

THE EFFECT OF OCCUPANT CHARACTERISTICS ON INJURY RISK AND THE DEVELOPMENT OF ACTIVE-ADAPTIVE RESTRAINT SYSTEMS

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ABSTRACT

"Smart" restraint systems are being researched and developed. However, whilst technology can ultimately be produced that will give rise to adaptive restraint systems, injury research is necessary in order to identify and quantify the most important occupant characteristics. This is necessary to ensure that future adaptive restraint systems are optimised.

12,605 car occupant records from phases 4 and 5 of the UK Co-operative Crash Injury Study (CCIS) were analysed to establish the injury potential for front seat occupants in both frontal and side impacts. Casualties were grouped by gender, seating position and injury severity, with the latter measured in relation to the Maximum Abbreviated Injury Scale (MAIS). Data from a further 4,758 accidents contained within a Fatals database was also incorporated into the analysis.

Cumulative frequency graphs for occupant characteristics such as age, weight, height and Body Mass Index (BMI) were produced against accident parameters, such as injury severity (MAIS) for each occupant grouping. The aim was to identify specific occupant characteristics for which active-adaptive restraint systems might confer the most significant injury reductions.

This paper describes and discusses the analysis and identifies casualty groups who are at above average risk in frontal and side impacts. For example, in frontal impacts male drivers with a high BMI were shown to be at an increased risk of serious injury, compared with male drivers with an 'average' BMI. The effect of each occupant characteristic on injury severity in frontal and side automobile collisions are described and discussed and their implications for active-adaptive restraint systems emphasised.

INTRODUCTION

Intelligent restraint systems adapt to specific occupant characteristics in order to minimise injury severity. Therefore, the analysis of occupant

characteristics with respect to their effect on injury severity is a necessary step to design and optimise active-adaptive restraint systems. This paper describes the analysis procedure and identifies casualty groups who are at above average risk in frontal and side impacts. The effect of each occupant characteristic on injury severity is discussed in terms of the implications for active-adaptive restraint systems.

Accident data from the Co-operative Crash Injury Study (CCIS) and the Fatals database were used in order to identify occupant characteristics, and associated body regions of injury, for which active adaptive technology might confer the most benefit in terms of injury mitigation.

METHOD

CCIS Data Sources

Phases 4 and 5 of the Co-operative Crash Injury Study (CCIS) were analysed. This data comprised 9,260 car occupants involved in qualifying accidents that occurred between June 1992 and March 1996 in which the vehicle was damaged sufficiently for it to be towed from the scene. An additional analysis of CCIS phases 1 to 3 was performed by Julian Hill, Alan Kirk and others at BARC, the results of which are referenced throughout the paper.

Each occupant characteristic was investigated by plotting cumulative frequency graphs in order to compare the distribution of each characteristic by injury severity. Statistical tests were employed to assess the significance of any observed trends.

Occupant characteristics. The CCIS data was filtered based on the following parameters:

Occupant parameters

- Front seat occupants (drivers and front seat passengers)
- Correctly seated occupants
- Seatbelts fitted and in use at time of accident

Vehicle parameters

- Single impact on vehicle
- Frontal or side impact damage, depending on analysis
- Frontal impacts: principal direction of force between 10 and 02 o'clock inclusive
- Side impacts: principal direction of force between 01 and 05 o'clock or 07 and 11 o'clock inclusive

Accident parameters

- No fire involved
- No vehicle rollover involved

The occupant characteristics investigated were age, height, weight and Body Mass Index (BMI). This paper focuses on the BMI and age of the occupant, since the effects of height and weight on injury risk are incorporated within BMI. The BMI was derived using the following equation.

$$\text{BMI} = \text{weight (kg)} / (\text{height (m)})^2$$

Front seat occupants were analysed as follows:

- Male Drivers
- Female Drivers
- Male Front Seat Passengers (FSPs)
- Female Front Seat Passengers (FSPs)

For each occupant type, a range of accident parameters was investigated. These parameters were compared against injury severity in order to attempt to identify any important trends. Injury severity was measured by examining the Maximum AIS (MAIS) injury, which represented the most severe injury according to the Abbreviated Injury Scale (AIS, 1990). The analysis examined how the occupant characteristics affected injury outcomes for each type of occupant.

To analyse any apparent differences, indicated by diverging cumulative frequency plots, a test for differences in median values was performed on the appropriate data range. Mann-Whitney tests were used which examined the values and ranked them in order of magnitude; the test returned a P-value that related to the probability that the groups of data had significantly different median values.

