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THE EFFECT OF FRONTAL AIRBAGS ON BELTED DRIVER INJURY PATTERNS IN EUROPE AND THE U.S. - WHERE DO FUTURE PRIORITIES LIE?

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ABSTRACT

Injury patterns by body region were compared for belted drivers who had sustained at least one moderate or greater injury (MAIS 2+ belted drivers) in airbag equipped and non-airbag cars. For airbag equipped cars, both European and US data showed about a 30% decrease in the fraction of these drivers who sustained AIS 2+ head injuries. European data found little difference in the relative frequency of AIS 2+ chest injury and cervical strain, whereas U.S. data showed a decreased frequency of AIS 2+ chest injury for MAIS 2+ belted drivers in airbag equipped cars. Both European and U.S. data show a substantially increased frequency of AIS 2+ upper limb injury for these drivers. AIS 2+ shoulder injuries contributed significantly to the increase. U.K., U.S. and German data show only a very small risk of head injury for all belted drivers in the no-deployment condition. On the other hand, European data suggests that the airbag appears to have little effect on injury outcome below 30 km/h delta v for all belted drivers.

Currently, the North American experience of frontal airbag field performance is more extensive than it is in Europe. This is a consequence of their much earlier introduction into the car fleet. U.S. field studies show that airbags are effective in reducing occupant fatality by 31% in purely frontal crashes (NHTSA, 1996). Studies have also looked at effectiveness related specifically to airbag and belt combinations, belt only and airbag only. They show that drivers have a higher chance 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). Other studies show that, for serious injury, an 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).

U.S. regulation requires airbags which protect unbelted and belted occupants, resulting in the need for larger, higher powered airbags which can cause injury to out of position occupants (Phen et al, 1998, Winston and Reed, 1996, NHTSA, 1996). European airbags have developed primarily to protect belted occupants, so they are generally less powerful and deploy at higher crash severity thresholds.

Few in-depth field studies have been conducted to assess the effectiveness of European airbag systems. Available results, from small samples, indicate that injured drivers in airbag deployed vehicles incur proportionally fewer head injuries and proportionally more upper limb injuries than drivers in 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 strain injury rates do not benefit from airbag deployment. An insurance data study by Langweider et al (1997), suggested that, in severe crashes, airbags are beneficial, reducing serious and critical injuries to the head and trunk of drivers.

The development of airbag systems to meet revised criteria (March, 1997) for FMVSS 208 frontal crash protection, the 30 mph unbelted sled test, as allowed the development in North America of less powerful airbag systems which are more closely aligned to those used in Europe. There is still a requirement however, for protection of unbelted occupants. Belt usage has been increasing in the U.S. so European studies of airbag effectiveness may now have direct relevance to the situation in North America.

METHODOLOGY

This study is based on in-depth crash injury data from the U.K. Co-operative Crash Injury Study (CCIS), the Medical University of Hannover Study (MHH) and the U.S. National Automotive Sampling System (NASS). CCIS cases were available from calendar years 1992-2000 and MHH cases from 1996-99. The result is one of the largest, currently available European sources of in-depth crash injury information from airbag equipped vehicles. Both studies select cases for investigation using a random sampling procedure based on injury criteria and in both studies there are many common variables. For a comprehensive description of CCIS, the reader is referred to Mackay et al, 1985, for MHH to Otte, 1994 and for NASS to the Crashworthiness Data System, 1990-98. The focus of this study concerned frontal crashes. 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 delta v. Model year 1990-98 towed passenger cars involved in a single impact to the front were selected from the 1990-98 calendar years of NASS. There were very few vehicles with de-powered bags in the sample so they were not examined separately.

For each dataset, cases were interrogated for trends related to the performance of airbag restraints. Injury severity was assessed in each study by the Abbreviated Injury Scale (AAAM, 1990). Where statistical tests were employed, a 5% level was used to accept significance. In the preceding analyses, sample sizes vary from the original data selection based on availability of valid information for certain variables.

