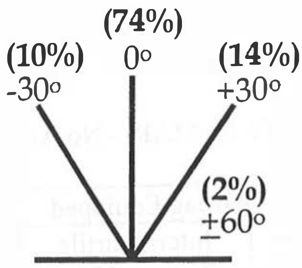
No Airbag Fitted N=2335 (CCIS, MAIS 0-6)



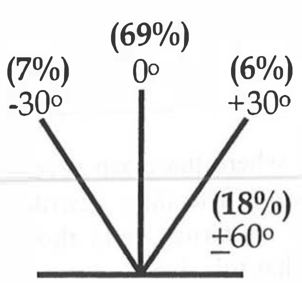
Airbag Equipped N=550 (CCIS, MAIS 0-6)



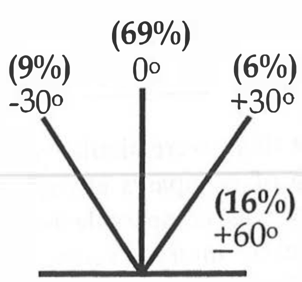
No Airbag Fitted N=693 (CCIS, MAIS 2+)



Airbag Equipped N=129 (CCIS, MAIS 2+)



No Airbag Fitted N=868 (MHH, MAIS 0-6)



Airbag Equipped N=284 (MHH, MAIS 0-6)

Figure 1: Direction of Impact

Table 2 compares the nature of the struck object for belted drivers with no airbag fitted and for those in airbag equipped cars.

Table 2: Struck Object – No Airbag Fitted and Airbag Equipped (CCIS)

	Airbag Status			
OBJECT STRUCK	None Fitted MAIS 0-6	Equipped MAIS 0-6	None Fitted MAIS 2+	Equipped MAIS 2+
Car	65%	64%	63%	55%
M/cycle	1%	1%	0%	0%
Light Goods Vehicle	6%	5%	7%	9%
Heavy Goods Vehicle	10%	11%	16%	21%
Pole/Tree	7%	7%	6%	5%
Wide Object	8%	10%	7%	9%
Pedestrian	1%	0%	0%	0%
Not Known	2%	2%	1%	1%
Total N	2335 (100%)	550 (100%)	693 (100%)	129 (100%)

The distribution of struck objects was comparable between the two groups of drivers. Car to car impacts predominated. Impacts which pose particular challenges for airbag deployments are those into narrow objects like trees and poles because the contact can be between or outside of the rigid front structures of the vehicle. Those impacts accounted for 7% of impacts for both groups of occupants with MAIS 0-6. For more seriously injured drivers without airbags (MAIS 2+), 6% experienced impact to a narrow object, the corresponding proportion was 5% for drivers in airbag equipped cars.

Crash severity in the CCIS is estimated by calculating a delta v or an Equivalent Test Speed (ETS). Because of the number of parameters necessary to calculate delta v from vehicle crush measures, ETS is more commonly calculated. In table 3, ETS distributions are compared for belted drivers with no airbag fitted and for those in airbag equipped cars. The assumption has been made that systematic over or under estimations of ETS will be the same for both groups of cases.

Table 3: ETS by MAIS - No Airbag Fitted and Airbag Equipped (CCIS)

	Airbag Equipped			No Airbag Fitted		
	Median ETS (km/h)	Inter-quartile Range of ETS (km/h)	N	Median ETS (km/h)	Inter-quartile Range of ETS (km/h)	N
MAIS 0-6	26	20-37	382	29	22-38	1591
MAIS 1+	27	20-38	337	30	23-39	1340
MAIS 2+	38	29-49	94	38	29-52	496
MAIS 3+	48	38-59	33	49	37-64	168

It should be noted that there were similar proportions of cases where the crash severity was not calculated for each group of occupants at each injury severity level. The inter-quartile range and median for crash severity was comparable between drivers with no airbags and those in airbag equipped cars, at each level of injury severity. It should be noted that this does not imply negligible improvements in crash safety, because CCIS accident sampling is biased toward serious injury and most cases with uninjured occupants are not sampled.

Generally, the CCIS data showed that belted drivers in airbag vehicles had experienced similar frontal crashes to those with no airbags fitted. Angle of impact, struck objects and crash severities were also similar between the groups when drivers with MAIS 2+ injuries were considered.

Belted Driver Injury Patterns - No Airbag Fitted and Airbag Equipped: Maximum injury severity, as described by the MAIS was compared between belted drivers with no airbag fitted and for those in airbag equipped cars. The distributions are shown in table 4.