The analysis was somewhat limited by low sample sizes, especially for the side impacts section. This was due to the filtering procedure, which reduced the number of records that were available for analysis. The main reason for this was that many of the

occupant characteristics were not recorded in sufficient detail in the CCIS data from 1992 to 1996. Thus, when occupant characteristics such as height or weight were used, much of the sample was lost due to the values being unavailable. Thus, in some cases statistical significance could not be achieved since apparently obvious differences may have been due to random factors.

Furthermore, the measurement of MAIS relates only to the most severe injury of the occupant, and did not contain any information on the location or total number of injuries. This variable is frequently used as an approximation of injury, although the overall accuracy of MAIS must be considered when deriving conclusions about injuries from this data.

The accident data was also analysed by crash severity (ETS), although the results of this analysis are not presented here. This analysis yielded no significant correlations when $\text{MAIS} \geq 2$ injuries were considered, although trends were observed for higher crash severities to be associated with younger occupant age and greater occupant weight.

Fatals Database

Data. The Fatals database consists of information collected from police accident reports on accidents that resulted in at least one fatality in Great Britain. The data used for the analysis comprised 4,758 accidents.

Method of analysis. Data was then selected according to compliance with the following criteria:

- Occupants in a car or car derivative
- Single impact on vehicle
- Front seat occupants only
- Belted occupants only
- Non fire-related

This analysis was repeated for four separate accident groups: frontal impacts, offside impacts, nearside impacts and rear impacts. The tests were considered significant if the P-value was equal to or less than 0.05 (i.e. the 95% confidence level).

A combination of a further two variables, impact location and impact direction were used to specify that the main impact direction was normal to the impact location. The tolerance of the impact direction was approximately $\pm 20^\circ$ and the data therefore included some angled impacts.

For side impacts, it was considered that the seating position relative to the impact site was more relevant, since the movement of the occupants in an accident is likely to be parallel to the fascia and steering wheel. Consequently, the data were manipulated to give the information for occupants seated on the struck, and non-struck sides of the vehicle. As with frontal impacts, all impacts with an impact direction more than 20° from normal (in relation to the impact location) were necessarily excluded. In angled impacts it was considered that the crush dynamics of the vehicle may be markedly different, therefore influencing injury type, and diluting the most important trends in the accident data.

RESULTS

CCIS Database

Presenting the results of every analysis performed is beyond the scope of this paper. However the most important results relating to occupant age and BMI are presented below and these findings are discussed in Section 4.

It should be noted that this paper is based on work undertaken to identify the main occupant characteristics that affect injury risk. This paper analyses each characteristic separately to identify the important factors. Further multivariate analysis of the data is required to assess the degree to which the factors are interrelated. The more detailed research on which this paper is based, employed multivariate analysis techniques and found there are significant benefits that active adaptive safety may provide to occupants who have characteristics at the extreme of those found in the population.

Frontal impacts

Occupant age

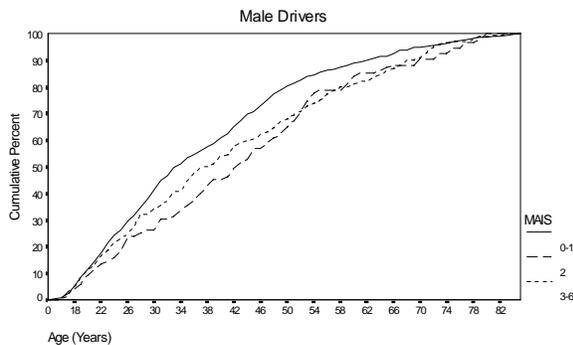


Figure 1. Male Drivers

Table 1. Male Drivers

MAIS	Age (years)									
	N	10%ile	20%ile	30%ile	40%ile	50%ile	60%ile	70%ile	80%ile	90%ile
0-1	631	20.0	23.0	27.0	30.0	34.0	40.0	45.0	50.0	62.8
2	185	20.0	24.0	28.0	33.0	38.0	44.6	52.0	59.6	68.8
3-6	95	20.6	26.0	31.0	37.4	43.0	48.0	52.2	59.0	71.2

