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# A COMPARISON OF INJURY RISK AND PATTERN OF INJURY FOR MALE AND FEMALE OCCUPANTS OF MODERN EUROPEAN PASSENGER CARS

**James Lenard, Ruth Welsh, Vehicle Safety Research Centre, Loughborough University, UK**

## ABSTRACT

Accident injury data from the UK Cooperative Crash Injury Study (CCIS) was examined for differences between men and women in accident circumstances and injury outcomes. The CCIS database from 1992 to 2000 contains "in-depth" information on almost 14000 car occupants from real road accidents. Although females constitute only around 40% of the sample, they outnumber males in the passenger seats. This shows that women should not be neglected in the design of vehicle safety systems. Soft tissue neck injury (whiplash) is more common among women in all accident types, and there are other differences in the vulnerability to injury and the body region most likely to be injured in frontal, side and rear impacts. The tuning of advanced restraint systems and vehicle crumple zones may offer further potential benefits to women. Today's vehicle safety community has inherited an emphasis on male characteristics in its knowledge base, research and testing programs, and regulations. Funding bodies should be aware of this and encourage a balanced consideration of female characteristics.

Keywords: accident analysis, injury probability, injuries, occupants, women

**THE RESULTS PRESENTED IN** this paper provide an overview on differences in injury outcomes between male and female occupants of modern European passenger cars. The data is drawn from the UK Cooperative Crash Injury Study (CCIS) which collects vehicle information from crashed vehicles away from the crash scene and injury information from hospital records, autopsy reports, and interview forms. CCIS is a stratified sample of accidents from selected regions around England. It includes nearly all the fatal accidents that occur in these areas, 80-90% of the serious accidents (admission to hospital), and around 20-30% of the slight accidents (medical treatment). This paper contains no adjustment for the weighting towards serious and fatal accidents in the sample.

Numerous references to gender differences are found in the existing literature (see References for recent papers). The results presented here are unique in dealing with restrained occupants in modern, European passenger cars using a large sample size. The context of this work is described in more detail in Welsh & Lenard (2001).

## RESULTS

**Table 1: Number of occupants on CCIS database 1992-2000**

| | | Seatbelt used | | | | | | Seatbelt not used | Other | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Front | Side | Rear | Roll | NS side* | Other | | | |
| Male | Driver | 2354 | 535 | 232 | 622 | 384 | 23 | 726 | 1881 | 8346 |
| | Front pass. | 581 | 115 | 66 | 227 | 115 | 7 | 487 | | |
| Female | Driver | 1193 | 325 | 150 | 257 | 174 | 9 | 174 | 1355 | 5644 |
| | Front pass. | 938 | 185 | 105 | 203 | 185 | 19 | 378 | | |

*Non-struck side impacts (NS side) are impacts to the side of the vehicle *opposite* to the side in which an occupant is seated.

Table 1 shows the overall number of occupants in CCIS for the years 1992 to 2000. There are around 14000 occupants of whom 8346 (60%) are male and 5644 (40%) are female. The three most numerous cells for women are drivers in frontal impacts (1193), passengers in frontal impacts (938), and drivers in struck-side impacts (325). For men the most numerous cells are drivers in frontal impacts (2354), drivers in rollovers (622), and passengers in frontal impacts (581). Clearly it cannot be presumed that the priorities for vehicle safety design are identical for men and women.

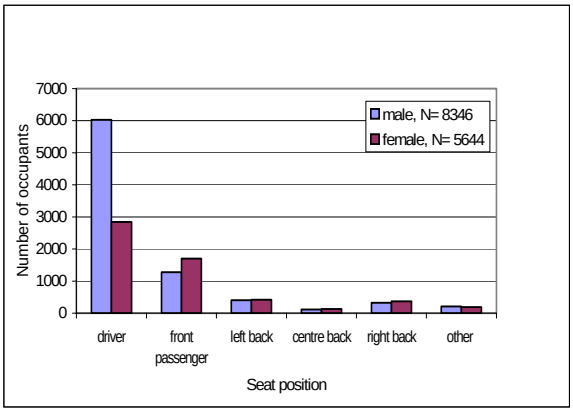



**Figure 1: Seat position**

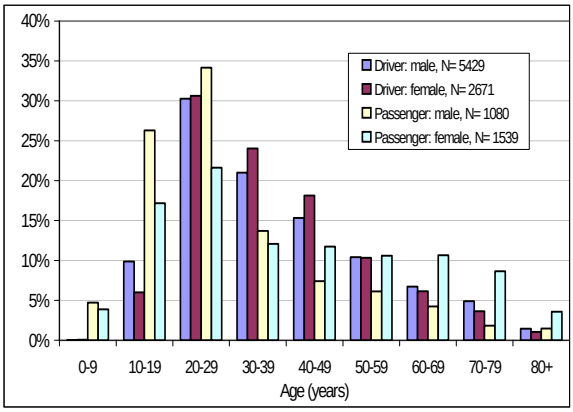



**Figure 2: Age of front occupants**

Figure 1 shows the numbers of men and women in the five common seating positions. Around 50% of women are drivers and 30% of women are front passengers; in contrast 72% of men are drivers and only 15% are front passengers. Despite being a minority of the overall sample, female occupants equal or outnumber male occupants in the passenger seating positions. This shows that the restraint systems and surrounds of the passenger seats should be no less well designed for women than for men.