It should be noted that airbag fitment in U.S. and European cars did not generally occur in isolation from changes to restraint systems and vehicle structures. Additionally, factors such as the mass distribution of vehicles on U.S. versus European roads may play an important role in injury outcome. In this study, comparisons were made between groups of vehicles based primarily on airbag fitted or airbag not fitted and does not attempt to control for any other changes to vehicle design.

The European results are based on review of the CCIS and MHH cases. The complex, stratified NASS sampling process requires the use of weighted data to provide valid estimates. All figures and tables show the unweighted NASS sample size (N). The purpose of this study is to provide a comparison of U.S. and European airbag performance in particular areas of interest and to provide pointers for future in-depth study.

RESULTS

STUDY CASES - Table 1 shows airbag fitment and deployment by the number of occupants available for this study. It should be noted that the European airbags represented here are a mixture of European and U.S. systems, although the majority are European. The majority of occupants were belted. Belt use was proven for 73% of occupants in the CCIS sample, 81% in the MHH sample and reported in 70% of the NASS sample.

Table 1 - Occupant Seat Position and Airbag Status – Frontal Crashes – CCIS/NASS/MHH

	CCIS		NASS		MHH	
	Driver	Pass.	Driver	Pass.	Driver	Pass.
Deployed	512	30	1906	265	132	26
Not Deployed	200	12	281	71	212	36
Not Fitted	3215	1246	1596	742	1075	259
Total	3927	1288	3783	1078	1419	321

Maximum injury severity, as described by the MAIS was compared between drivers with no airbag fitted and for those with an airbag. The distributions are shown in table 2.

Table 2 - MAIS Distributions – No Airbag Fitted and Airbag Equipped (CCIS, NASS)

MAIS	No Airbag Fitted (CCIS)	Airbag Equipped (CCIS)	No Airbag Fitted (NASS)	Airbag Equipped (NASS)
0	19%	16%	49%	42%
1	51%	60%	39%	49%
2+	30%	24%	12%	9%
Total N	3215 (100%)	712 (100%)	1596 (100%)	2187 (100%)

In both CCIS and NASS, airbag equipped cars contained a smaller proportion of drivers with MAIS 2+ injury than those in non-airbag cars.

In the general crash population, slight injuries (AIS 1) are much more frequent than moderate to serious injuries. Although not life threatening, slight injuries are important to consider, especially those with long lasting effects, like cervical strains. The priority injuries to address in terms of severity are those of AIS 2 and above. Note that the difference in the reported frequency (Table 2) of AIS 2+ between CCIS and NASS relates to the nature of the sampling discussed in the methodology. In-depth accident studies allow an examination of how cars equipped with airbags might be changing the pattern of AIS 2+ injuries and can provide the focus for future priorities in injury prevention.

Belted Driver AIS 2+ Injury Patterns - No Airbag Fitted And Airbag Equipped – Injury patterns were compared between U.K. and U.S. belted drivers who had sustained at least one moderate or greater injury (MAIS 2+ belted drivers) in airbag equipped and non-airbag cars. Using similar subsets of the injury population allowed a more meaningful comparison between the two datasets. Figure 1 shows which body regions contributed to a MAIS of 2+ for belted drivers in airbag equipped/non-airbag cars in the U.K. data. Figure 2 shows that information for the U.S. data. It should be noted that when a belted driver sustained a MAIS 2+ in an airbag car in CCIS, 18/129 (14%) of bags remained undeployed. For equivalent NASS data, less than 1% of bags remained undeployed.