Table 4: MAIS Distributions – No Airbag Fitted and Airbag Equipped (CCIS)

MAIS	No Airbag Fitted	Airbag Equipped
0	17%	15%
1	54%	61%
2	18%	15%
3	6%	4%
4	2%	2%
5	2%	2%
6	1%	1%
Total N	2335 (100%)	550 (100%)

There was a higher proportion of drivers injured to MAIS 2 and above in non-airbag cars (29% compared to 24% in airbag equipped vehicles). This difference was statistically verified (p=0.02). The key issue to explore is whether airbags do in fact alter the pattern of driver injuries. Figure 2 shows which body regions were injured when belted drivers only sustained slight injuries (MAIS 1) with and without airbags. Figure 3 shows which injured body regions contributed to a MAIS of 2+.

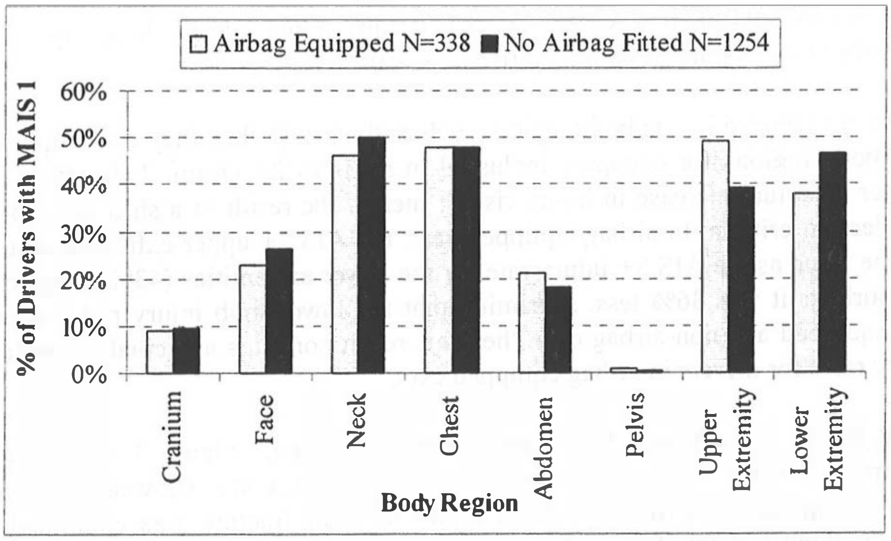


Figure 2: AIS 1 Body Region Injury Rates for Belted Drivers with MAIS 1 (CCIS)

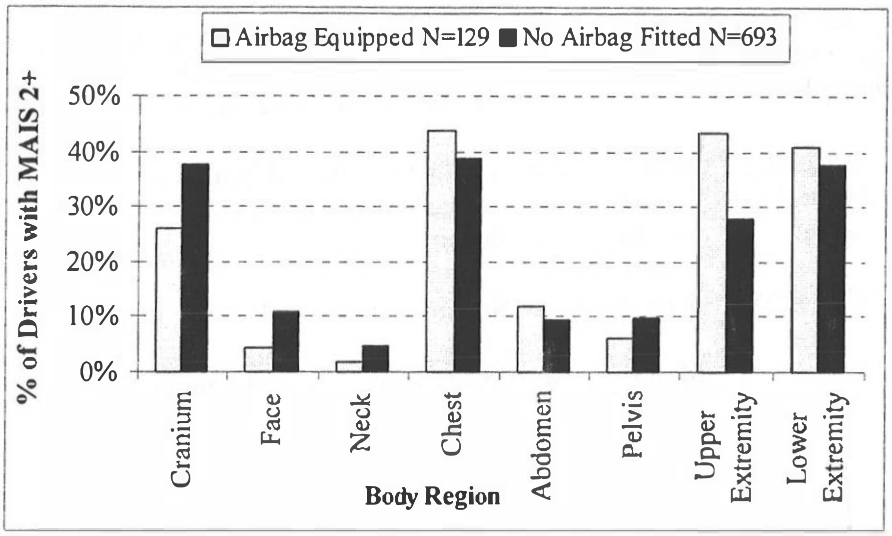


Figure 3: AIS 2+ Body Region Injury Rates for Belted Drivers with MAIS 2+ (CCIS)

Figure 2 shows very little difference in rates of AIS 1 injury across body regions except for the upper extremities where the relative rate was 26% greater in airbag equipped vehicles. When drivers were injured to MAIS 2 and above however (Figure 3), there was a more marked difference in the pattern of injured body regions with and without airbags.