Figure 2 shows the age distribution of front occupants. Just over 30% of both male and female drivers fall into the 20-29 year old age band. The younger and older age bands (under 19 and over 60) contain proportionally more male drivers. The age distribution of front passengers presents a greater contrast between men and women. The majority of male front passengers (60%) are below 30 years of age and there are progressively fewer with increasing age. The age distribution of female front passengers is much flatter. Around 40% are below 30 years of age, but there are over 10% in each of the 30s, 40s, 50s, 60s, and over 70 groups. The front passenger seat therefore tends to contain younger males and older females. This is highly relevant to the design and optimisation of restraint systems (seat belts, pretensioners and airbags) for front passengers.

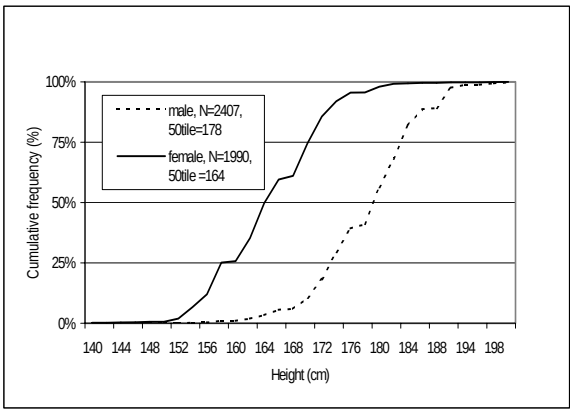



**Figure 3: Height of adult occupants**

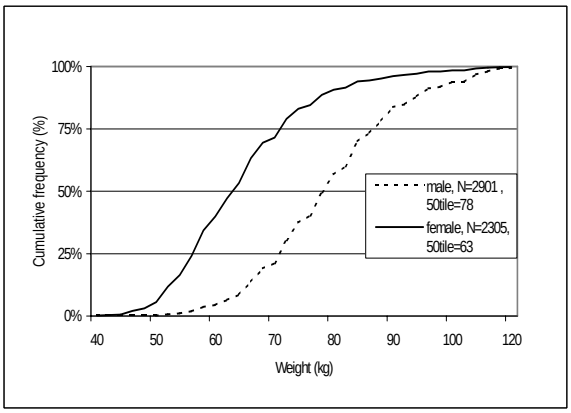



**Figure 4: Weight of adult occupants**

Figure 3 shows the cumulative frequency of height for all adult occupants. The 50th percentile adult height is 178 cm and 164 cm for men and women respectively. Over 95% of women are shorter than 178 cm. Figure 4 shows the cumulative frequency of weight for all adult occupants. As with height, women are seen to be lighter than men. The 50th percentile weight is 78 kg for men and 63 kg for women. Around 90% of women are lighter than the average male figure. These results show the relevant characteristics of the UK population involved in crashes and make it clear that most such women are poorly represented by the height and weight of the 50th percentile male when it is used as the reference point for designing or testing airbag and other vehicle safety systems.

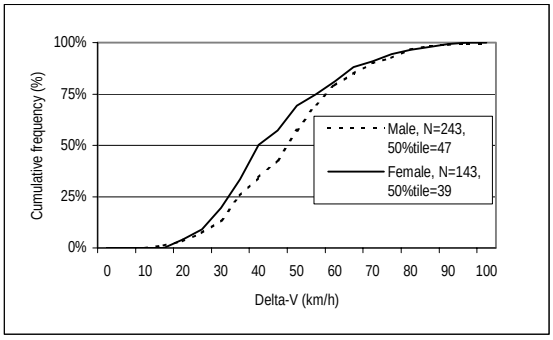
The remainder of this paper deals with restrained occupants. They are the large majority of passenger car occupants in the UK and the forces and accelerations applied to their bodies during an impact can be more readily controlled and mitigated by vehicle design than for unrestrained occupants. Four groups are considered: drivers in frontal impacts, front passengers in frontal impacts, front occupants in side (i.e. struck side) impacts, and front occupants in rear impacts.

**Table 2: MAIS distribution for restrained occupants by impact type**

| | | Uninjured | Injured | | | | | |
|---|---|---|---|---|---|---|---|---|
| Impact type | Sex | N | N | MAIS 1 | MAIS 2 | MAIS 3 | MAIS 4 | MAIS 5 | MAIS 6 |
| Frontal impact (drivers) | male | 456 | 1772 | 66% | 22% | 7% | 3% | 2% | 1% |
| | female | 88 | 1040 | 66% | 21% | 8% | 3% | 1% | 1% |
| Frontal impact (front passengers) | male | 62 | 315 | 68% | 18% | 7% | 3% | 2% | 1% |
| | female | 51 | 630 | 65% | 24% | 7% | 3% | 1% | 0% |
| Struck side impact | male | 74 | 516 | 53% | 17% | 13% | 8% | 5% | 3% |
| | female | 41 | 406 | 60% | 17% | 11% | 7% | 4% | 1% |
| Rear impact | male | 47 | 212 | 82% | 12% | 2% | 2% | 1% | 1% |
| | female | 31 | 191 | 89% | 7% | 1% | 1% | 1% | 1% |

Table 2 shows the distribution of MAIS for the four groups mentioned. There are some observable differences between the sexes in each group, however these are not so great as to overly influence the distribution of injuries over the body regions described in the following sections (frontal drivers, N=2812, d.f.=5, $\chi^2$=2.9, p>0.05; frontal front passengers, N=945, d.f.=5, $\chi^2$=5.7, p>0.05; side, N=922, d.f.=5, $\chi^2$=7.8, p>0.05; rear, N=403, d.f.=5, $\chi^2$=5.3, p>0.05).