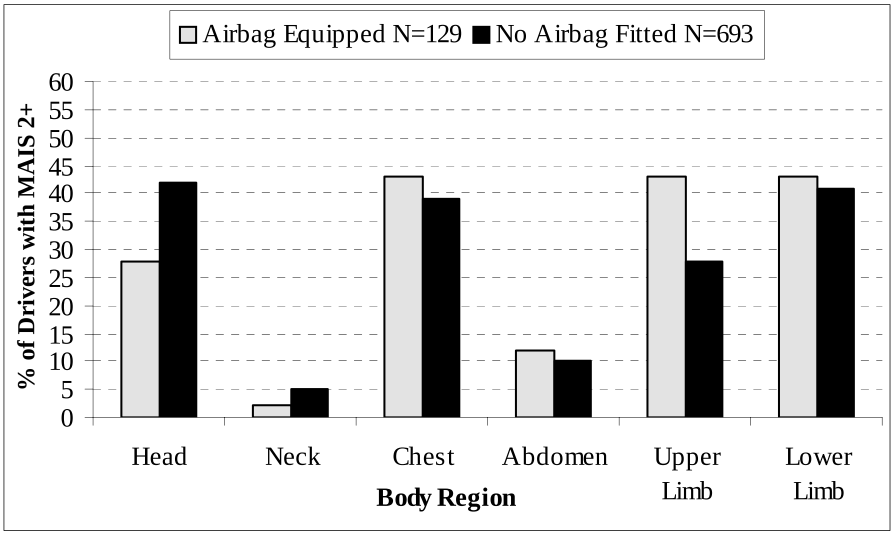

Figure 1 - AIS 2+ Body Region Injury Patterns for MAIS 2+ Belted Drivers (CCIS)

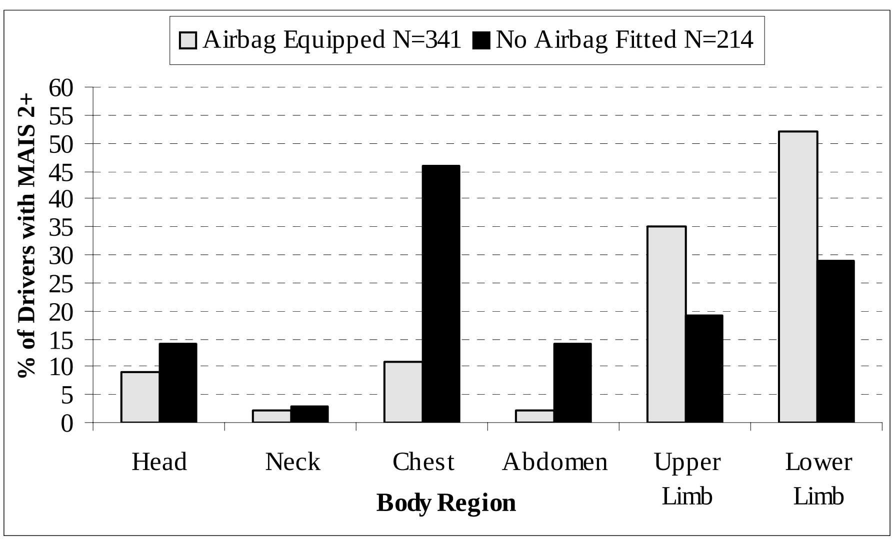

Figure 2 - AIS 2+ Body Region Injury Patterns for MAIS 2+ Belted Drivers (NASS)

In U.K. and U.S. non-airbag cars, the incidence of AIS 2+ injury was comparable for the chest and the extremities, however, the incidence of AIS 2+ head injury in CCIS was higher than in NASS

(42% compared to 14%). In U.K. airbag equipped cars there was a 33% relative decrease in the frequency of head injuries, a 10% increase in the frequency of chest injuries ($p > 0.05$), a 54% increase in the frequency of upper limb injuries and a 5% increase in the frequency of lower limb injuries ($p > 0.05$). In NASS there was a 30% relative decrease in the frequency of head injuries, a 77% decrease in the frequency of chest injuries, a 74% increase in the frequency of upper limb injuries and an 82% increase in the frequency of lower limb injuries. These values are summarised in figure 3.