The AIS 2+ cranium injury rate airbag vehicles was 32% lower relative to the rate without airbags. That difference was statistically significant ($p<0.05$). Similarly, the relative rate of AIS 2+ face injury was 55% lower in airbag vehicles. Again, statistically significant ($p<0.05$). Chest injury rates were not significantly different between airbag equipped and non-airbag cars ($p>0.05$) neither were lower extremity injury rates ($p>0.05$). The AIS 2+ upper extremity injury rate in airbag equipped cars was 54% higher relative to the condition without airbags ($p<0.05$).

When injuries are reduced in one body region (such as the head), then they could appear relatively higher in other body regions for occupant inclusion in a MAIS 2+ group. This effect needs to be qualified as either an actual increase in injury risk or merely the result of a shift in emphasis due to the MAIS 2+ selection criteria. In airbag equipped cars, the AIS 2+ upper extremity injury rate was almost exactly the same as the AIS 2+ injury rate for the lower extremities (43% compared to 41%). In cars without airbags it was 36% less. Assuming that the lower limb injury risk was comparable between airbag equipped and non-airbag cars, then this result confirms an actual increase in AIS 2+ upper limb injury rates for drivers in airbag equipped cars.

<u>AIS 2+ Head Injury - No Airbag Fitted and Airbag Deployed:</u> Figure 3 showed that airbags reduce the occurrence of AIS 2+ head injuries. However, the figure also showed that they have not been completely eliminated. The ratio of brain injury to skull fracture was examined for belted drivers with and without airbags. Figure 4 shows the result. Proportions are calculated from total numbers of belted drivers with brain injury only, or skull fracture only or both brain injury and skull fracture.

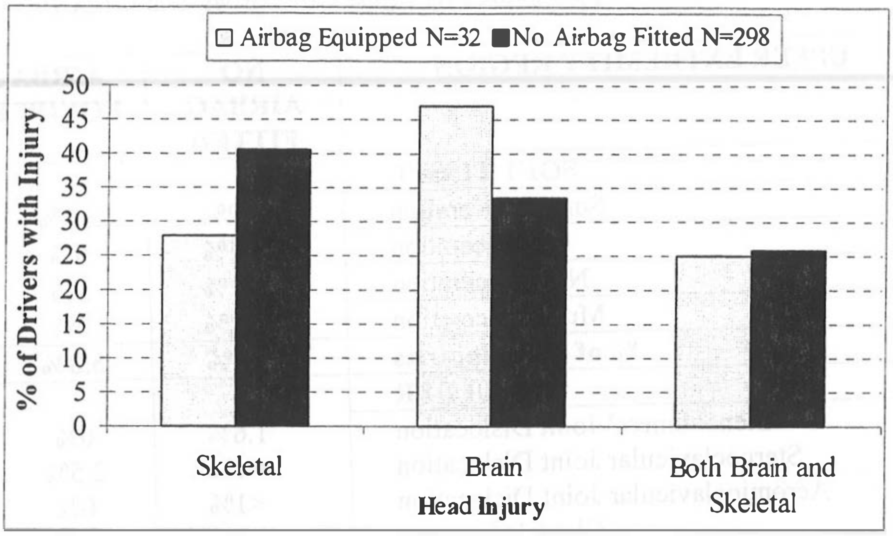


Figure 4: Proportions of Belted Drivers with Skull Fractures and Internal Head Injury (CCIS)

When serious head injury occurred in airbag cars, there was a trend toward a higher proportion of only brain injury than only skull fracture compared to the situation without an airbag. The difference in proportions was tested using the Chi-square test for significance. Although the difference is not statistically significant ($p>0.05$) care should be exercised in interpreting this result due to the small number of drivers in the airbag equipped sample.

Upper Extremity Fractures: The kinds of AIS 2+ upper extremity injuries sustained by belted drivers is shown in table 5. It can be seen that most of those injuries were fractures (92% in non-airbag vehicles and 91% in airbag equipped cars). The shoulder and forearm were the most common injury sites for cases with and without airbags.

In both groups, the majority of AIS 2+ shoulder injuries were clavicle fractures. AIS 2+ forearm injuries consisted of fractures to the radius and ulna. In both groups, fractures of the radius were more common than those of the ulna.