## FRONTAL IMPACTS (DRIVERS)



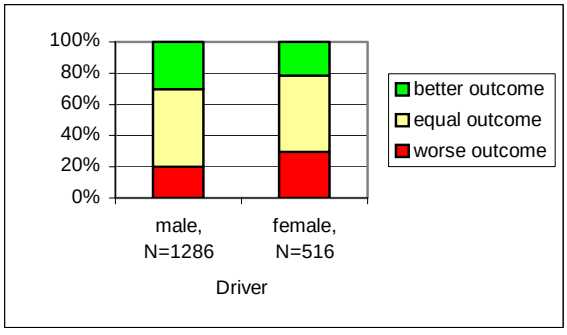




**Figure 5 (left): Delta-V (km/h) for MAIS 2+ restrained drivers in frontal impacts**

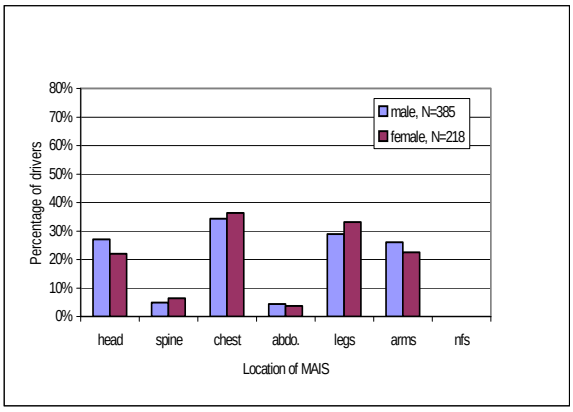
**Figure 6 (right): Driver MAIS compared to front passenger in frontal impacts**

Figure 5 show the cumulative frequency of injury against delta-V for restrained MAIS 2+ drivers in frontal impacts. Delta-V is the change of velocity during impact as calculated from the residual damage to the colliding vehicles after impact. The 50th percentile level of delta-V is 47 km/h for men and 39 km/h for women. This means that 50% of women in this group were injured at an impact velocity of less than 39 km/h whereas the corresponding figure for men is 47 km/h. This result indicates that

female drivers are more vulnerable to MAIS 2+ injury than men based on impact velocity (N=386, Mann-Whitney U=15034, $p<0.05$).

The change of velocity during impact is not available for a significant proportion of cases. A approach that does not rely on an estimation of impact severity is to compare injury outcomes between drivers and front passengers in the same vehicle. Figure 6 shows the relative injury outcome of drivers compared to front passengers in frontal impacts. Of 1286 male drivers, 20% had a worse outcome by MAIS than the front passenger and 30% had a better outcome. For the 516 female drivers, 29% had a worse outcome and 22% had a better outcome. This is an unfavourable statistic for female drivers compared to male drivers, since a higher proportion of female drivers were worse off than their accompanying front passenger and a lower proportion were better off than their front passenger (N=1802, df=2, $\chi^2=25.0$, $p<0.05$).

These figures are based on the subgroup of vehicles in which a driver and front passenger are both present. They compare the injury outcome of the driver to the passenger in each vehicle. The results are not directly influenced by the difference in age distribution between male and female front passengers mentioned above, provided the age and sex of front passengers who accompany male drivers is similar to the age and sex of those who accompany female drivers. Around 67% of male drivers in this group have a female front passenger compared to 58% of female drivers; this provides limited scope for an age effect to affect the gender comparison.



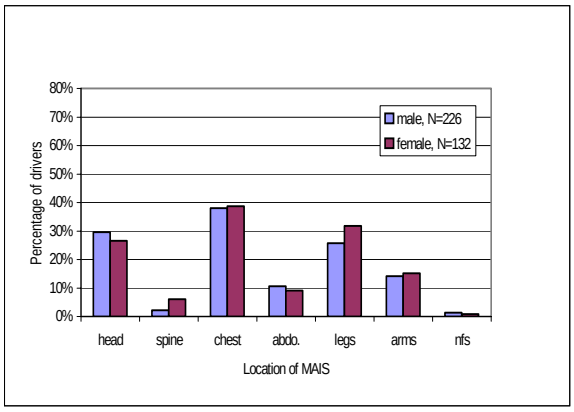




**Figure 7 (left): Location of most severe injury for MAIS 2 drivers in frontal impacts**

**Figure 8 (right): Location of most severe injury for MAIS 3+ drivers in frontal impacts**

Figure 7 shows the body regions in which AIS 2 injuries occurred for restrained drivers who were injured to a maximum level of AIS 2 (N=753 injuries, df=5 excluding body region 'not further specified', $\chi^2=3.8$, $p>0.05$). The incidence of chest and leg injuries is higher for women. These include many skeletal fractures. Figure 8 shows the body regions in which the most severe injury occurred for MAIS 3+ restrained drivers in frontal impacts (N=440 injuries, df=5 excluding body region 'not further specified', $\chi^2=4.7$, $p>0.05$). The chest remains the region in which the highest proportion of drivers had a maximal injury, as at MAIS 2 level. A higher proportion of women than men had the injuries to the legs and spine, a consistent trend for restrained drivers in frontal impacts in the CCIS database.