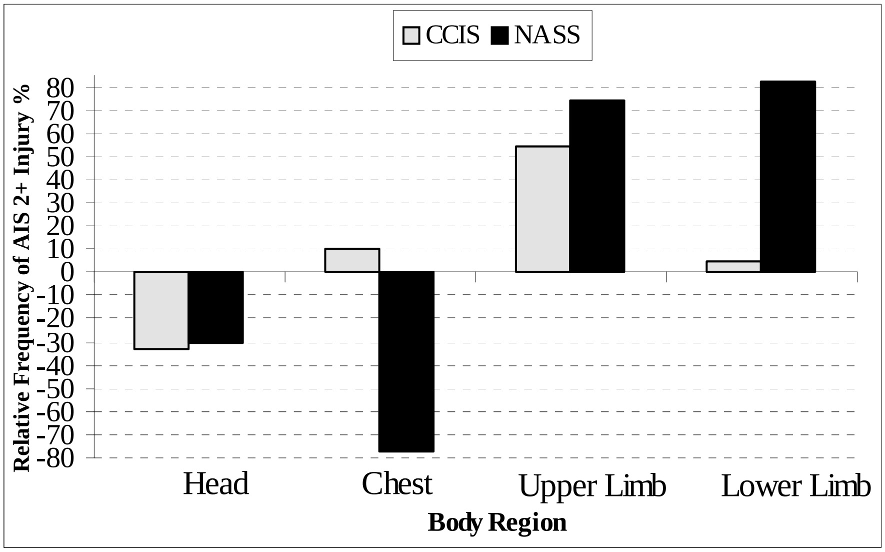

Figure 3 - Relative Frequency of AIS 2+ Injury for MAIS 2+ Belted Drivers – Airbag Equipped Cars Compared to Non-Airbag Cars

<u>Upper Extremity Injury</u> - Figure 1 showed a higher frequency of AIS 2+ upper extremity injury in airbag equipped U.K. cars. Most of those injuries were fractures (91%). Similarly, in non-airbag vehicles most AIS 2+ upper limb injuries were fractures (92%), the remaining being soft tissue injuries of the veins, nerves and muscles. To examine any relationship to airbag deployment, it was considered necessary to determine which sites of upper limb injury had contributed to the difference in injury frequencies. For belted drivers with MAIS 2+, figure 4 shows the frequency of AIS 2+ injury to individual parts of the upper limbs. Any differences in frequencies between airbag equipped/non-airbag cases were assessed for statistical significance using Chi-squared tests.

Figure 4 suggests no clear statistical difference in AIS 2+ injury frequencies 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 injured only the outboard limb (84% with no airbag and 95% with an airbag). Most of those injuries were caused by crash loads from the seat belt shoulder strap.

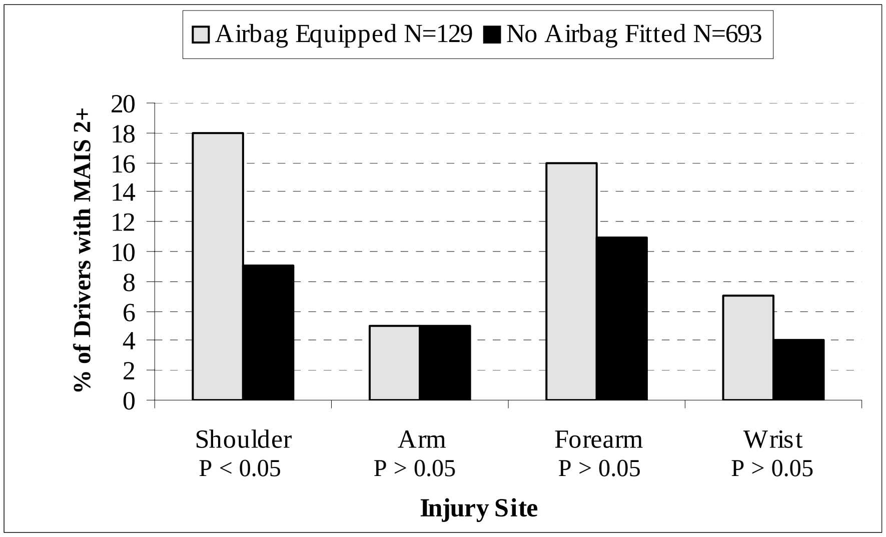

Figure 4 - AIS 2+ Upper Limb Injury Patterns –
MAIS 2+ Belted Drivers (CCIS)

