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The Influence of European Air Bags on Crash Injury Outcomes

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Paper Number 98-S5-O-01

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ABSTRACT

The UK Co-operative Crash Injury Study currently includes data on 205 seat belted drivers from frontal impacts in which an air bag deployed; of these, 142 suffered some degree of injury. To detect the influence of frontal air bags, the distribution of injury over the body regions of these drivers was compared to that of a much larger group from vehicles without air bags. The injured drivers from air bag vehicles showed relatively fewer head injuries, especially fractures, and relatively more arm injuries. No abnormal types of injury or circumstances of injury were identified for the air bag group. Air bags generally appear to deploy at vehicle impact severities that pose a statistical risk of significant head injury, and also in a proportion of lower severity impacts. As a group, the air bag equipped vehicles were larger, more modern, and more often fitted with seat belt pretensioners than the non air bag vehicles, with an older and more male driving population.

INTRODUCTION

Motor vehicle manufacturers have tended to customise air bag characteristics differently for the North American and European markets, particularly with regard to deployment threshold, inflation rate and air bag volume. This has arisen in response to different regulatory requirements, consumer preferences, advocacy group pressures and legal considerations. Additionally, seat belt use and the size, mass, and structural properties of the car fleets diverge considerably. The effectiveness of air bags in North America has been extensively studied by several authors [Backaitis and Roberts (1987), Huelke and Moore (1993), Crandall et al (1994), Liberty (1995), Dalmotas et al (1996)]. However it has not been possible to assume that the benefits and problems associated with air bags in North America are being replicated on the roads of Europe.

Australian studies have also addressed how air bags influence injury outcome. Fildes et al (1996) presented results which suggested that head, face, chest, abdomen and pelvis injuries were reduced in Holden Commodore cars fitted with air bags, using 63 air bag cases and 85

non air bag cases. The Commodore air bag has a higher deployment threshold, lower deployment speed and faster venting than many US air bags because it was designed for belted occupants. In these respects it has similarities to European systems. However, the size of the vehicle and the 65 litre driver bag do not compare well with European vehicle and air bag sizes.

Some results of European studies are available. In Germany, Otte (1995) compared 31 belted occupants with air bag deployment to 1483 belted occupants without air bags. He noted a lower overall injury severity in the air bag cases but a higher incidence of cervical spine strain. Morris et al (1996) investigated driver injury patterns in 97 European and Japanese cars with air bag deployment and mixed belt use. He concluded that air bags appeared to be improving injury outcome for the head but also suggested that cervical spine strain rates were not decreasing. The study also showed that, for the air bag cases, the most common site of moderate to serious injury (AIS 2+) was the lower limb followed by the upper limb. Langwieder et al (1996) compared a sample of 188 drivers with deployed air bags (mostly belted) to German insurance data for non air bag cars. He reported that AIS 2+ injuries in air bag cars occurred predominantly to the lower and upper extremities rather than to the head or chest, concluding that driver air bags lead to a substantial reduction in head injuries.

To date, the evaluation of air bag effectiveness in Europe has been based on a relatively low number of cases of air bag deployment. This remains a constraint. However a clearer picture is beginning to emerge as the number of relevant accidents that are systematically investigated and documented begins to accelerate. The findings presented in this paper are based on the latest release of results from the UK Co-operative Crash Injury Study (CCIS), which is a major source of in-depth crash investigation data in Europe.

The CCIS study has been funded by the British government and a consortium of motor manufacturers since its inception in 1983. It is managed by the Transport Research Laboratory. Teams from Loughborough University, Birmingham University, and the Vehicle Inspectorate examine approximately 1600 vehicles per year. The three groups use the same data collection forms

and methods, and the case studies are combined into a single computer database. This whole database contains anonymous information on over 13000 vehicles, 21000 occupants and 68000 injuries.

Crashed vehicles from regional catchment areas around England are admitted to the sample depending on police assessment of accident severity. Accidents where an occupant from any vehicle dies, is admitted to hospital as an inpatient, or requires medical treatment are classified as fatal, serious, and slight accidents respectively. When an accident is selected, CCIS attempts to include all vehicles involved, provided the vehicle in which injury occurred is no more than seven years old. Currently CCIS succeeds in obtaining almost all eligible fatal accidents, about 80% of eligible serious accidents, and a quota (25%) of slight accidents. These criteria have varied over the period of data collection relevant to this paper, but not dramatically. The weighting of the sample is therefore linked to the severity of occupant injury.

This connection between injury level and admission to the sample means that it is not completely straightforward to demonstrate the effectiveness of air bags in mitigating (or aggravating) injury. One approach might be to compare the level of injury of occupants from air bag equipped vehicles to that of occupants from non air bag vehicles. This may work if the two groups are selected at random, on vehicle impact severity, or some other injury-independent basis. However in the CCIS sample someone in the accident is required to be fatally, seriously, or slightly injured—the selection of *all* occupants is consequently biased towards injury cases. This distorts the perceived effectiveness of the air bag in mitigating or aggravating occupant injury.

The approach adopted in this paper is to look for differences in the pattern of injury between the two groups, specifically in the distribution of injury over body regions. The air bag's intended function is to protect the head. If it succeeded perfectly in this respect (which is impossible) the CCIS sample would still contain slightly, seriously, and fatally injured occupants from air bag deployed vehicles, but these subjects would have no head injuries. The extent to which the air bag actually works should be reflected in a shift away from head injuries among *injured* occupants from air bag vehicles—relatively less head injuries and, by the same token, relatively more injuries to other regions of the body.

The introduction of air bags has coincided with other developments in vehicle safety: among these are seat belt pretensioners and the design of vehicle body structure for a variety of crash tests with instrumented dummies. No attempt is made in this paper to distinguish the separate contributions of the various coexisting safety features. This would place excessive load on limited data. The comparisons made here are between air bag equipped vehicles, with all their accompanying secondary safety

features, and non air bag vehicles, with all their secondary safety characteristics.