Figure 9 presents a different perspective on male and female injury patterns to the preceding charts. The percentages here are based on all restrained drivers in frontal impacts, injured and uninjured. In looking at the distribution of maximum severity injuries, as in Figure 8, the percentages are necessarily based on injured occupants only. Superficial injuries, i.e. skin injuries of AIS level 1, are not included in Figure 9; nor are brief loss of consciousness and neck strain (whiplash), the second of which is given a separate treatment below. The categories presented are skeletal head injuries (including the face); internal head injuries (excluding MAIS 1-2 brief loss of consciousness); spinal injuries (excluding neck strain); skeletal chest injuries; internal chest injuries; abdominal (internal) and pelvic (skeletal) injuries; skeletal leg injuries; and skeletal arm injuries. The lesions are ‘non-superficial’ and medically

identifiable, unlike brief loss of consciousness which is often diagnosed on indirect evidence and neck strain which is often identified by symptoms of pain.

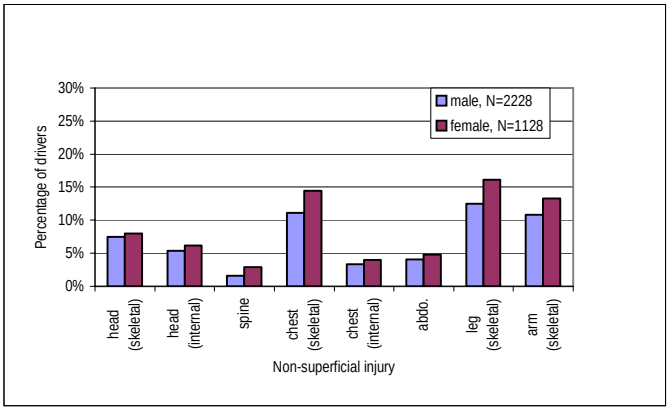
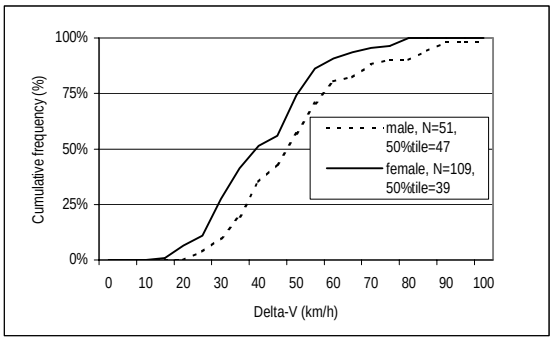



**Figure 9: Incidence of non-superficial injury for restrained drivers in frontal impacts**

Among all restrained drivers in frontal impacts in the CCIS sample, injured and uninjured, skeletal chest, leg, and arm injuries were the most common and were more frequent among women than men (N=2043 injuries, df=7, $\chi^2$=4.5, p>0.05). The clavicle, which is vulnerable to fracture from seatbelt forces, is included here as part of the upper limb.

In summary, for restrained drivers in frontal impacts, there is a trend indicating the special importance of chest, leg and spinal injuries among women. It is known that leg injuries among restrained drivers in frontal impacts frequently involve contact with the lower instrument panel and steering column; also that chest injuries involve seat belt forces and contact with the steering wheel. The optimisation of the seatbelt and secondary restraint systems is an important consideration for women, along with a recognition that they often need to adopt a more forward adjustment of the driver's seat which brings them closer to the frontal components of the passenger compartment.

**FRONTAL IMPACTS (FRONT PASSENGERS)**



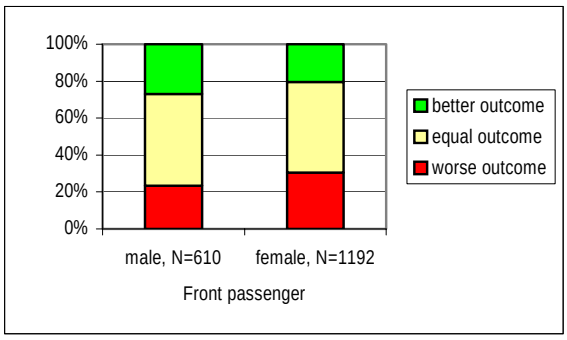
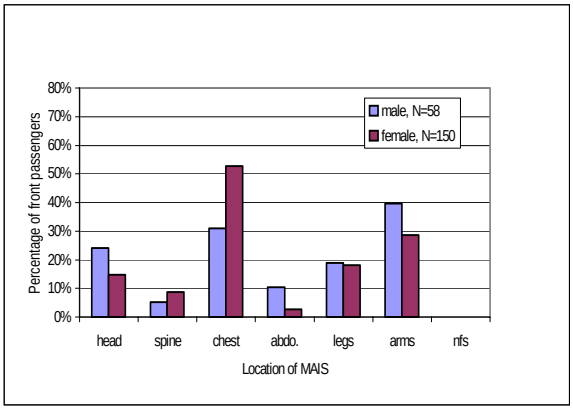




**Figure 10 (left): Delta-V for MAIS 2+ restrained front passengers in frontal impacts**

**Figure 11 (right)**: **Front passenger MAIS compared to driver in frontal impacts**

Figure 10 shows the cumulative frequency of injury for restrained front passengers injured to MAIS 2+ level in frontal impacts. The delta-V value below which 50% of women in this category are injured is 39 km/h compared to 47 km/h for men. This degree of displacement between the male and female curves indicates that female front passengers are more vulnerable to AIS 2+ injuries than men (N=160, Mann-Whitney U=1992, p<0.05).