Airbag Deployment Thresholds - The crash severity at which to deploy airbags is a topic of considerable importance and of considerable complexity. Thresholds cannot be set independent of the entire range of crash severities over which an airbag is designed to provide protection. That is, the requirement for higher speed protection (of an unbelted occupant in an abrupt high-speed barrier crash, for example) necessarily dictates the timing of deployment and thus the threshold for deployment. Advanced restraint systems which can resolve some of these complexities are just now being introduced into the U.S. fleet. Putting these complexities aside, however, it is axiomatic that if the threshold is relatively low, then the airbag may itself generate injuries in a situation where injury may not have occurred. On the other hand, if the threshold is relatively high, then there may not be adequate protection in crash conditions which pose a significant risk of injury. Figure 5 examines the head injuries to belted drivers in vehicles with an undeployed airbag.

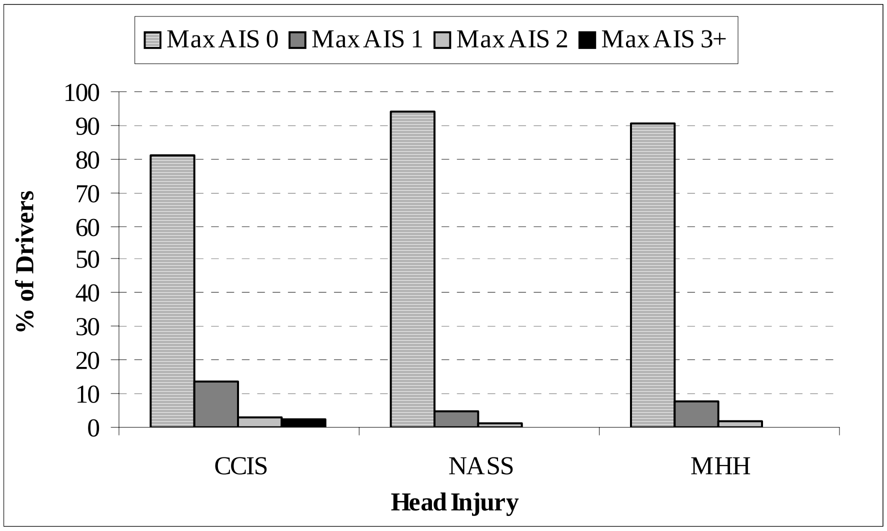

Figure 5 - Maximum Head Injury Severity for Belted Drivers with Undeployed Airbags (N=134 CCIS), (N=296 NASS), (N=172 MHH)

The crash conditions where airbags do not deploy appear to pose very little threat of injury to the head in the U.K., German or U.S. data. Head injuries were extremely rare for the undeployed situation. In the U.K. sample, two drivers sustained AIS 5 injuries and one an AIS 6. All were caused by head impact to trucks that 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.

Figure 6 describes the deployment/non-deployment situation by estimated 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 this data. In the MHH sample, at delta v up to 10 km/h, only 4% of airbags had deployed compared to 49% in the NASS sample. Once delta v was over 30 km/h, most (88%) airbags had deployed in the MHH sample and in the NASS sample (100%). In European cars there was an 11 to 30 km/h transition between almost certain deployment and almost certain non-deployment where 45-60% of airbags deployed. Between 11 and 30 km/h, most bags (78%-96%) in the NASS sample had deployed.