Figure 3 showed that, for MAIS 2+ belted drivers, there was a significantly higher rate of AIS 2+ upper extremity injury in airbag equipped cars. To examine a possible connection with airbag deployment, it was considered necessary to first determine which specific sites of upper limb injury had contributed to that difference in injury rates. This is shown in table 6.

Table 6 shows the rates of injury to individual sites of the upper limb for belted drivers with MAIS 2+ injury. Any differences in rates between airbag equipped/non-airbag cases were assessed for statistical significance using the Chi-squared test.

Table 6 suggests no clear statistical difference in AIS 2+ injury rates to the arm, forearm or wrists of drivers with and without airbags. On the other hand, drivers in airbag equipped vehicles experienced a significantly higher risk of AIS 2+ shoulder injury. Closer examination showed that the majority of drivers with AIS 2+ shoulder injury had damaged only the outboard limb (84% with no airbag and 95% with an airbag). Virtually all of those injuries were caused by crash loads imparted via the seat belt shoulder strap.

Table 5: AIS 2+ Upper Extremity Injuries by Airbag Status (CCIS)

UPPER EXTREMITY REGION	NO AIRBAG FITTED	AIRBAG EQUIPPED
SOFT TISSUE		
Surface laceration	1.2%	3.8%
Vein laceration	<1%	0%
Nerve laceration	<1%	0%
Muscle laceration	1.2%	0%
% of Total Injuries	**3.2%**	**3.8%**
SHOULDER		
Glenohumeral Joint Dislocation	1.6%	0%
Sternoclavicular Joint Dislocation	<1%	2.5%
Acromioclavicular Joint Dislocation	<1%	0%
Clavicle Fracture	20.7%	28.8%
Scapula Fracture	1.2%	2.2%
% of Total Injuries	**24.7%**	**33.5%**
ARM		
Acromion Fracture	<1%	0%
Humerus Fracture	14.8%	10.0%
% of Total Injuries	**15.2%**	**10%**
FOREARM		
Radius Fracture	21.2%	23.9%
Ulna Fracture	17.2%	16.3%
% of Total Injuries	**38.4%**	**40.2%**
WRIST		
Joint Dislocation	1.6%	2.5%
Carpus/Metacarpus Fracture	11.4%	10.0%
% of Total Injuries	**13%**	**12.5%**
HAND		
Finger Amputation	5.5%	0%
% of Total Injuries	**5.5%**	**0%**
Total Injuries	**100%**	**100%**
Total AIS 2+ Injuries	**259**	**80**

Table 6: Rates of Injury to Sites of the Upper Limb -
Belted Drivers with MAIS 2+ Injury (CCIS)

	Rate of Injury		
Site of AIS 2+ Upper Limb Injury	No Airbag Fitted N=693	Airbag Equipped N=129	Chi-squared Significance
Shoulder	9%	18%	P<0.05
Arm	5%	5%	P>0.05
Forearm	11%	16%	P>0.05
Wrist	4%	7%	P>0.05

Airbag Deployment Thresholds: The crash severity at which to deploy airbags is a topic of considerable importance and this needs to be set at a level which will address the threshold of occurrence of the injuries which are to be prevented. If set too low, then the airbag may itself generate injuries which might otherwise not have occurred. (the US experience has shown this, albeit with larger more powerful airbag systems). If set too high then the head may not be protected adequately in crash conditions which pose a significant risk of injury. It is difficult to use real world crash injury data to examine possible cases of late deployment because acceleration time traces are not readily available. However, using the criteria of deployed/not deployed, it is possible to come to some conclusions as to the validity of the deployment threshold in relation to injury risk. Figure 5 examines the head injuries to belted drivers in vehicles with an undeployed airbag.

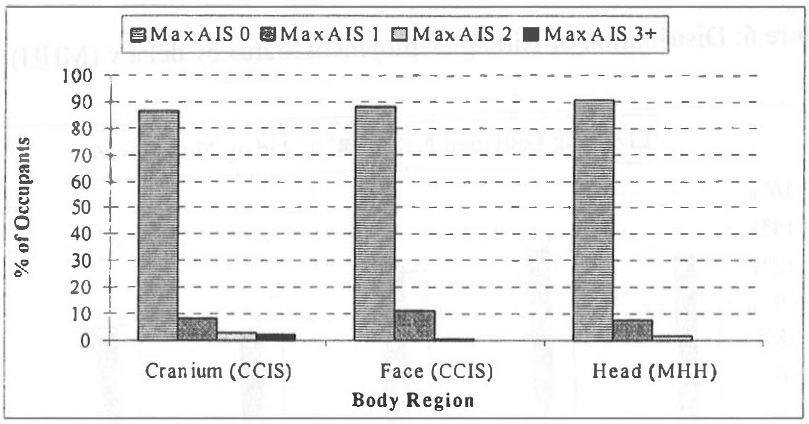


Figure 5: Maximum Head Injury Severity for Belted Drivers with Undeployed Airbags (N=134 CCIS), (N=172 MHH)