Figure 11 shows how frequently the MAIS of a front passenger was higher, lower, or equal to the MAIS of the driver in frontal impacts. Only restrained front occupants are considered. In this group there are 610 male and 1192 female front passengers. 30% of female passengers had a worse outcome than the driver, compared to 23% of males; on the other hand, 20% had a better outcome than the driver, compared to 23% of men. This is an unfavourable statistic for women (N=1802, df=2, $\chi^2$=14.6, p<0.05). The age difference between male and female front passengers noted above could be a contributing factor; however it is beyond the scope of this paper to distinguish the separate effects of age and sex (see Evans, 2001).



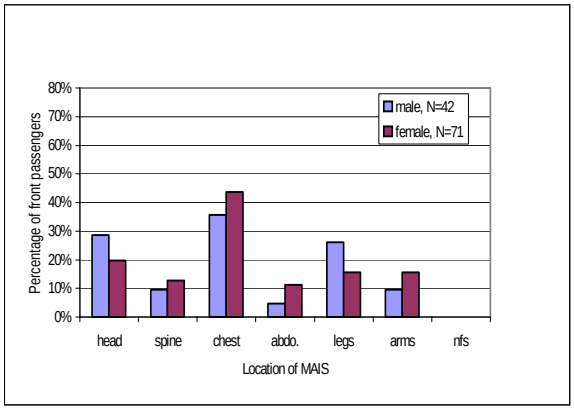




**Figure 12 (left): Location of most severe injury for MAIS 2 front passengers in frontal impacts**
**Figure 13 (right): Location of most severe injury for MAIS 3+ front passengers**

At the MAIS 2 level, women have a markedly higher incidence of chest injuries, as shown in Figure 12. These are known to include a significant proportion of rib and sternum fractures (N=263 injuries, df=5 excluding body region 'not further specified', $\chi^2$=13.5, p<0.05). There is also a higher incidence of spinal injury for women.

Figure 13 shows where the most severe injuries occurred for restrained front passengers in front impacts who were injured to AIS 3 level or higher. This severity of injury often requires admission to hospital and includes life-threatening injuries. The number of occupants is lower in the sample, 42 male and 71 female. Each individual male contributes 2-3% to the results, so random fluctuations are more noticeable here (N=132 injuries, df=5 excluding body region 'not further specified', $\chi^2$=5.1, p>0.05). The trend towards females having a high incidence of chest injuries appears again in this figure.

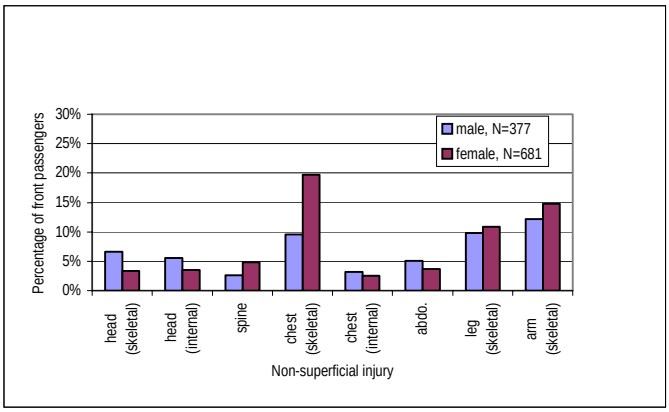


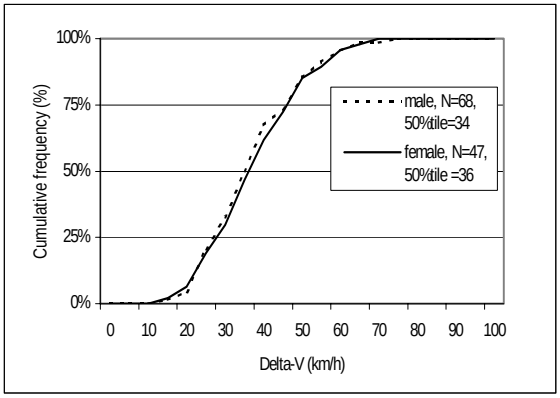

**Figure 14: Incidence of non-superficial injury for restrained front passengers in frontal impacts**

Figure 14 is the same type of chart as Figure 9 applied in this case to restrained front passengers in frontal impacts. It shows that the incidence of skeletal chest injury among all injured and uninjured front passengers is 20% among females and 10% for males (N=637 injuries, df=7, $\chi^2$=27.6, p<0.05). The incidence of internal chest injury is much lower: around 2-3% for both males and females.

In summary, there is a trend towards a higher incidence of chest injury among female restrained front passengers in frontal impacts. The data points specifically to skeletal chest injuries. Seat belt forces are highly relevant to the occurrence of skeletal chest injuries among this group. This implies that the design of the seat belt and secondary restraint systems is an area of special importance to women in the front passenger seat. There is naturally a trade-off to be made between seat belt forces (stiff belts) and head and chest excursion (soft belts) in frontal impacts. The optimum design may well be different for men and women due to their different height, weight and perhaps age distributions. The result on skeletal chest injuries points to the importance of factoring female characteristics and injury outcomes into the design process.