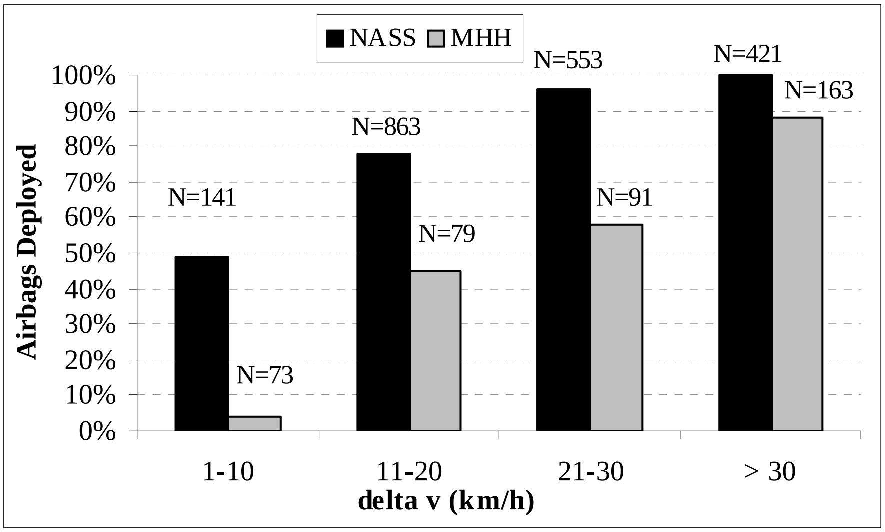

Figure 6 - Proportion of Airbag Deployments by Crash Severity (MHH, NASS)

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 40-60% 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 from the MHH cases.

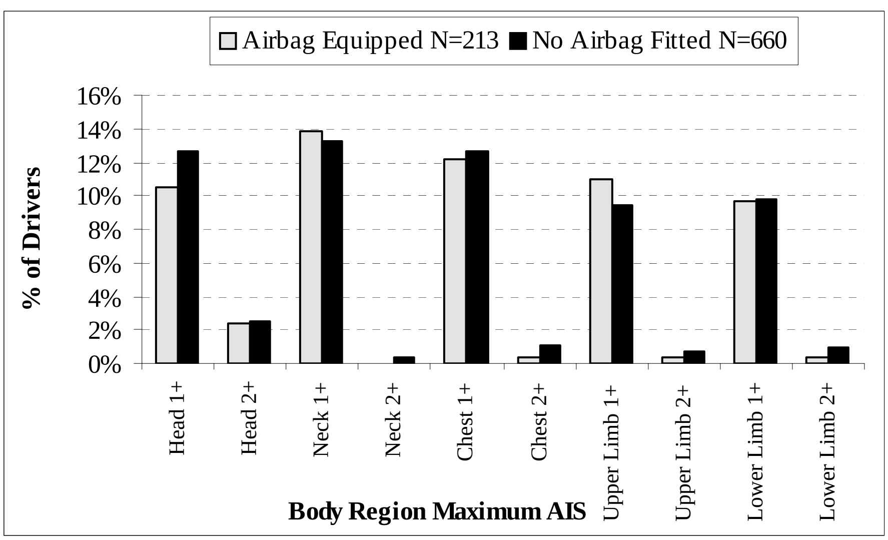

Figure 7 - Injury Distribution for Belted Drivers of Airbag and Non-Airbag Cars – delta v $\leq$ 30 km/h (MHH)

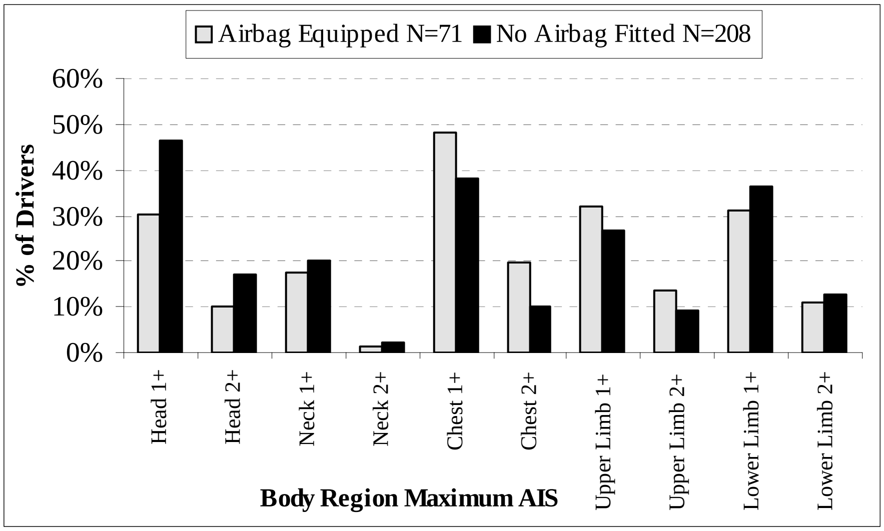

Figure 8 - Injury Distribution for Belted Drivers of Airbag and Non-Airbag Cars – delta v > 30 km/h (MHH)

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 for belted drivers 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 are similar to those seen in the U.K. data. AIS 1+ neck injuries were predominantly cervical 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.