OVERVIEW OF CCIS DATABASE 1992-98

Air bag equipped vehicles first appeared in the CCIS sample during phase IV of the project which started in mid 1992. The collection of data for phase V is due to end in mid 1998. The results presented in this paper are drawn from these two phases—this includes all air bag equipped vehicles documented to March 1998. Although weighting factors can be applied to the CCIS data to undo the sampling bias in favour of more severe injury cases, the analysis here is directly descriptive of the sample.

Table 1.
CCIS 1992-98:

Maximum Occupant Injury Severity per Vehicle		
Injury Severity	Vehicles	
Fatal	218	4%
Serious	1370	22%
Slight	2665	43%
Uninjured	1434	23%
Unknown	514	8%
Total	6201	100%

There are details on 6201 vehicles. The maximum level of injury within each vehicle is shown in Table 1. Slight injury cases make up almost half of the sample; fatal and serious injury cases together are about one quarter, as are non-injury cases.

Table 2.
CCIS 1992-98: Accident Type

Accident Type	Vehicles	
Front	3380	55%
Side	1512	24%
Rear	415	7%
Rollover	743	12%
Other	151	2%
Total	6201	100%

Frontal impacts make up over half of the sample, as Table 2 shows. This is where the effectiveness of (frontal) air bags should manifest itself.

Table 3.
CCIS 1992-98: Air Bags

Air bag	Vehicles	
Not fitted	5651	91%
Deployed	312	5%
Not deployed	238	4%
Total	6201	100%

The presence of air bags is shown in Table 3. A large majority of vehicles were not fitted with air bags, and many air bags were not triggered by impact. This left 5% with air bags fitted and deployed.

Table 4.
CCIS 1992-98: Seat Belt Use

Seat belt	Front occupants	
Used	5746	71%
Not used	844	10%
Not known	1516	19%
Total	8106	100%

Details are available on 8106 drivers and front passengers from the 6201 vehicles. Over 70% of these occupants had seat belt use confirmed by physical evidence collected at the vehicle examination. Taking account of the unknown cases, it is likely that over 80% were wearing seat belts. This usage rate is high enough to warrant focussing on the effectiveness of air bags in their intended role in Europe as supplementary restraint systems, used in conjunction with seat belts.

FRONTAL IMPACTS WITH BELTED DRIVERS

With a high rate of seat belt use and the intended role of European air bags as supplements to conventional restraints, drivers known to have not worn their seat belts were excluded from the examination of air bag effectiveness. Occupants who were fully ejected from the vehicle or burnt by fire were also excluded.

It is not uncommon for crashed vehicles to make contact with more than one object during an accident. Here impact type is defined by the *most severe* impact, as assessed by the accident investigators. (There is usually no difference between the most severe vehicle impact and the vehicle impact that results in the most severe injury; where there is, the investigators are required to take injury consequences into account.) If the impact was to the front of the car, and the direction of impact force was within 45 degrees of head on (11 o'clock to 1 o'clock), and the car at no stage rolled over, the impact was defined as a frontal. Of the 3380 frontal impact vehicles mentioned in Table 2, 2711 met these definitional requirements, as shown in table 5.

Table 5. Air Bags

Air bag	Vehicles
Not fitted	2445
Deployed	205
Not deployed	61
Total	2711

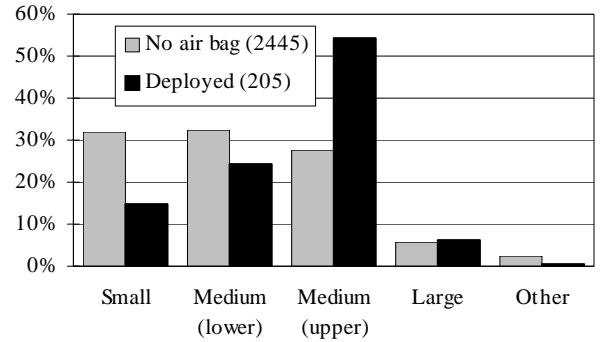


Figure 1. Vehicle size category.

The distribution of vehicle size is shown in Figure 1. Air bag vehicles in the sample tend to be larger than those without air bags: only 39% were categorised as small or lower medium compared to 64% of non air bag vehicles. This probably reflects the phased introduction of air bags into the European fleet via upmarket models.

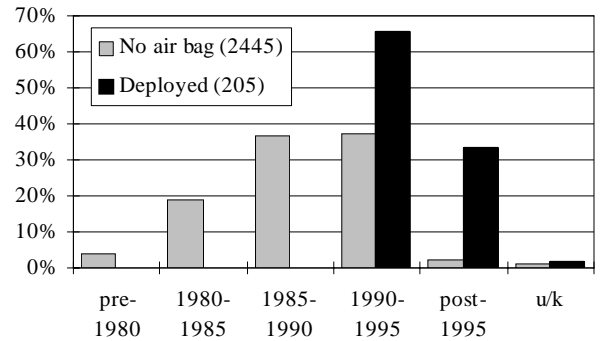


Figure 2. Vehicle year of first registration.

The year of first registration is shown in Figure 2. Vehicles equipped with air bags tend to be newer than vehicles in the comparison group: all vehicles with air bags date from 1990-95, compared to 40% of those without air bags.

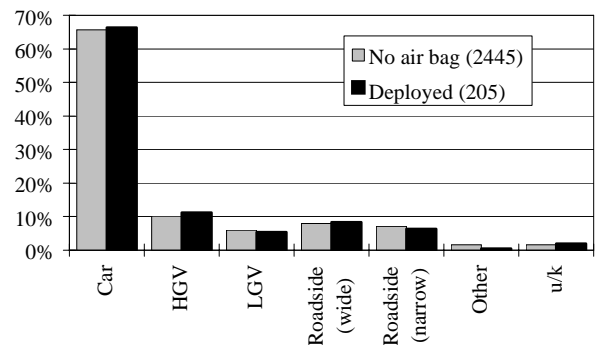


Figure 3. Collision partner (object struck).