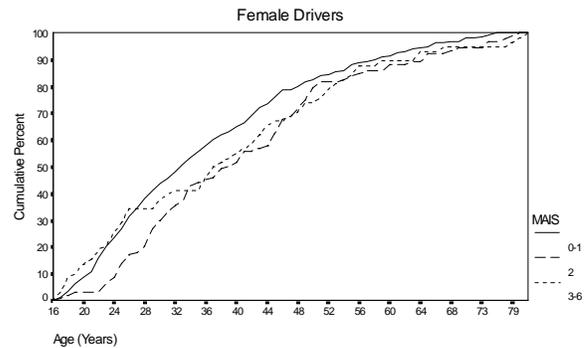


Figure 2. Female Drivers

Table 2. Female Drivers

MAIS	Age (years)									
	N	10%ile	20%ile	30%ile	40%ile	50%ile	60%ile	70%ile	80%ile	90%ile
0-1	329	21.0	23.0	26.0	29.0	33.0	37.0	43.0	49.0	59.0
2	94	25.0	28.0	30.5	34.0	39.5	45.0	48.0	51.0	65.0
3-6	58	18.9	22.8	25.7	31.6	37.5	43.0	48.3	53.2	64.0

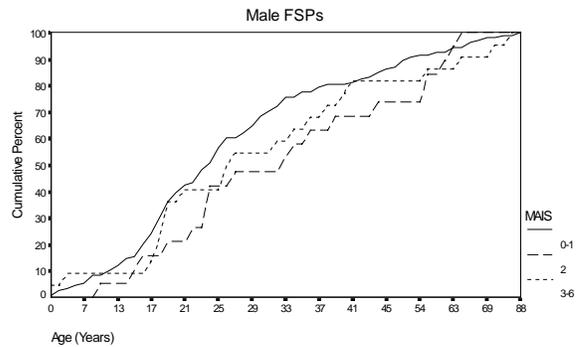


Figure 3. Male Front Seat Passengers

Table 3.
Male Front Seat Passengers

MAIS	Age (years)									
	N	10%ile	20%ile	30%ile	40%ile	50%ile	60%ile	70%ile	80%ile	90%ile
0-1	107	12.8	16.6	18.4	21.0	24.0	27.6	31.6	39.2	51.6
2	19	15.0	19.0	24.0	24.0	33.0	36.0	44.0	55.0	63.0
3-6	21	17.2	18.4	19.0	25.0	27.0	34.4	38.8	49.4	72.8

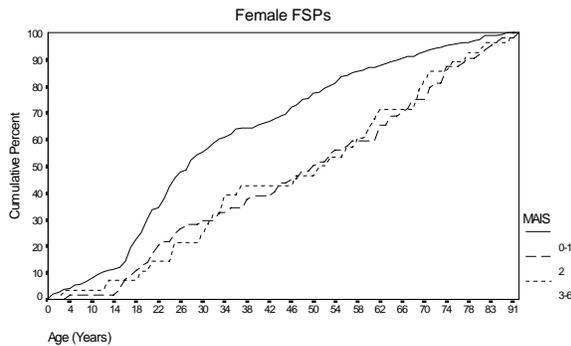


Figure 4. Female Front Seat Passengers

Table 4.
Female Front Seat Passengers

MAIS	Age (years)									
	N	10%ile	20%ile	30%ile	40%ile	50%ile	60%ile	70%ile	80%ile	90%ile
0-1	209	13.0	18.0	20.0	24.0	28.0	33.0	46.0	53.0	66.0
2	64	17.5	22.0	31.5	43.0	50.5	62.0	66.5	72.0	79.0
3-6	28	18.4	25.0	31.7	35.8	52.0	58.8	64.1	70.2	78.4

All occupant types exhibited a tendency for increasing age to be associated with increasing injury severity. This may be verified by examination of the overall age distribution in Tables 1 to 4 and Figures 1 to 4. Statistical tests showed that when considering male drivers and FSPs of both sexes, there was a significant trend ($P < 0.001$) for the median age of occupants suffering MAIS injuries greater or equal to AIS 2 to be greater than those with injuries of MAIS 0-1. Female drivers also exhibited a strong tendency for this difference, but the difference between trivial (MAIS 0-1) and non-trivial injuries ($\text{MAIS} \geq 2$) was not statistically significant ($P = 0.0794$).

The most severely injured casualties (MAIS 3-6) showed median ages between 3 and 24 years greater

than for occupants sustaining MAIS 0-1 injuries (see Tables 1 to 4). However, there were no significant differences found for any occupant type when considering differences in median age between MAIS 2 and MAIS 3-6 injuries.