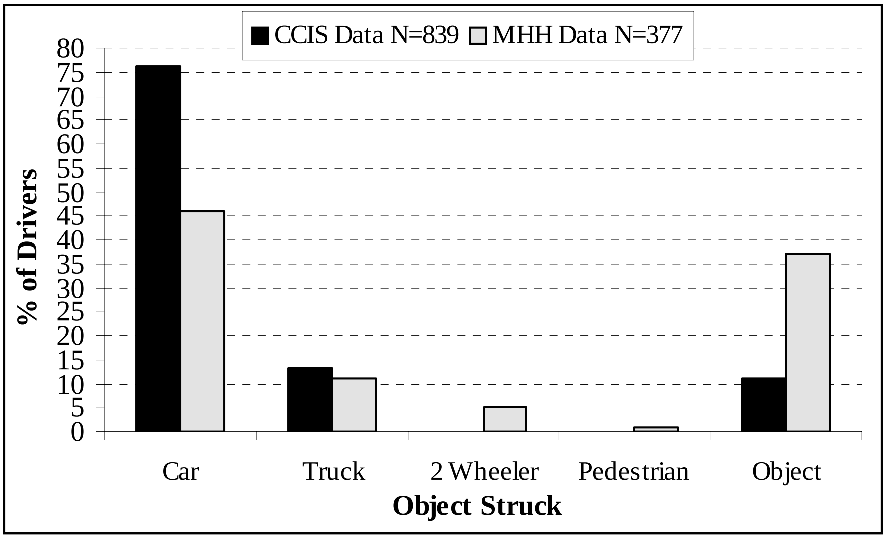

Figure 9 - Distribution of Object Struck for Belted Drivers with Crash Severity > 30 km/h (delta v [MHH], ETS [CCIS])

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% collided with roadside objects, most of which were trees and poles. These differences in crash conditions mean that it is important for crash sensing to address car to car and car to roadside object impacts.

DISCUSSION

Increasing seat belt usage in the United States, together with de-powering of frontal airbags mean that studies of airbag effectiveness in Europe may now have direct relevance to the situation in North America. To date, few real world crash injury studies have examined the effectiveness of European airbag systems. Those that do exist have been limited by small sample sizes. For example, Otte (1995) examined a sample of 41 cars with deployed airbags, Morris et al (1996) a sample of 130 and Lenard et al (1998) sampled 205 vehicles.

In this study, 712 driver airbag equipped vehicles were available from U.K. data and 344 from German data. The study has concentrated on an examination of airbag systems in European cars but some comparison was made with U.S. data where 2,187 driver airbag equipped cases were available.

For belted drivers with MAIS 2+, the U.K. data showed differences in the relative frequencies of AIS 2+ injury to individual body regions, depending on airbag fitment. Compared to belted drivers in cars not equipped with airbags, those with airbags showed a 33% reduction in the frequency of AIS 2+ head injuries, a 54% increase in the frequency of AIS 2+ upper limb injuries, but no significant effect on the frequency of AIS 2+ injuries for the chest or lower limb. 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 protect the heads of belted drivers. When belted drivers are injured to MAIS 2+ in European airbag cars, they are more likely to have sustained AIS 2+ injury to the upper limbs than the head but the likelihood of AIS 2+ chest and lower limb injury remains unchanged.