The collision partners of the vehicles are shown in Figure 3. Car to car impacts predominate; collisions with heavy goods vehicles (HGV) or light goods vehicles (LGV) are about as frequent as with fixed roadside objects. The distribution is very similar between the air bag and non air bag groups.

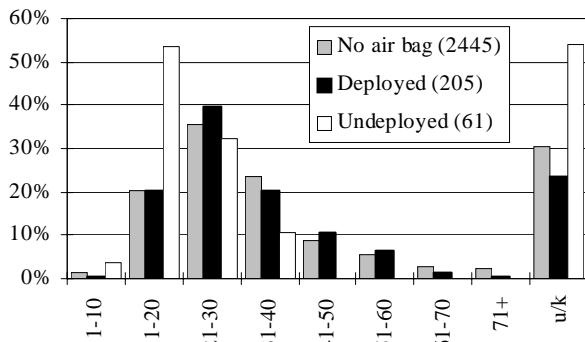


Figure 4. Impact severity—Equivalent Test Speed (km/h).

One measure of impact severity available on the CCIS database is Equivalent Test Speed (ETS), which may be described as the speed with which a vehicle would need to strike a rigid barrier to cause the observed amount of damage. ETS was calculated from vehicle damage (crush profiles) using Crash3—a standard accident reconstruction computer program. There is a close correspondence between the speeds calculated for vehicles without air bags and vehicles with deployed air bags. Where ETS is known, approximately 60% of both groups fall into the 21-40 km/h band with the remaining 40% split equally above and below. In contrast, the vehicles with undeployed air bags peak in the lower range of 11-20 km/h with nothing above 40 km/h.

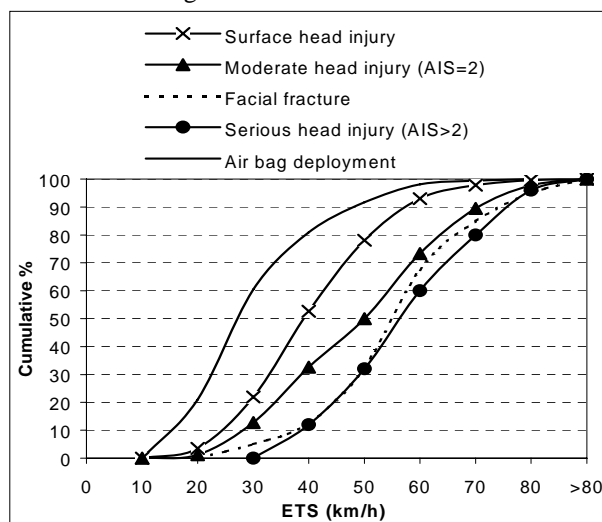


Figure 5. Equivalent Test Speed for air bag deployment and belted drivers with head injury from steering wheel contact in non air bag cars.

In Figure 5 the distribution of ETS for air bag deployments is shown plotted with the ETS distributions for belted drivers who sustained head injury from steering wheel contact in cars not equipped with air bags (Frampton, 1997). There are indications that some air bags may be deploying where the risk of moderate to serious head injury is minimal. One fifth of air bags deployed below 20 km/h where virtually no head injury was sustained from steering wheel contact.

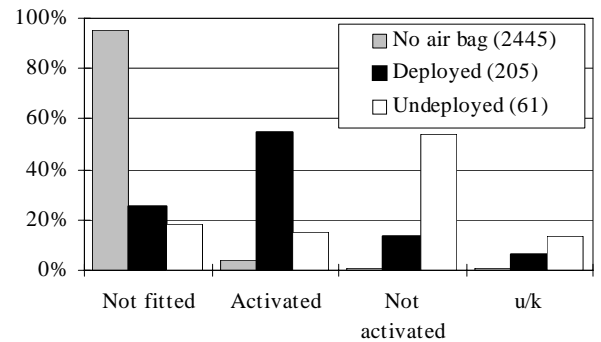


Figure 6. Seat belt pretensioners.

Seat belt pretensioners tend to accompany air bags, and they tend to activate when air bags deploy. Only 5% of non air bag vehicles in the sample were fitted with pretensioners, compared to around 70% of air bag equipped vehicles, as Figure 6 indicates. However where seat belt pretensioners were fitted, the activation rate was 82%, 80%, and 21% for the no air bag, deployed air bag, and undeployed air bag groups respectively.

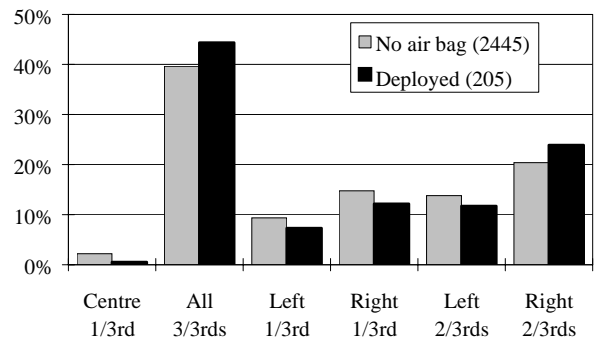


Figure 7. Zone of direct contact on vehicle front end.

Figure 7 shows which thirds of the vehicles' front end came into contact with the object struck. The region of direct contact (partly or wholly) encompassed all three thirds of the front end in 40-45% of cases, and the left or right two thirds of the front end in about 35% of cases. The distribution of contact zones is similar for the air bag and non air bag groups.