These results accord well with Hill *et al* (1998) who also demonstrated a statistically significant trend for male drivers and female drivers to have greater median ages for MAIS injuries greater than 2, when compared to trivial injuries (MAIS 0-1). Female FSPs were also shown to have significantly ($P < 0.05$) more severe injuries (MAIS 3-6) at ages over 65 years compared with MAIS 2 injuries over the same age range.

Occupant weight. Analysis of cumulative frequency plots for this factor showed that male drivers exhibited a trend for greater weights to be associated with MAIS 3-6 injury. However this trend was not statistically significant when compared with lower injury severities. The results also showed a tendency for female drivers less than 70kg to sustain more serious (MAIS 3-6) injuries. However, this was not a significant difference, and may be explained by the small number of cases (15) in this weight range. The low sample size for front seat passengers prevented any meaningful analysis from being performed. Overall, this data showed little evidence that weight has any significant effect on the injuries incurred by any particular occupant type. This was also the conclusion of Hill *et al* (1998).

Occupant height. In CCIS Phases 4 and 5, occupant height was recorded to the nearest 0.1m, resulting in some detail regarding this characteristic being lost. However, analysis of the data showed a trend for male drivers over 1.8m and female drivers under 1.5m to be associated with greater injury. However, these differences were not statistically significant. Despite the fact the CCIS Phases 1 to 3 recorded height more carefully, Hill *et al* (1998) also concluded that there was no statistically significant correlation between occupant height and the severity of the injury sustained that could be identified from the injury data.

Occupant Body Mass Index (BMI). The BMI cumulative frequency graphs for drivers of both sexes are presented below. However, the graphs for FSPs have been excluded because the sample sizes involved were less scientifically rigorous.



Figure 5. Male Drivers

Table 5. Male Drivers

MAIS	BMI (kg/m ²)									
	N	10%ile	20%ile	30%ile	40%ile	50%ile	60%ile	70%ile	80%ile	90%ile
0-1	329	21.0	22.2	23.4	24.4	25.3	26.2	27.0	28.3	29.6
2	100	20.4	21.6	22.5	23.6	25.5	26.3	27.3	28.3	33.0
3-6	37	20.0	21.7	22.9	24.2	25.9	27.1	28.2	28.7	31.2

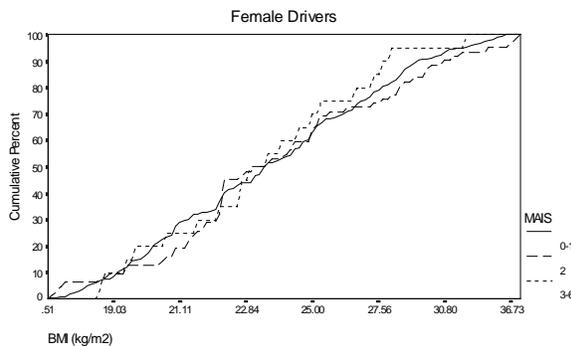


Figure 6. Female Drivers

Table 6. Female Drivers

MAIS	BMI (kg/m ²)									
	N	10%ile	20%ile	30%ile	40%ile	50%ile	60%ile	70%ile	80%ile	90%ile
0-1	193	19.5	20.6	21.5	22.4	23.4	25.0	26.1	28.0	29.3
2	58	20.8	21.5	22.3	22.3	23.8	25.0	26.5	28.8	31.1
3-6	20	18.9	20.1	21.7	22.7	23.1	24.2	25.2	27.1	28.1

Table 7. Male Front Seat Passengers

MAIS	BMI (kg/m ²)									
	N	10%ile	20%ile	30%ile	40%ile	50%ile	60%ile	70%ile	80%ile	90%ile
0-1	53	16.0	19.7	20.7	21.9	22.8	24.1	25.6	26.3	28.6
2	8	18.0	22.1	23.4	23.5	28.8	24.4	25.6	27.4	.
3-6	3	17.7	17.7	18.7	20.8	22.8	22.9	23.0	.	.