**STRUCK SIDE IMPACTS**

Struck side, or 'side', impacts are impacts to the right side of the vehicle for an occupant sitting in a right-hand seat or to the left side of the vehicle for an occupant sitting in a left-hand seat.



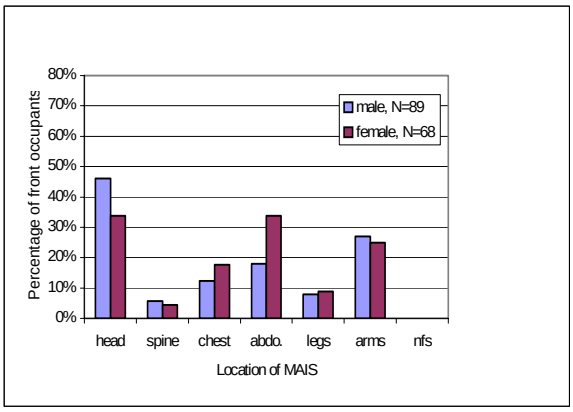
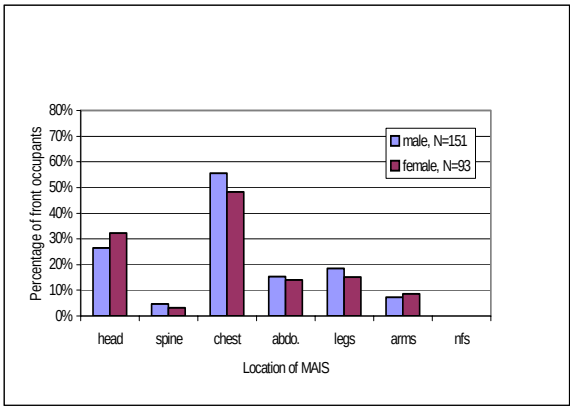




**Figure 15 (left): Delta-V for MAIS 2+ restrained occupants in struck side impacts**
**Figure 16: (right) Location of most severe injury for MAIS 2 front occupants in side impacts**

Figure 15 shows the cumulative frequency of injury for restrained drivers and front passengers injured to MAIS 2-6 level in struck side impacts. There is little discernible difference between the curves for men and women (N=115, Mann-Whitney U=1524, p>0.05).

Figure 16 (N=188 injuries, df=5 excluding body region 'not further specified', $\chi^2$=6.1, p>0.05) shows that the abdomen/pelvis is more frequently the location of AIS 2 injuries for women than men among MAIS 2 front occupants. This category of injury includes many pelvic fractures.

At the MAIS 3 level for this group of occupants, Figure 17 shows that the most frequent region of maximum injury is the chest, where a higher proportion of males were injured (N=306 injuries, df=5 excluding body region 'not further specified', $\chi^2$=2.0, p>0.05). The incidence of abdomen and pelvic injury decreases for females compared to MAIS 2 level (Figure 16); this indicates that the greater difference between males and females lies in the incidence of pelvic fractures rather than internal abdominal injuries (which are often severity AIS 3+).



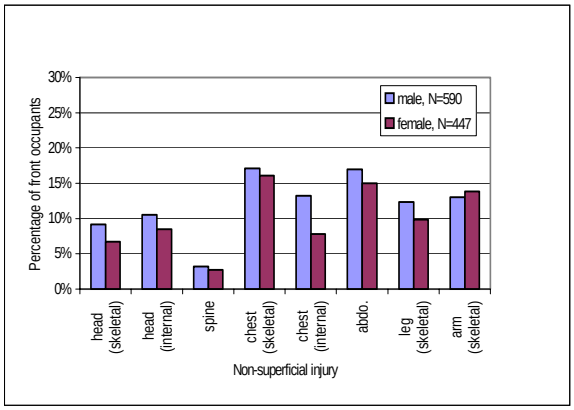



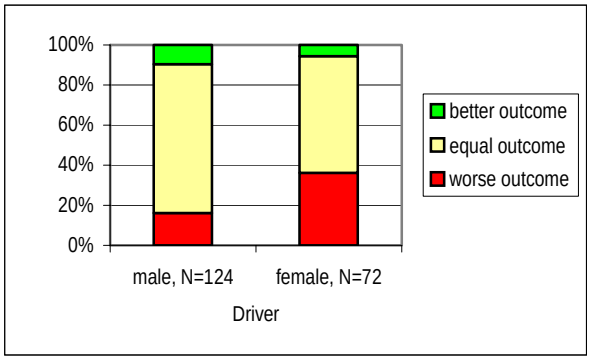

**Figure 17 (left): Location of most severe injury for MAIS 3+ front occupants in side impacts**
**Figure 18 (right): Incidence of non-superficial injury for front occupants in struck-side impacts**

Figure 18 (N=924 injuries, df=7, $\chi^2$=6.0, p>0.05) shows the incidence of non-superficial injuries among the whole CCIS sample of restrained front drivers and front passengers in struck side impacts, including uninjured occupants. The incidence of injury is higher for males in every category except the skeletal arm.