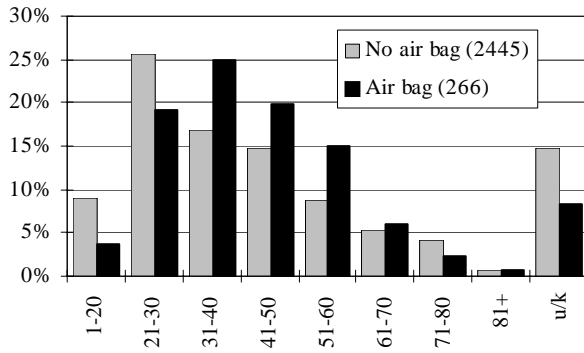


Figure 8. Driver age (years)

Figure 8 shows driver age for vehicles with and without air bags. Drivers of air bag equipped vehicles seem to be older. The modal, or most frequent, age group is 21-30 years for non air bag cars, but 31-40 for the air bag equipped group.

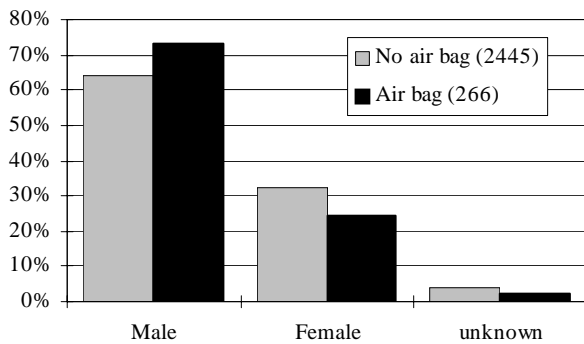


Figure 9. Driver sex.

Figure 9 shows that the proportion of male drivers—already high—is slightly higher for air bag equipped vehicles: 70-75%, compared to around 65% for non air bag vehicles.

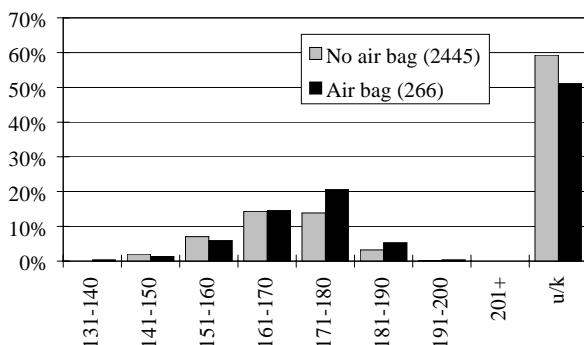


Figure 10. Driver height (cm).

Figure 10 suggests a tendency for drivers from air bag equipped vehicles to be taller: the modal group for non air bag equipped vehicles is 161-170 cm, compared to 171-180

cm for air bag equipped vehicles. This may be a consequence of the higher proportion of males in air bag equipped vehicles. The height of many drivers is not known.

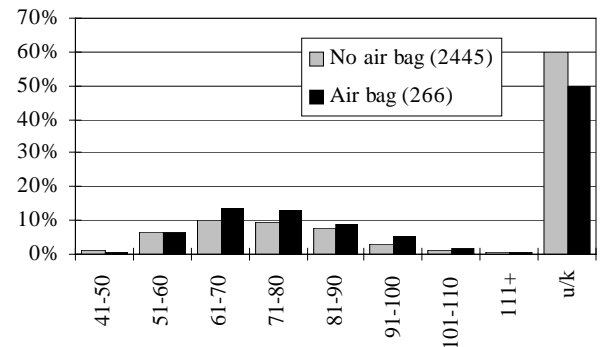


Figure 11. Driver weight (kg).

Figure 11 indicates no clear differences in the distribution of occupant weight. The weight of many drivers is not known.

INJURY PATTERNS OF BELTED DRIVERS IN FRONTAL IMPACTS

As already mentioned, the approach taken in this paper is to detect the influence of air bag on crash injury outcomes by comparing groups of *injured* occupants from air bag and non air bag vehicles. Air bags are designed to improve protection of the head—if this were their only effect, drivers with air bags would incur the same non-head injuries but enjoy a lower incidence or severity of head injury. Therefore among injured drivers from air bag vehicles, there would be a reduction in the ratio of head injuries to non-head injuries, as represented in Figure 12. This is the same thing as a rise in the ratio of non-head injuries to head injuries. In interpreting the 'location of injury' histograms in this section, it should be borne in mind that an increased proportion of non-head injuries does not necessarily imply a reduced level of protection of the chest, abdomen, legs, and so on.

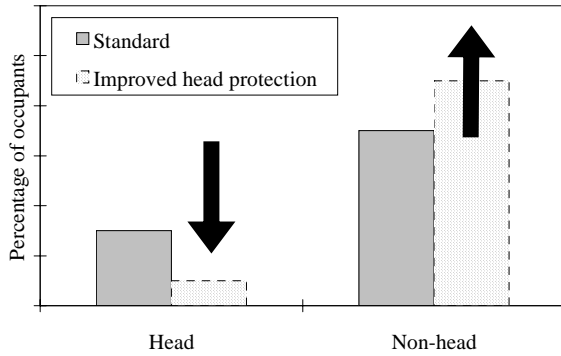


Figure 12. Schematic of how improved head protection may alter the ratio of head to non-head injuries in an injured population.

MAIS distributions and 'location of injury' charts are presented for a number of injured driver populations in this section. The point of showing (similar) MAIS distributions for the air bag and non air bag groups is to support the inference that differences in injury patterns arise from the influence of the air bag, since there would be little validity in drawing this conclusion if air bag fatalities were being compared to non air bag slight injury cases, or vice-versa. The selection of subgroups is intended to identify where the effect of air bags, if present, is most pronounced.

Table 6. Driver MAIS injury severity

	Air bag not fitted	Air bag deployed	Air bag undeployed
Not injured	862	63	32
MAIS 1	992	99	24
MAIS 2	367	28	5
MAIS 3	137	9	0
MAIS 4	35	2	0
MAIS 5	34	3	0
MAIS 6	18	1	0
Total	2445	205	61

The distribution of MAIS injury severity for drivers from frontal impacts is shown in Table 6. Uninjured drivers cannot contribute to the investigation of injury patterns, and the number of injured drivers from the undeployed group is rather low to sustain analysis. This leaves 1583 and 142 injured drivers from the non air bag and air bag deployed groups respectively as the main basis for analysis. Figure 13 shows that the distribution of maximum injury severity for the two groups is quite similar: 63-70% MAIS 1, 20-23% MAIS 2, and 11-14% MAIS 3-6.