The crash conditions where airbags do not deploy appear to pose very little threat of injury to the head. Injuries to the cranium and face were extremely rare for the undeployed situation. In the UK sample, two drivers sustained AIS 5 head injuries and one an AIS 6. All were caused by head impact to heavy goods vehicles which had been underrun. The overall conclusion is that generally, deployment thresholds are not set above those relating to moderate/serious head injury risk when drivers are belted. The question as to whether the deployment threshold is set too low can be examined by comparing crash severities associated with airbag deployment/non-deployment against those associated with occupant injury.

Figure 6 describes the deployment/non-deployment situation by vehicle delta v. Whilst it is recognised that the crash pulse is a more direct measure of deployment thresholds, delta v is the best proxy variable available from the crash injury data and provides an adequate indication of crash severity. At delta v less than 10 km/h, only 4% of airbags had deployed. That proportion continued to increase with crash severity so that once delta v was over 30 km/h most airbags deployed (88%). There was however a 10 to 30 km/h grey area between almost certain deployment and almost certain non-deployment where 45-57% of airbags deployed.

If the airbag is successful in reducing injury risk, then injury patterns above 30 km/h in airbag equipped cars are expected to be different compared to those without airbags. That is because virtually all airbags have deployed above 30 km/h. If, however the airbag has an effect at low crash severities we would expect a change in injury pattern there also because the data shows that 45-57% of airbags do deploy below 30 km/h. Figures 7 and 8 illustrate belted driver injury patterns below and above 30 km/h delta v.

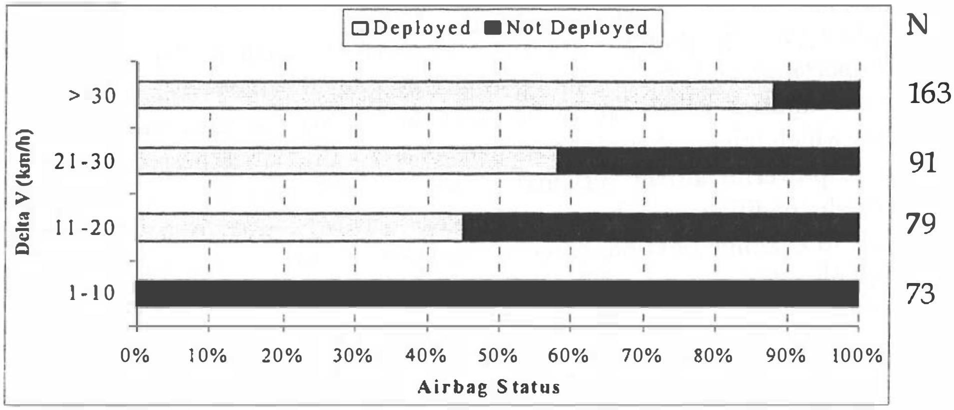


Figure 6: Distribution of Airbag Deployment Status by delta v (MHH)