Table 8. Female Front Seat Passengers

MAIS	BMI (kg/m ²)									
	N	10%ile	20%ile	30%ile	40%ile	50%ile	60%ile	70%ile	80%ile	90%ile
0-1	96	18.7	20.4	21.1	22.2	22.4	23.9	25.0	27.2	30.4
2	23	19.1	20.0	20.8	22.1	22.7	25.0	25.4	27.5	31.6
3-6	10	20.8	21.6	22.0	22.2	22.3	23.2	24.9	27.8	32.4

Considering occupant BMI, female drivers exhibited a trend for higher MAIS injury at BMI values between 25kg/m² and 28 kg/m², although the divergence of the MAIS 3-6 cumulative frequency plot from lower MAIS injuries was not significant (See Figure 6) and the trend may be because of the low number of cases in this group. Male drivers exhibited a trend for higher BMI values to be associated with greater injury severity (see Figure 5 and Table 5). This non-significant trend was also noted by Hill *et al* (1998). The cumulative frequency graphs for FSPs have small samples for the higher MAIS groups and therefore could not be reliably compared. As found by Hill *et al* (1998) there was no statistically significant relationship between MAIS and BMI, and this can be easily seen by examining the median BMI values for each injury severity in Tables 5 to 8.

Side impacts. Lateral impacts were analysed using the same methodology as for frontal impacts. The sample size for side impacts was smaller than for frontal impacts, and for this reason, only selected graphs and tables are presented in the following sections. The analysis of side impact data was especially limited by the small sample of occupants sustaining higher injury severities. The following analysis relates to occupants on the ‘struck side’ of the vehicle.

Occupant age.



Figure 7. Male Drivers

Table 9. Male Drivers

MAIS	Age (years)									
	N	10%ile	20%ile	30%ile	40%ile	50%ile	60%ile	70%ile	80%ile	90%ile
0-1	96	19.0	24.0	27.1	31.0	34.5	41.0	48.7	60.2	67.9
2	29	23.0	28.0	31.0	34.0	40.0	44.0	51.0	71.0	74.0
3-6	56	19.7	26.0	28.0	32.0	34.5	43.2	58.9	66.2	80.3

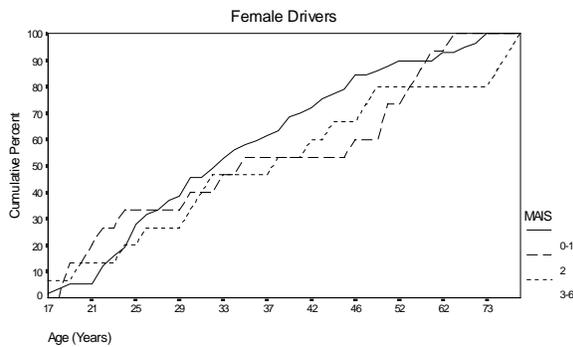


Figure 8. Female Drivers

Table 10. Female Drivers

MAIS	Age (years)									
	N	10%ile	20%ile	30%ile	40%ile	50%ile	60%ile	70%ile	80%ile	90%ile
0-1	57	22.0	24.6	26.0	30.0	33.0	36.8	41.6	46.0	62.0
2	15	19.0	21.2	23.6	31.2	35.0	49.0	51.6	56.4	61.4
3-6	15	18.8	24.4	29.2	31.4	39.0	43.2	47.2	69.6	78.0

Considering the entire age range for drivers, there was no significant difference in injury severity when considering MAIS 0-1 and MAIS 3-6. When considering ages greater than or equal to 55, a significant difference between the MAIS 0-1 and MAIS 3-6 cumulative frequency plots for female drivers ($P < 0.05$) was identified, indicating a tendency for more severe injury at older ages.

Also tested was the apparent trend for young female drivers ($\text{age} \leq 25$) to be associated with higher MAIS injury, as noted by Hill *et al* (1998), however, this trend was found to be non-significant.

Occupant weight. The data from CCIS Phases 4 and 5 was limited by small sample sizes, which meant that no significant differences were identified. However, Hill *et al* (1998) found a non-significant trend ($P = 0.0648$) for heavier male drivers to be associated with more severe injuries (MAIS 3-6) and it is possible that a real difference may exist if the sample size available were larger. In addition, female drivers under 67kg showed a significant trend for MAIS 2 injuries to be associated with lower weight than MAIS 0-1 injuries ($P < 0.05$). This trend was also noted in the Phase 4 and 5 data, but sample size limitation prevented meaningful analysis of the trend. Similarly, the data for FSPs was insufficient to enable any differences to be identified.

Occupant height. Hill *et al* (1998) found that taller male drivers were susceptible to more serious (MAIS ≥ 2) injuries ($P < 0.05$), and that taller female drivers were at a significantly greater risk of MAIS 3-6 injuries when compared with MAIS 2 injuries ($P < 0.05$).

Occupant BMI.