Overall, when belted drivers are injured to MAIS 2+ in U.S. airbag cars, they are more likely to have sustained AIS 2+ injury to the upper and lower limbs than the head and chest, compared to belted drivers with MAIS 2+ in non-airbag cars. Of particular interest was the 77% reduction in the frequency of AIS 2+ chest injuries for belted drivers in airbag equipped cars relative to the frequency in non-airbag cars. This contrasts with the neutral effect of airbags on chest injuries in the U.K. data. This emerging trend is of great interest but warrants further, careful consideration because of other differences between vehicle designs in Europe and the U.S. Many more airbag equipped cars in Europe are fitted with seatbelt pre-tensioners, the mass distribution of the vehicles may be different and structures may be different due to the need to meet different crash test requirements. The apparent reduction in relative chest injury risk in U.S. vehicles may also need further qualification. In the NASS no airbag fitted sample, there was a higher proportion of smaller and older vehicles than in the airbag fitted sample. That may, in turn, influence occupant demographics such as age and gender, which will have an effect on injury outcome. All these factors need to be considered in detail in order to further clarify the effect that different airbag systems might have on belted driver chest protection.

Some U.S. studies have shown that airbags can increase the risk of upper extremity fractures (Huelke, 1995). The European data, with generally smaller, less powerful airbags was interrogated for an airbag effect on the upper extremity. For belted drivers with MAIS 2+, the increase in upper extremity fractures in airbag cars could not be fully explained by a increased forearm fractures because the most significant increase in frequency was to the shoulder, mainly clavicle fractures. These were attributed to loads from the seat belt webbing. Previous work by Lenard et al (1998), was not able to isolate injury risk to different parts of the upper limb, therefore this is a new result. Overall, it appears that the "airbag effect" on upper limb injury may not be substantial but there is a need to further investigate the reasons for changes in the pattern of clavicle fracture. Development of a method to measure loading to the clavicle would be helpful in that regard.

In European vehicles with undeployed airbags, very few head injuries occurred which would warrant deployment. This was also the case for NASS data. There was therefore no evidence that airbag deployment thresholds have been set at too high a level for protection of the head. Conversely, there is some evidence to support minimising deployment at the lower crash severities for belted drivers in Europe. German data show that the airbag had little effect on injury outcome in crashes below 30 km/h delta v, yet between 10 and 30 km/h, some 45-60% of airbags had deployed. Between those crash severities, some 80-95% of airbags in the NASS data had deployed, evidence of the apparent lower deployment thresholds for U.S. airbag systems.

Examining German airbag versus non-airbag crashes over 30 km/h showed no difference in the rates of AIS 1+ neck injury (which were mainly cervical strains). A similar result was seen for crash severities below 30 km/h, so this data does not support conclusions from previous European studies that airbag deployment increases the risk of acceleration injury to the neck (Otte, 1995).

Collisions where the vehicle structural members are not impacted directly can pose particular challenges for airbag triggering because the crash pulse often starts with low deceleration. The importance of considering all types of struck objects is demonstrated by the comparison of MHH and CCIS, which showed large differences in the distribution of collision partners. German data showed a much higher proportion of impacts to trees and poles and it is recommended that the injury outcome in such collisions be examined in specific detail in future work.

Examination of real world crash injury data from two European countries suggests changing patterns of AIS 2+ injury in airbag equipped cars. 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 still 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 European belted drivers with moderate to serious injuries, a reduction in AIS 2+ head injuries in airbag equipped cars has shifted the emphasis in occupant protection toward the upper extremities, while there is still a need to address AIS 2+ injuries to the chest and lower limbs. For belted drivers with MAIS 2+ injuries in U.S. airbag equipped vehicles, there is a need to maintain the reduction in head and chest injuries while addressing AIS 2+ injuries to the upper and lower limbs.

CONCLUSIONS

The following findings apply to belted drivers, with injury severity of MAIS 2+, in frontal crashes in European cars (unless otherwise stated).

- Airbags provide a 33% reduction in the frequency of AIS 2+ head injuries when MAIS 2+ injury occurs.
- Airbags do not appear to provide any benefits in chest injury reduction. NASS data show that U.S. airbag cars have a lower frequency of AIS 2+ chest injuries than those without airbags.
- In airbag equipped cars there are proportionately more AIS 2+ upper extremity injuries than in non-airbag cars, particularly to the forearm and shoulder.
- The risk of AIS 2+ lower limb injury in airbag equipped cars is similar to that in cars not equipped with airbags.

The following are general findings related to belted drivers in frontal crashes in European cars.

- There is no evidence to support previous conclusions that airbags change the risk of cervical strain.
- 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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