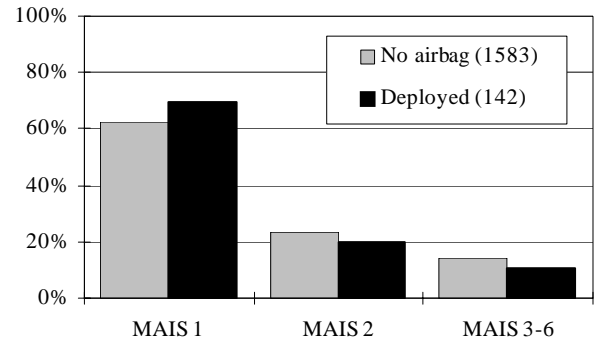


Figure 13. Maximum injury severity.

The location on the body of each driver's most severe injury is shown in Figure 14. Where an occupant had more than one body region with equally severe injuries, the body regions were weighted accordingly. For example, if an occupant had injuries of MAIS level to the chest and legs, the MAIS location was assigned 0.5 to the chest and 0.5 to the legs; similarly, if injuries of MAIS severity occurred in three regions, each region was assigned 0.33.

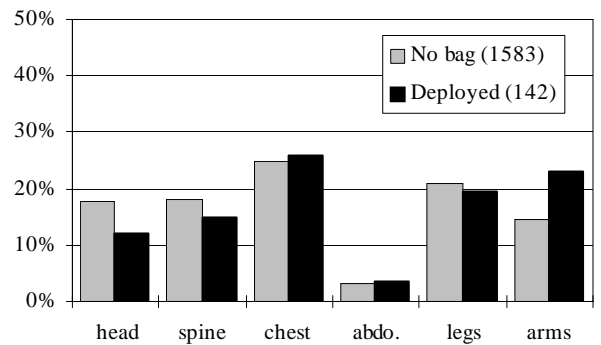


Figure 14. Location of most severe injury.

The most severe injury was only occasionally abdominal—about 3% of occupants. The chest was the most common individual site, at around 25%; the other four regions took shares around the 15-20% range. Drivers from air bag deployed vehicles had their most severe injury less often to the head and more often to the arms.

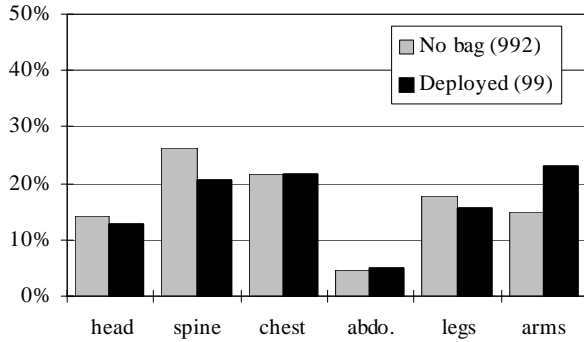


Figure 15. Location of most severe injury for MAIS 1 drivers.

Among MAIS 1 occupants, Figure 15 suggests a shift towards proportionally more arm injury and away from spinal (and neck) injury for the air bag group. The types of injury alluded to in this chart are mainly superficial bruises, abrasions and lacerations, except for the spine, which is mainly whiplash (muscle strain).

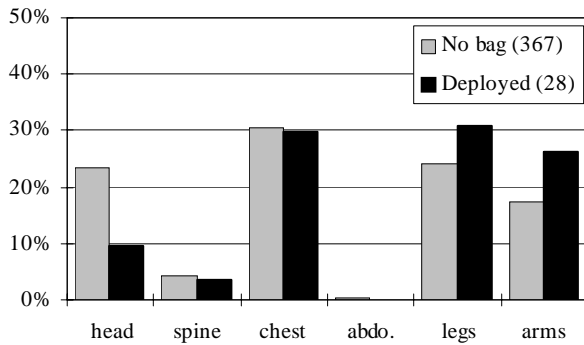


Figure 16. Location of most severe injury for MAIS 2 drivers.

Among MAIS 2 occupants, few occupants had their most severe injury located in the spine or abdomen. Figure 16 suggests a shift away from head injury among drivers from air bag vehicles.

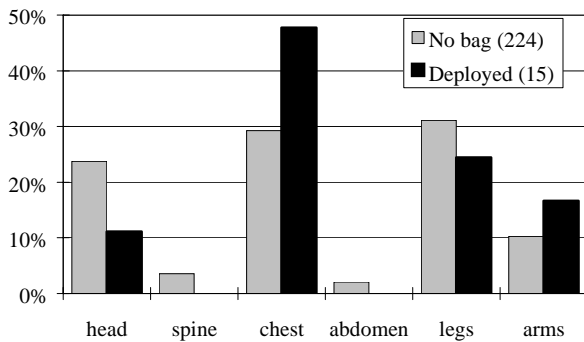


Figure 17. Location of most severe injury for MAIS 3-6 drivers.

Among MAIS 3-6 occupants, Figure 17 also suggests a shift away from head injury, in this case mainly towards

the chest. With only 15 drivers from air bag deployed vehicles in this category, these results are liable to be erratic.