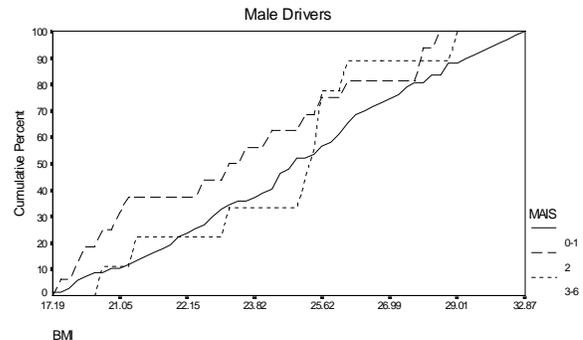


Figure 9. Male Drivers

**Table 11.
Male Drivers**

MAIS	BMI (kg/m ²)									
	N	10%ile	20%ile	30%ile	40%ile	50%ile	60%ile	70%ile	80%ile	90%ile
0-1	67	20.9	21.9	23.1	24.3	25.3	26.2	26.8	27.8	30.1
2	16	19.1	20.3	21.1	22.3	23.6	24.5	25.6	27.5	28.4
3-6	9	20.8	21.6	23.5	25.5	25.6	25.6	25.6	26.3	.

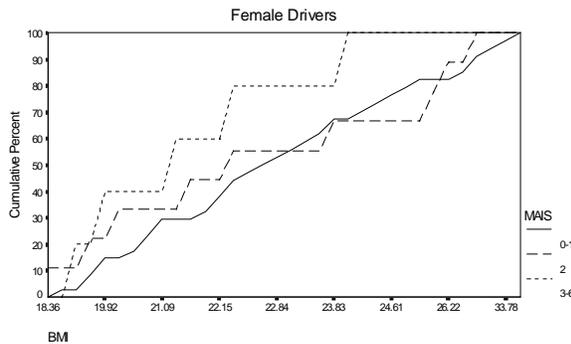


Figure 10. Female Drivers

**Table 12.
Female Drivers**

MAIS	BMI (kg/m ²)									
	N	10%ile	20%ile	30%ile	40%ile	50%ile	60%ile	70%ile	80%ile	90%ile
0-1	34	19.9	20.8	21.4	22.3	22.8	23.5	24.5	25.0	28.5
2	9	18.4	19.7	20.1	21.5	22.3	23.8	25.4	26.2	.
3-6	5	19.4	19.5	19.8	20.5	21.3	21.9	22.7	23.8	.

For male drivers, it appeared that MAIS 2 injuries were associated with lower BMI values, although the cumulative frequency plot for MAIS 3-6 was more similar to that of MAIS 0-1, indicating that this difference is probably due to random variation. Female drivers showed a trend for MAIS 3-6 injuries to be associated with lower BMI values, although this is not significant due to the sample size (see Table 12).

In contrast, Hill *et al* (1998) identified a trend for male drivers with BMI values greater than about 24.5kg/m² to be associated with more serious (MAIS 3-6) injuries. Figure 9 and Table 11 of this analysis also shows a trend for greater injury at BMI values above 25kg/m², although the sample size prevents any reliable conclusion being drawn.

FATALS DATABASE

Frontal Impacts

Body region of MAIS injury. Accident data contained within the FATALS database was analysed to ascertain the types and severity of injuries for each occupant type. The body region of injury was defined from those relating to the Injury Severity Score (ISS) body region. These body regions are defined as follows (AIS, 1990).

- 1= Head or neck (including injury to brain or cervical spine, skull or cervical spine fractures)
- 2= Face (including mouth, ears, nose and facial bones)
- 3= Chest (including all lesions in region, diaphragm, rib cage and thoracic spine)
- 4= Abdominal or pelvic contents (including all lesions in region)
- 5= Extremities or pelvic girdle (including fractures, dislocations, and amputations, except for spinal column, skull and rib cage)
- 6= External (including lacerations, contusions, abrasions and burns)

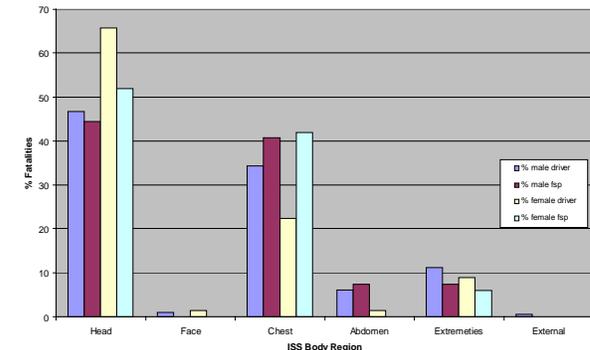


Figure 11. Body Region of MAIS injury by gender and seat position

Figure 11 shows that when considering MAIS injuries in frontal impacts, head and chest injuries account for the majority of injuries. Head injury predominated for all occupant types, constituting more than 45% for each occupant type. Injuries in this category were expected to predominate because of the increased risk of contact with the fascia and steering wheel.