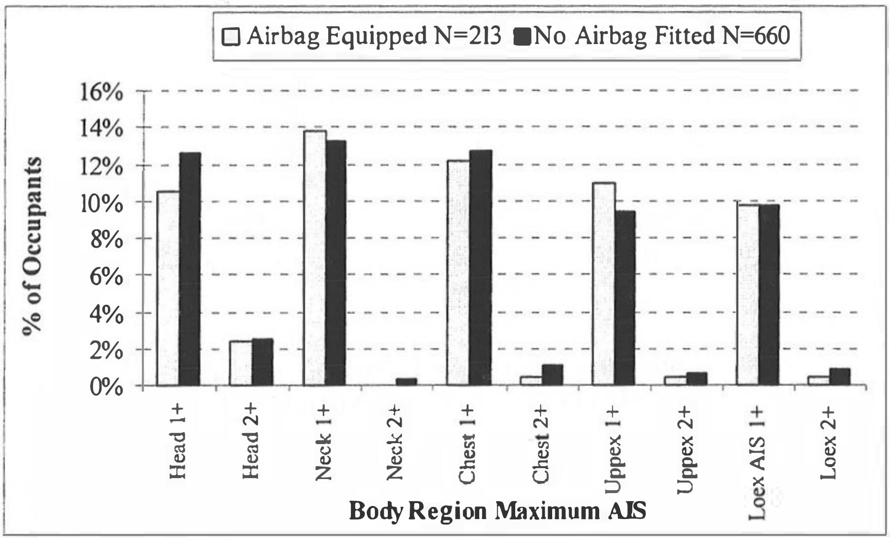


Figure 7: Injury Distribution of Airbag and Non-Airbag Cars – delta v ≤ 30 km/h (MHH)

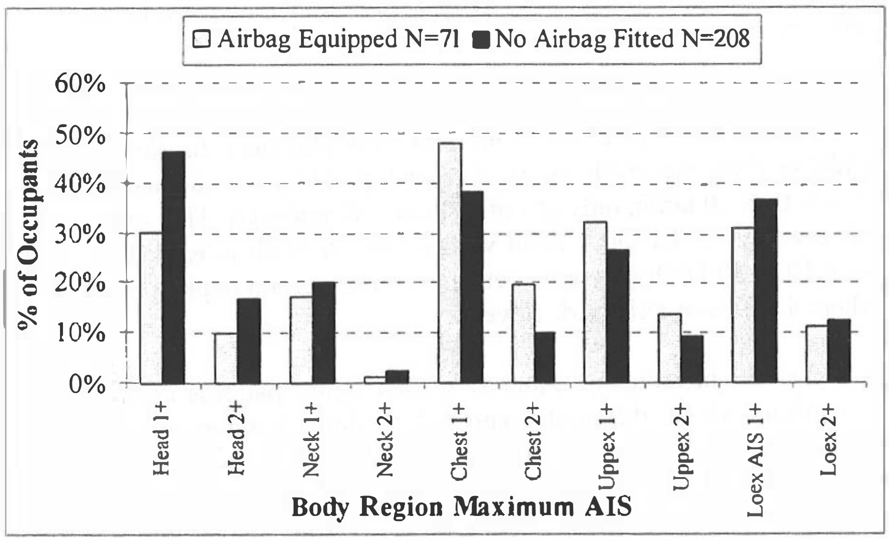


Figure 8: Injury Distribution of Airbag and Non-Airbag Cars – delta v > 30 km/h (MHH)

Overall, AIS 2+ injury rates were greater for the group of crashes above 30 km/h, irrespective of whether the vehicle was airbag equipped. Below 30 km/h injury rates were similar between groups of vehicles which supports the idea that airbag deployment has little bearing on injury outcome at these low crash severities. The airbag was more effective in reducing head injury at higher crash severities. Once 30 km/h was exceeded, airbag equipped cars showed proportionately less AIS 1+ and AIS 2+ head injury. There were however, proportionately more AIS 2+ chest and upper extremity injury in airbag equipped vehicles. These trends reflect those seen in the UK data. AIS 1+ neck injuries were predominantly cervical spine strains. The rate of these injuries appears unaltered by the airbag at either low or high delta v.

Crashes into narrow objects can pose particular challenges for airbag deployment when the crash pulse starts with low deceleration. It is not enough that the airbag deploys but the timing of the deployment needs to be appropriate also. In that regard, it is important to consider the objects struck where the airbag is most effective (over 30 km/h delta v). Figure 9 shows the distribution of objects struck for all belted drivers in crashes with delta v over 30 km/h in the MHH data. The equivalent data is shown for CCIS using ETS over 30 km/h. Although the two crash severity parameters are not the same, ETS is used here only to select out low severity crashes.