In summary, the data presented in this section does not demonstrate a special vulnerability to injury for either sex. Pelvic fractures are indirectly indicated as an area of concern to female restrained drivers and front passengers, although this finding should be regarded as provisional on statistical grounds.

**REAR IMPACTS**

The large majority of injured occupants of both sexes in rear impacts are only lightly injured to MAIS 1 level, as shown above in Table 2. Consequently the number of cases in CCIS for which impact severity (delta-V or ETS) can be calculated for MAIS 2+ occupants is too low to produce meaningful cumulative frequency curves.



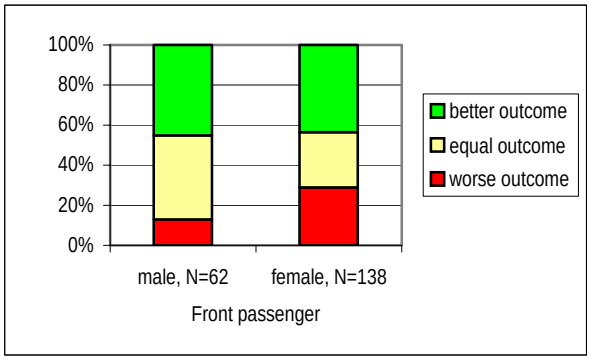




**Figure 19 (left): Driver MAIS compared to front passenger in rear impacts**
**Figure 20 (right): Front passenger MAIS compared to driver in rear impacts**

Figure 19 shows the relative injury outcome of drivers compared to front passengers in rear impacts. Only restrained occupants are considered. A distinctly higher proportion of female than male drivers have a worse outcome than the front passenger, and a lower proportion of female drivers have a better outcome (N=196, df=2, $\chi^2$=10.4, p<0.05). Figure 20 shows the relative injury outcome of front passengers compared to drivers in rear impacts. A greater proportion of female than male passengers have a worse outcome than the driver and a lower proportion of female than male passengers have a better outcome (N=196, df=2, $\chi^2$=0.7, p>0.05).

There are not enough cases (39 male and 21 female) to produce a smooth distribution of body region location of MAIS for MAIS 2+ drivers and front passengers.

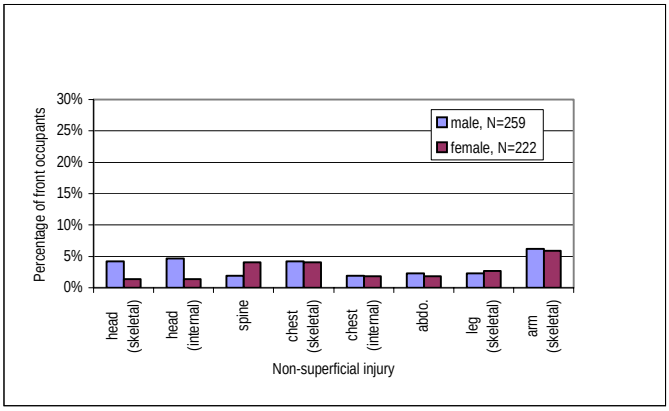



**Figure 21: Incidence of non-superficial injury for front occupants in rear impacts**

Figure 21 shows the incidence of non-superficial injury among all restrained drivers and front passengers in rear impacts, injured and uninjured (N=123 injuries, df=7, $\chi^2$=8.8, p>0.05). The rate of internal and skeletal injuries is less than 6% in all categories for both men and women.

In summary, no clear, consistent trend in the distribution of body regions injured in rear impacts emerge from the data presented in this section (although the incidence of neck strain shown below in Figure 22 should be noted). There is an indication, particularly in Figure 19, of a greater female vulnerability to injury.

**NECK STRAIN**

The incidence of neck strain was filtered from the charts presenting “non-superficial” injuries. Figure 22 shows a higher proportion of neck strain among restrained females in every category considered: drivers in frontal impacts, front passengers in frontal impacts, front occupants in struck side impacts, and front occupants in rear impacts (combined data: N=5932, df=1, $\chi^2$=71.6, p<0.05).

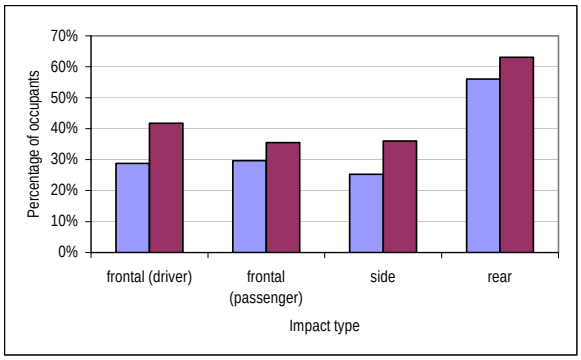



**Figure 22: Incidence of soft tissue neck injury for restrained occupants**

## DISCUSSION

The tables and charts presented in the preceding sections touch on a number of specialist topics. The comments and observations that can be made here are necessarily brief.

Perhaps the most salient fact about females in the CCIS accident database is that they outnumber males in the passenger seats despite being an overall minority of the sample. Assuming that women are

no less vulnerable to injury than men, this immediately implies that there is no factual basis for discriminating in favour of men in the design of safety systems for car passengers. Currently about one third of drivers involved in accidents are female, a proportion that may increase in coming years in line with other societal changes. This ratio is already high enough to warrant that female characteristics should not be neglected in the design of driver safety features.