Figure 13 to Figure 17. Two trends emerge for drivers from air bag deployed vehicles: the head is less often the location of the most severe injury, particularly at the MAIS 2 and MAIS 3-6 levels; and the arms are more often the location of the most severe injury. At the higher injury severity levels, the incidence of the head being the most severely injured region is less than half, 10% compared to 23%; for the arms at all severities, the incidence is 23% compared to 15%. These results are consistent with the mitigation of head injury and the aggravation of arm injury in air bag deployed vehicles. At MAIS 1 level, the spine (and neck) is a common site of injury and there is a lower incidence among the air bag deployed group. This result should be interpreted with caution, since air bags tend not to deploy at the lowest impact severities when MAIS 1 outcomes and reports of whiplash are quite common. The air bag group is therefore probably understocked with these cases compared to the non air bag group (cf. Figure 4). Whiplash is discussed separately in connection with Table 7 below. A second result that should be interpreted with caution is the relatively high incidence the chest as the location of the most severe injury among the air bag group at the MAIS 3-6 level. The sample size supporting this result is low and other results in this paper do not support the conjecture that air bags are detrimental to the chest.

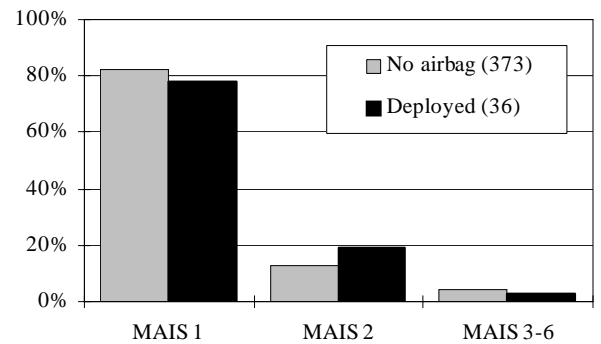


Figure 18. Distribution of MAIS for drivers with injury to one body region only.

About one quarter of drivers had injury to only one body region: 373 from non air bag group vehicles and 36 from air bag vehicles. The distribution of MAIS for these occupants is shown in Figure 18. The two groups were generally lightly injured, with around 80% MAIS 1 and less than 5% MAIS 3-6.

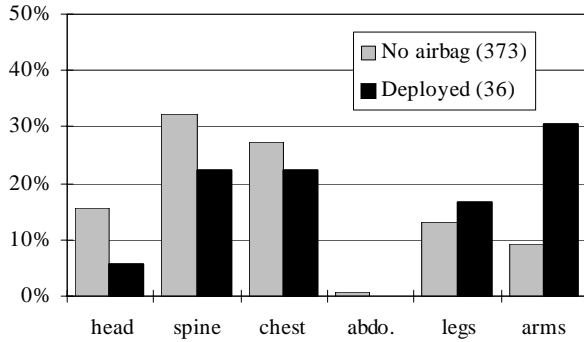


Figure 19. Location of injury for drivers with injury to one body region only.

Figure 19 shows where drivers with only one injured body region were injured. The most marked difference between the two groups of occupants is in the region of the arms: 31% for the air bag group compared to 9% for the non air bag group. This suggests that drivers of air bag deployed vehicles are specifically vulnerable to localised arm injuries, under circumstances when they may otherwise have been uninjured. The difference in spinal and neck injury is the whiplash phenomenon discussed above.

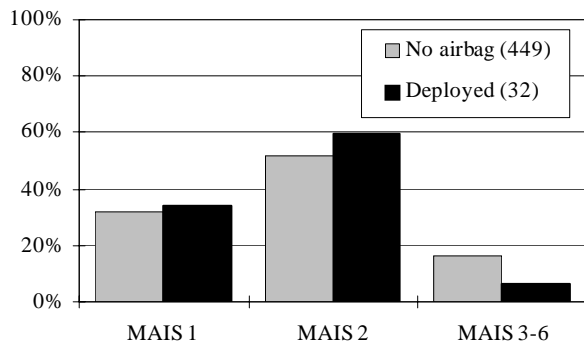


Figure 20. Distribution of MAIS for drivers with skeletal or internal injury to one body region.

Figure 20 shows the distribution of MAIS for drivers with injury to the skeletal system (mainly fractures) or internal organs in exactly one body region. There are 449 drivers from non air bag vehicles and 32 drivers from air bag deployed vehicles in this category. Lesions of the skin, brief loss of consciousness, and whiplash (muscle strain) are the main common types of injury not considered here. This group tends to be drawn from the intermediate range of injury severity. The distribution of MAIS for the two groups is similar, with over half having injury at MAIS 2 level. The MAIS 1 level injuries are mostly bone fractures.

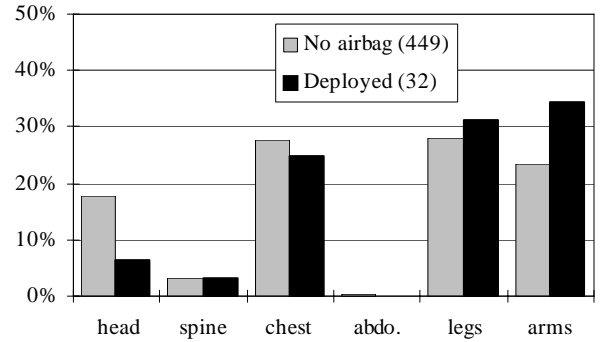


Figure 21. Location of injury for drivers with skeletal or internal injury to one body region.

Figure 21 shows where the skeletal or internal injury was located for these groups. The difference between the two groups is greatest in the region of the head and arm, indicating that the air bag influences injuries of this nature. The incidence of head injury is lower among drivers from air bag vehicles (6% compared to 18%) but arm injury is higher (34% compared to 23%).

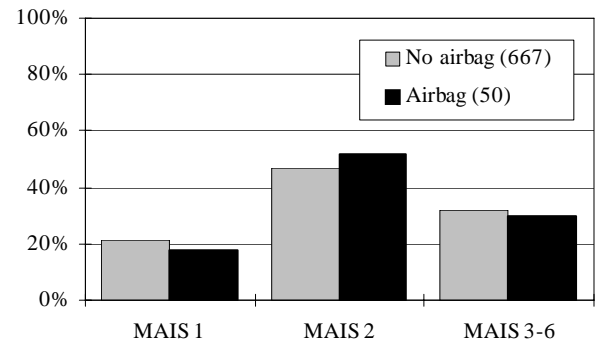


Figure 22. Distribution of MAIS for drivers with skeletal injury.