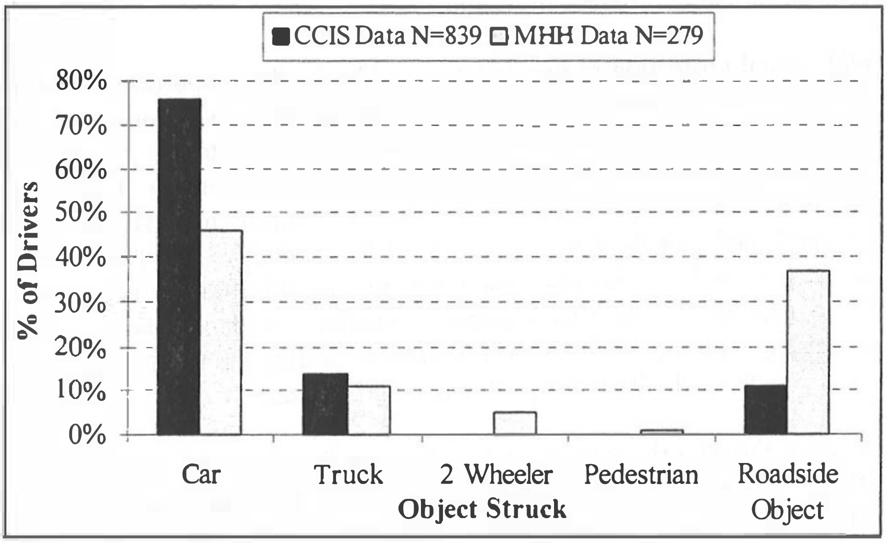


Figure 9: Distribution of Object Struck for Belted Drivers with Crash Severity > 30 km/h (delta v [MHH], ETS [CCIS])

The CCIS data shows a majority of impacts into other cars (76%) while the MHH data shows only 46% of crashes were with another car. Only 11% of vehicles in the CCIS sample collided with roadside objects, about half of which were trees and poles. In the MHH data, 37% of cars collided with roadside objects, most of which were trees and poles.

DISCUSSION

To date, few real world crash injury studies have examined the effectiveness of European airbag systems. Those that do exist have been limited by accident sample sizes. For example, Otte (1995) examined a sample of 41 cars with airbags deployed, Morris et al (1996) a sample of 130 while Lenard et al (1998) examined 205 vehicles in frontal impacts with deployed airbags. In this study, 542 such vehicles were available from UK data and 158 from German data. In order to isolate the influence of airbags on belted driver injury outcome it was essential to initially determine the similarities/differences between crashes involving vehicles with and without airbags. The results verified that for the UK data, angle of frontal impact, object impacted and crash severity were similar for these two groups. This enabled any differences in injury outcome to be more confidently attributed to the airbag as one major factor, although it should be noted that, with the introduction of airbags, came other changes in restraints and vehicle structure.

German injury data for frontal crashes suggested that airbags do not radically change injury patterns below 30 km/h delta v, when drivers are belted. The UK data for occupants with MAIS 1 and low crash severities reflect this trend, with the exception of a marked increase in surface injuries to the upper extremities in airbag equipped cars. Examining German airbag equipped versus non-airbag crashes over 30 km/h showed no difference in the rates of AIS 1+ neck injury (which were mainly cervical spine strains). This study does not support conclusions from previous European studies that airbag deployment alters the risk of acceleration injury to the neck (Otte, 1995).

Belted drivers with moderate to serious injury (MAIS 2+) were specifically examined to a) determine whether injury patterns were changed by the airbag and b) given a change in injury patterns, focus on the injuries that could still be a priority for occupant protection systems. The UK data revealed that when belted drivers were injured to MAIS 2 and above, airbags provided relative reductions of 35% and 56% in injury to the cranium and face respectively but there was no apparent benefit in terms of chest injury reduction. These trends concur with those found by Lenard et al (1998). Finding this trend with a larger dataset adds support to the conclusion that European airbags do carry out their design function to reduce head injury.

If air bags provide equal protection to the skeleton and brain, the proportion of skull fractures to brain injuries should be similar to that which occurs in cars not fitted with airbags. It was seen that when serious head injury did occur, drivers in airbag equipped cars sustained a higher proportion of only brain injury to only skull fracture compared to those without an airbag. This trend was noted previously by Lenard et al (1998). It suggests that airbags, while improving head protection generally, might provide a greater benefit for the bony structures of the head. The trend was not proven to be statistically significant, nevertheless, this issue should be re-visited in future studies, with more data, before drawing firm conclusions. Future work needs to examine, in detail, those cases where head injury still occurs in airbag equipped vehicles, specifically regarding the mechanisms of injury. This would be beneficial in providing the basis for further head protection.