Chest injuries accounted for between 20-40% of MAIS injuries, with injuries to the extremities and the pelvic girdle area were resulting in major injury in approximately 5-10% of cases for each occupant type.

Analysis of this data using standard errors, showed that compared to male drivers, female drivers have a significantly higher proportion of MAIS head injuries ($P < 0.05$). This difference may be due to the average female being seated nearer the steering wheel than the average male, and, therefore, more likely to sustain head injuries.

The difference between the head injuries of female drivers and female front seat passengers appears noticeable, with female drivers sustaining a higher proportion of head injuries. This may be interpreted as being indicative that female drivers sit nearer the wheel in order to operate the controls. When seated as a front seat passenger there is no need to move the seat forward. However, when analysed, there was no significant difference between female drivers and female front seat passengers with respect to MAIS head injury, although it is considered that a larger sample may yield a significant difference. In contrast, the proportions for male drivers and male front seat passengers are approximately similar, possibly reflecting a similar seat position relative to the wheel or fascia, regardless of the seat position occupied.

Analysis of standard errors shows that female front seat passengers had a significantly higher proportion of chest MAIS injuries than female drivers ($P < 0.05$). Reasons for this difference are unclear, but may be due to the fact that a large proportion of female drivers sustain more serious head injuries in frontal impacts due to contact with the steering wheel.

Side Impacts – Seat Position.

Table 13.
Age of fatality and seat position relative to impact

	Struck		Non-struck		Total
	No.	%	No.	%	
Male	68	66.0	35	34.0	103
Female	40	76.9	12	23.1	52
Total	108	69.7	47	30.3	155

As might be expected, those seated on the struck-side of the vehicle account for a greater proportion of the fatalities. However, this data also indicates that a significant number of occupants seated on the non-struck side of the vehicle, which might be expected to be unaffected by intrusion, also sustained fatal injuries.

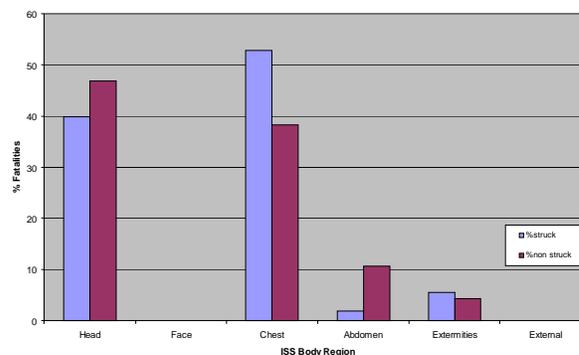


Figure 12. ISS body region of MAIS injury by impact location relative to front occupant.

Figure 12 reiterates that in side impacts, the worst injuries when considering fatalities are to the head and chest. Standard error analysis showed there was no significant differences in proportions between struck and non-struck chest injuries. However, a significant difference was found when considering abdomen injuries ($P < 0.05$); this may be due to the small number of injuries in this category and the fact that struck-side occupants are likely to have even worse injuries in the head or chest body regions.

DISCUSSION

CCIS Data

The CCIS data for frontal and side impacts have identified similar trends in the accident data with respect to the occupant characteristics analysed. Some trends observed, such as the bias towards young male FSPs are a result of differences in exposure of these groups to injury. However, by comparing the relative injury levels the parameters that expose the occupant to greater injury risk may be identified and are discussed in the following sections.

Occupant Age. The results show significant trends that older occupants are at greater risk of more severe injury. This may indicate difference in injury tolerance in relation to age, although the trends may be a result of other differences, such as driver behaviour or reaction times which are much more difficult to quantify.

This shows that active adaptive systems may benefit older occupants proportionately more than other occupants in both frontal and side impacts.

Occupant weight, height and BMI. This analysis has shown trends which strongly suggest that heavier, taller occupants and also smaller, lighter

occupants are generally at risk of greater injury in both frontal and side collisions.