Over one quarter of injured drivers suffered skeletal injury (mainly fractures): 677 from non air bag vehicles and 50 from air bag vehicles. The distribution of MAIS for these occupants is shown in Figure 22 and is similar for the two groups. This subpopulation includes most injured drivers with MAIS 2 or MAIS 3-6 injuries (90%) but only a minority of MAIS 1 drivers (10-15%).

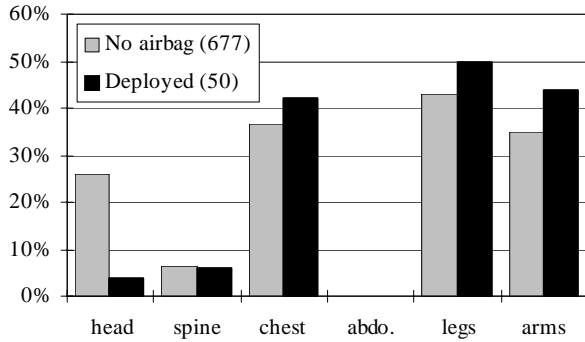


Figure 23. Location of skeletal injury.

Figure 23 shows where skeletal injuries occurred. The totals add up to more than 100% because occupants could have fractures to more than one body region. The abdomen was defined to include no bony structures and therefore registers zero. A distinctly lower proportion of drivers from air bag vehicles had fractures to the face or skull compared to drivers from non air bag vehicles (4% compared to 26%). This reduction is balanced by an even spread of increased incidence to the arms, legs, and chest (5-10%). This result strongly indicates that air bags provide protection against head fractures.

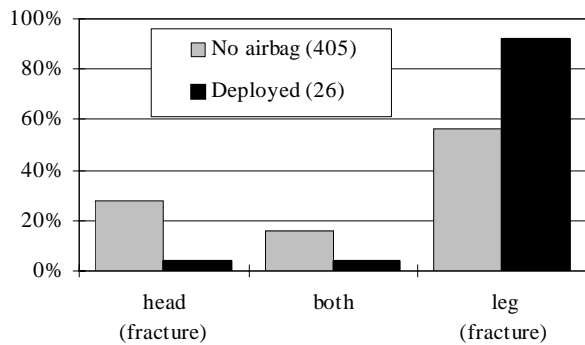


Figure 24. Ratio of occupants with head fractures and leg fractures.

In elaboration of Figure 23, Figure 24 shows the overlap between head and leg fractures for the 405 drivers from non air bag vehicles and the 26 drivers from air bag vehicles who had these injuries. Among the non air bag group, 28% had a head fracture but no leg fracture; 56% had a leg fracture but no head fracture; and 16% had both head and leg fractures. These proportions are markedly different for drivers of air bag deployed vehicles, with a shift away from head fractures, albeit on low numbers—there is only one air bag driver in the 'head (fracture)' and 'both' categories. This change of balance is repeated for head and chest fractures shown in Figure 25.

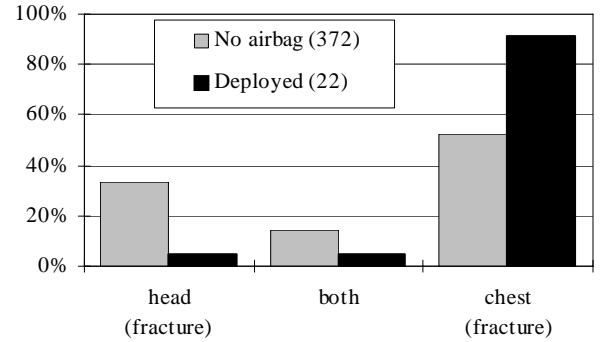


Figure 25. Ratio of occupants with head fractures and chest fractures.

The relationship between head, chest and leg fractures suggests a strong shift away from the head for drivers from air bag vehicles. These occupants were in impacts serious enough to cause leg and chest fractures but did not incur the higher ratio of facial and skull fractures experienced by the non air bag group.

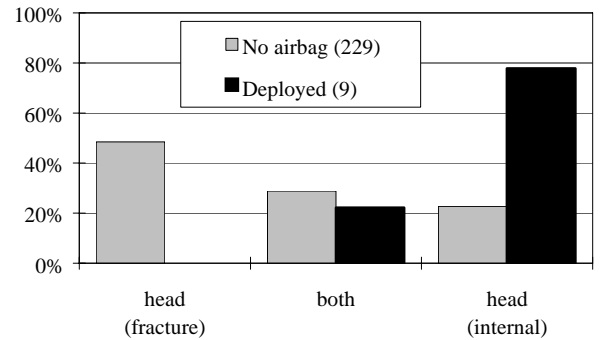


Figure 26. Ratio of occupants with head fractures and internal head injury.

Figure 26 shows the overlap between head fractures and internal head injuries (excluding brief loss of consciousness, amnesia, and other AIS 1-2 head injuries.) None of the 9 drivers from air bag deployed vehicles in this category incurred a head fracture without brain injury, in contrast to close to half of the non air bag group. This early result suggests that air bag equipped vehicles are more protective against head fractures than internal head (brain) injury. It should be noted that the number of occupants from air bag vehicles available to support this conjecture is low, only nine, and the result is therefore tentative.

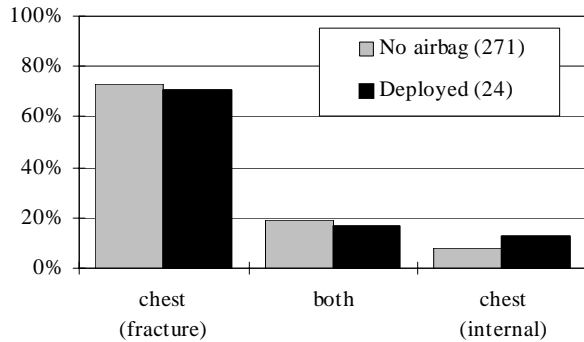


Figure 27. Ratio of occupants with chest fractures and internal chest injury.