The analyses presented focus on restrained (seat belted) occupants. These people make up the large majority of drivers and passengers in the UK and are the group for whom crash conditions within a vehicle can best be 'managed' by interior and structural design. The remarks in the rest of this section relate to restrained occupants.

A consistent trend in the CCIS data is that women generally appear to be either equally or more vulnerable to injury than men whether this is judged by the severity of impact (delta-V) or by comparing injury outcomes between men and women in the same car. This difference cannot necessarily be fully attributed to women's use of smaller cars (Welsh & Lenard, 2001). The influence of mass is incorporated into the calculation of delta-V, although lighter vehicles tend to be smaller than heavier vehicles and so there could be greater intrusion for the same delta-V in a smaller vehicle. This does not however influence the comparison of injury outcomes between front occupants in the same vehicle: this is a comparison between men and women in the same vehicles, large or small. Different injury outcomes are seen most clearly for drivers and front passengers in frontal and (struck) side impacts. In particular, differences in the incidence of soft tissue neck injury (whiplash) and skeletal injuries between the sexes are apparent. These skeletal injuries appear to be to the chest and legs of drivers in frontal impacts; to the chest of front passengers in frontal impacts; and to the pelvis of front occupants in side impacts. Several of these conclusions are tentative, subject to statistical considerations and restrictions on the amount of data that can be presented here.

The higher incidence of soft tissue neck injury (and spinal injuries in general) for women is consistently associated with a lower incidence of head injury. Whether these are causally related, for example by head contacts for men preventing a spinal injury from occurring, is not known.

The high incidence of skeletal chest injuries for women points to the importance of the restraint system - seat belt, pretensioner and airbag - and vehicle crumple zone. These strongly influence the acceleration forces applied to the body, particularly the chest, during a frontal impact. Field data cannot easily show whether women are intrinsically more vulnerable to chest fractures or whether the restraint system and crumple zone are less well optimised for women. It is conceivable that if seat belts were more flexible or crumple zones softer, women might be spared bone fractures, perhaps at the expense of men who might be heavy enough to stretch the seat belt forward and make injurious contact with frontal components of the passenger compartment. It is simplistic to argue that women are smaller and weaker than men and therefore must suffer more bone fractures. Since they are lighter, the forces required to decelerate their bodies in a crash are also lower. It is not obvious that these lower forces must exceed the strength of their bones.

Finally with regard to injuries, fractures of the leg in frontal impacts and of the pelvis in side impacts merit special attention for women. The former may relate to the design of the lower dashboard and steering column for drivers who have adjusted the seat to a forward position. The pelvic injuries may (as may spinal injuries) arise from physiological differences. Adjustments to the design of the door, B-pillar, seat and side airbags could be beneficial.

As already noted, women make up the majority of car passengers and are a significant, and probably growing, proportion of car drivers. Women are, on the whole, distinctly shorter and lighter than men - two crucial parameters in the design of the vehicle interior and safety systems. There are also relevant anatomical differences between the sexes, in the spine, pelvis, muscles, and distribution of bodily weight for example. However to date in research and development, design and regulation, the male body has tended to predominate as the model of all human beings. This applies to the construction of anthropomorphic test dummies - no modern, instrumented, 50th percentile female

dummy is in common use - with flow-on effects on computer simulations. In EuroNCAP - a testing program intended for the benefit of the general public - the crash test “family” inside the car consists of two adult “males” in the front seats along with 1½ year old and 3 year old “children” in the back (Hobbs & McDonough, 1998). This is not yet a representative family in today's society. One hears in defence of the male bias that testing protocols and regulations which cater for the small (5th percentile) female result in adequate coverage of the average female. This may be true, however there is no ‘straight line’ between the average male and a small female in the kinematics and dynamics of a vehicle crash. Many irregularities and discontinuities exist in how a body interacts with a seat belt and air bag for example. A vehicle restraint system and crumple zone could work well for an average male and small female, and yet be poorly suited for an average female. The assumption that average women are well catered for by a system that works well for average males and small females needs a factual, experimentally sound basis.

It is late in the day to correct the apparent imbalance of knowledge and experience weighted in favour of males. This would be an expensive and difficult enterprise. However institutions that are involved with sponsoring vehicle safety activities should consider requiring applicants for funding to identify any sex bias that exists in the proposed activity; and, if so, to explain and justify why the activity should be supported, and to propose how the bias can be redressed.

## CONCLUSIONS

Female drivers account for one third of drivers involved in accidents sampled in the UK Cooperative Crash Injury Study and outnumber men in the passenger positions despite constituting only 40% of the whole sample. The 50th percentile height and weight of males on the database is around the 90-95th percentile for females. Average male characteristics therefore represent a large female when used as a design reference.

Soft tissue neck injury (whiplash) is more frequent among women across front, side and rear impacts. Female front occupants appear to be more vulnerable to injury in frontal impacts, especially with regard to the skeletal chest and possibly leg injuries. This points to potential further benefits in restraint system design for women (including the seat belt, pretensioners, and airbag). Males and females appear generally equally vulnerable to injury in struck-side impacts, on the data presented, although the site of injury is not necessarily identical. There is an indication that the frequency of abdominal injuries at AIS 2 level, which include pelvic fractures, may be relatively more frequent among women. Finally, in rear impacts, female drivers more frequently have an unfavourable injury outcome compared to accompanying front seat passengers than do male drivers.

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