Some US studies have linked airbags to the risk of forearm fractures, either through direct contact on the airbag or 'fling' into interior structures (Huelke, 1995). The European data, with generally smaller, less powerful airbags was interrogated for a similar effect. Drivers airbag vehicles did show higher upper extremity fracture rates compared to those without airbags. This was shown to be a real increase in risk when compared with the rate of AIS 2+ injury to the lower limb (a body region with similar injury rates in airbag equipped/non airbag cars). This increase was also noted by Lenard et al (1998) using European data. That study did not, however, isolate injury rates to different sites of the upper limb and so was unable to verify the possible implication of the airbag in causing upper limb injury. This current study shows that, although there is a trend toward higher forearm fracture rates with deployed airbags, the only statistically significant increase in AIS 2+ upper limb injury concerns the shoulder region (mainly clavicle fractures). These were almost always to the outboard shoulder only and caused by the seat belt webbing. The issue of why shoulder injuries rise needs to be qualified further. Development of a method to measure loading to the clavicle would be helpful in that regard.

Examination of occupant injury in vehicles with undeployed airbags showed that very few head injuries occurred which would warrant deployment. This result was substantiated by both UK and German data. There was therefore no evidence that airbag deployment thresholds have been set at too high a level. Additionally, the airbag had little effect on injury outcome in crashes below 30 km/h, its major effectiveness came in at higher crash severities. This means there is still some scope to minimise airbag deployment at the lower crash severities for systems designed to protect the belted driver.

The timing of airbag deployment during the crash event is important. Often, during impacts to narrow objects like trees and poles, the vehicle structural members are not impacted directly. That can pose particular challenges for airbag triggering because the crash pulse often starts with low deceleration. So the vehicle collision partners associated with collisions above 30 km/h crash severity were of particular interest. Compared to CCIS data, MHH crash injury data showed a substantially higher proportion of impacts to narrow objects. For the UK data, about 5% of impacts occurred with narrow objects while they contributed to about a third of crashes in the German data. This difference between the data samples highlights the value of considering different datasets as well as emphasising the need to consider the variety of crashes that occur in the real world.

Examination of real world crash injury data from two European countries suggest changing patterns of injury in airbag equipped vehicles. European airbag systems are optimised to protect belted occupants' heads. In that regard, this study has supported the findings of previous work that this design function is being fulfilled. The challenge in North America is how to protect unbelted occupants with less aggressive airbag systems. This study was unable to examine airbag effectiveness for unbelted occupants because of their small number in the data but this should be considered for future study as more accident data becomes available. For belted drivers, a reduction in head injuries has shifted the emphasis on occupant protection toward the chest and extremities.

CONCLUSIONS

The following findings apply to belted drivers in frontal crashes:

- For drivers with MAIS 2+ injury, European airbags reduce AIS 2+ injury to the cranium and face by 32% and 55% respectively.
- The maximum benefit of airbags can be seen in crashes exceeding 30 km/h delta v.
- There is no evidence to support previous research findings that airbag deployment alters the risk of cervical spine strain.
- European airbags do not provide any benefits in terms of chest injury reduction.
- Drivers in airbag vehicles sustain proportionately more AIS 2+ upper extremity injuries (particularly to the shoulder) than those in non-airbag equipped vehicles.
- Airbag deployment thresholds do not appear to be set above the threshold of head injury.
- There is evidence to suggest that some deployments occur unnecessarily in low severity crashes.

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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

Huelke, D F., Moore, J. L., Compton, T. W., et al. Upper Extremity Injuries Related to Airbag Deployments. J Trauma, 38: 482-488; 1995

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, 1998

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

NHTSA Third Report to Congress; Effectiveness of Occupant Protection Systems and Their Use, December 1996

NHTSA, DEPARTMENT OF TRANSPORTATION. National Highway Traffic Safety Administration 49 CFR Parts 571, 585, 587, and 595 Docket No. NHTSA 98-4405; Notice 1 RIN 2127-AG70 Federal Motor Vehicle Safety Standards; Occupant Crash Protection, 1996

Otte, D. Review of the Airbag Effectiveness in Real Life Accidents – Demands for Positioning and Optimal Deployment of Airbag Systems. Procs 39th Stapp Car Crash Conf, Coronado, 1995

Phen, R. L., Dowdy, M. W., Ebbeler, D. H. Advanced Air Bag Technology Assessment Final Report prepared for NHTSA and NASA. April 1998

Winston, F., Reed, R. Airbags and Children: Results of a National Highway Traffic Safety Administration Special Investigation into Actual Crashes. Procs 40th STAPP Car Crash Conf, 1996