Figure 27 shows the overlap between chest fractures and internal chest injuries. There is essentially no difference between the air bag and non air bag groups. This implies that air bags have an equal influence on the skeleton and internal organs of the chest, unlike the head. For seat belted drivers, based on the trends apparent in the data so far, it is probably a neutral influence.

Table 7. Brief loss of consciousness and whiplash.

	Air bag not fitted (1583)	Air bag deployed (142)	Air bag not deployed (29)
Brief LOC	141 9%	5 4%	3 10%
Whiplash	599 38%	48 34%	17 59%

Brief loss of consciousness and whiplash were excluded from several analyses above. Table 7 shows a lower incidence of brief LOC among injured occupants from air bag vehicles than among those from non air bag vehicles: 4% compared to 9%. The incidence of whiplash among injured occupants from air bag and non air bag vehicles is 34% and 38% respectively. The high whiplash result for drivers from vehicles with undeployed air bag probably arises from an association between low impact severity and a high level of reported whiplash. If the two air bag groups are aggregated, there is no difference in the incidence of whiplash in air bag and non air bag vehicles (38%).

DISCUSSION

The results presented in the preceding sections cover various aspects of collision circumstances, vehicles, occupants, and injuries relevant to an assessment of air bag effectiveness. Vehicles with air bags in the CCIS sample are larger, more modern, and more often fitted with seat belt pretensioners than vehicles without air bags, and there appears to be a higher quotient of older males in the air bag equipped cars. On the other hand, the severity of impact (ETS), the objects struck, and the degree of frontal offset are very similar between the two groups. The differences associated with air bags-vehicle

age, size, pretensioners etc.-are undoubtedly relevant to injury outcomes, but how important compared to air bags is difficult to say. With a relatively low sample size, there is little option but to acknowledge that any differences in injury outcomes are a collective effect of all these factors.

The strongest finding noted in the tables and charts above is an apparently dramatic drop in the proportion of injured drivers from air bag deployed vehicles with facial or skull fractures. This is based on 50 drivers with skeletal injury (in any body region). With the number of relevant cases in the CCIS database rapidly growing, however, we retain an open mind on the robustness of this phenomenon. Interestingly, the first nine drivers from air bag deployed vehicles in the database with head fractures or significant brain injury showed no fractures without brain injury, unlike half of the non air bag comparison group. If air bags provide equal protection to the skeleton and brain, the proportion of fractures to brain injuries should remain steady. This result therefore raises the possibility that European SRS air bags are providing a greater benefit for the bony facial structures and cranium than for the brain, although it should be added that results for the whole head (skeleton and internal organs) also look positive.

A second consistent trend to emerge from the analysis is that drivers from air bag deployed vehicles have arm injuries more often than the law of averages would seem to dictate. In particular, there is a substantially higher proportion of drivers with injuries *only* to the arms among the air bag group. Although these are mainly minor AIS 1 lesions, the trend apparently persists into the higher levels of injury severity. It would of course be no surprise if the arms were vulnerable to injury, because of their close proximity to the steering wheel and inflating air bag during impact. No clear, consistent trends indicating an influence of the air bag on other body regions were identified.

A review of injuries specifically attributed to the air bag in the CCIS database revealed almost entirely bruises, abrasions, strains, and sprains, mainly to the face and arms. It is difficult, however, for anyone to judge in each individual case whether these common, minor injuries are introduced by the air bag or whether the air bag merely fails to prevent their occurrence, and they therefore have not been presented in detail. On the other hand, unusual injuries or exceptional circumstances of injury like those reported from North America would be noted by the crash investigators. Our examination of the CCIS database and a number of case files unearthed no such instances and we are not aware of opinion among the investigators that abnormal events are occurring with deployed air bags.

Finally there is every indication that air bags generally deploy at impact levels that pose a statistical risk of significant head injury. A proportion also deploy at low

crash severities, below where head injury occurs in non air bag equipped vehicles. There may be good technical reasons for initiating deployment at low crash severities to ensure the air bag always deploys at the threshold where head injury begins to occur.

Future work on the effectiveness of SRS air bag systems could profitably focus on head and arm injuries, particularly the relationship between facial fractures, skull fractures, and brain injury. As more data becomes available, it would be helpful to account for the separate influence of vehicle mass and other safety features associated with air bags in the European fleet. With a different method of analysis, the CCIS database may also support an assessment of the 'absolute' effectiveness of air bags in mitigating (or aggravating) occupant injury—this would be an assessment of the proportion of injuries prevented in real accidents by air bags.

CONCLUSIONS

Based on the data collected by the UK Co-operative Crash Injury Study, which currently includes details on over 140 seat belted drivers injured in frontal impacts with deployed air bags:

(1) Air bag deployment is associated with larger, more modern cars, seat belt pretensioners, and an older, more male driving population.

(2) Air bags generally appear to deploy in impacts that pose a statistical risk of significant head injury—when they are needed—and also in less severe impacts.

(3) Compared to injured drivers from non air bag vehicles, injured drivers from air bag deployed vehicles incur proportionally less head injuries and proportionally more arm injuries. The favourable head injury result arises most directly from a reduction in fractures. No clear, consistent trends indicating an influence of the air bag on the spine, chest, abdomen, or legs have been identified.

(4) No specific, exceptional types of injury or circumstances of injury associated with air bags have been identified.

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The views expressed in this paper are entirely those of the authors. The results and review of past work in the first half of the paper originate mainly from the research of R. Frampton; responsibility for the results in the second half and the overall co-ordination of the paper lies mainly with J. Lenard.

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