Male drivers exhibited a trend for greater weights to be associated with MAIS 3-6 injury in frontal impacts and there was also a trend for female drivers under 70kg to sustain more serious injury. A similar trend was found in the side impact data, which showed that female drivers under 67kg were at greater risk of sustaining a serious injury.

Considering height, there was a trend for male drivers over 1.8m and female drivers under 1.5m to be associated with greater injury levels in frontal impacts, although these differences were not statistically significant. In side impacts, these same trends were statistically significant.

Overall, the data suggested that occupants with a greater BMI are at greater risk of more severe injury and would therefore benefit from active adaptive technology. However, the trends were less significant and overall, there were no significant trends to demonstrate statistically that BMI was related to injury severity.

Fatals Data

Injury region. The body region of the most severe injury in both frontal and side impacts is also important in the development of active adaptive systems. Analysis of the Fatals database showed that when considering MAIS injuries in frontal impacts, head and chest injuries account for the majority of injuries. Injuries in this category may predominate because of the increased risk of contact with the fascia and steering wheel.

Analysis of this data using standard errors, showed that compared to male drivers, female drivers have a significantly higher proportion of MAIS head injuries ($P < 0.05$). This difference may be due to the average female being seated nearer the steering wheel than the average male, and therefore more likely to sustain head injuries. This suggests that an active adaptive system involving rearward movement of the occupant during the impact would be more beneficial to female drivers, probably because this occupant group is on average shorter and therefore, position their seat closer to the steering wheel.

The proportions of head injuries sustained by male drivers and front seat passengers are more similar than the proportions of female drivers and front seat passengers (see Figure 11). This suggests that males may adjust their seat to a similar position relative to

the wheel or fascia, regardless of the seat position occupied, whereas females may sit closer to the wheel when driving.

CONCLUSIONS

The trends found in the analysis of Phases 4 and 5 of the CCIS database are compatible with the findings made by the Birmingham Accident Research Centre (BARC), who examined Phases 1 to 3. The main findings of this analysis can be summarised as follows:

- A greater proportion of older occupants sustains serious injuries.
- Some evidence that a greater proportion of heavier male drivers sustains serious injuries.
- Some evidence that lighter female drivers sustain more serious injuries.
- Some evidence that a greater proportion of male drivers with high BMI values sustains serious injuries.
- Some evidence that a greater proportion of female drivers with low BMI values sustains serious injuries.
- Some evidence that taller males and shorter females sustain more serious injuries.

Head and chest injuries have been identified as the main injury regions in both frontal and side impacts. The injury risk for these regions may be increased by human characteristics such as height and weight because current systems do not take into account these differences and how they effect the seat position of the occupant.

Overall, active systems utilising adaptive airbags and variable restraints are likely to confer greater benefits to these occupant groups who differ most from the 50th percentile size.

Recommendations for Active Adaptive Safety

Active adaptive systems should be designed to minimise the injury severity of occupants involved in frontal and side collisions. This may be achieved by a variety of methods, including alterations to airbag size, airbag firing time, variable pre-tensioners and variable load limiters and "smart" seat movements in order to optimise the system.

Although modelling and testing has shown that active adaptive technologies have the potential to confer benefits to all occupants (Holding, ESV 2001, paper 328), the accident data suggests that older occupants

may benefit proportionately more from improvements to secondary safety. In addition, the data suggests that rearward seat movement in frontal impacts would benefit occupants who are smaller and lighter and therefore tend to position the seat close to the steering wheel. Active adaptive airbags and seat restraints would most benefit those occupants who have heights and weights at the extremes of the population distribution because the system would adapt and optimise to the characteristics of the occupant.

REFERENCES

AIS, 1990. The Abbreviated Injury Scale, 1990 Revision. Association for the Advancement of Automotive Medicine, 2340 Des Plaines River Road, Suite 106, Des Plaines, IL 60018 USA.

Hill J, Kirk A, Persaud C. (1998). Car Occupant Characteristics, Crash-Injury Factors and Adaptive Restraints: Analysis of Frontal and Side Impacts. BARC, University of Birmingham.

Holding P.N., Chinn B.P., Happian-Smith J. (2001). An Evaluation of the Benefits of Active Adaptive Restraint Systems in Frontal Impacts Through Computer Modelling and Dynamic Testing. ESV 2001 Paper 328.

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The report by Hill *et al* (1998) was carried out at the Birmingham Accident Research Centre (BARC), University of Birmingham on behalf of TRL.

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