

CRASH CHARACTERISTICS AND INJURY OUTCOMES FOR OLDER PASSENGER CAR OCCUPANTS

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ABSTRACT

For some time now, it has been recognised that a major shift is occurring in the population age distributions of most motorised countries resulting in a growing number of older persons with an increasing need for mobility. It is expected that the mobility of older persons will become even more reliant on the motor vehicle as European countries in particular undergo

transitions towards decentralisation and suburbanisation and because of the well-established longevity factor. This study compares injury outcomes in passenger car crashes for belted occupants of different ages. The study considers drivers and front seat passengers.

National accident data in the UK show that whilst older car occupants are less likely to be involved in a car accident than younger occupants, in the event of a crash, older occupants are more likely to be killed or to sustain serious injury. This, in conjunction with the increasing numbers of older licence holder and car users implies that the protection of the inherently frail elderly should become a priority for the future.

Analysis of the UK in-depth accident data revealed that the older car occupants were significantly more prone to serious chest injury than their younger counterparts and that these injuries were predominantly due to forces exerted by the restraint system, particularly in frontal impacts. Since by the year 2030 one in four persons will be aged over 65 in most Organisation for Economic Cooperation and Development (OECD) countries, the results suggest a need for intervention through vehicle design including in-vehicle crashworthiness systems that take into account the reduced tolerance to impact that occurs with ageing.

INTRODUCTION

As the population ages, there is a growing awareness of the need for vehicle safety to suit older occupants. It takes less energy to produce tissue damage in older adults, making this group more vulnerable to injury in a crash. Their skeletal structures are more easily damaged and the consequences of any assault are likely to be exaggerated by pre-existing health

conditions. In short, there is a need to improve the crashworthiness of vehicles to provide better protection for older occupants in the event of a crash.

The level of personal mobility and independence afforded by the motorcar is fundamentally important for older people. Most older people in western countries own their own car and make an overwhelming proportion of their trips in private vehicles (OECD, 2001). Over the next three decades, this pattern of travel is likely to increase at a rate consistent with growth in the number of older adults in the population. In many OECD countries, by the year 2030, one in every four persons will be aged 65 or over (OECD, 2001). The next generations of older drivers will bring a new set of challenges for road safety. The baby-boomer generation has grown up with the car, have higher licensing rates and travel longer distances by car than persons of their parents' generation. As a consequence of the increased number of older drivers and passengers in the community and their greater reliance on cars for mobility, older occupant safety is likely to become a bigger issue in the years ahead.

Research in the US by Hu et al (2000), suggests that over the next three decades, fatal crashes could be as much as *three* times more frequent than at present without active intervention. While the above predictions are for fatalities only, a similar increase in serious injury casualty crashes could be predicted using this model. Their model, which predicts a 286% increase in older driver fatalities, is predicated on four key factors: an increase in the proportion of older people in the population; an increase in the distance travelled by this group; an increase in the number of licensed older drivers; and an increase in their crash risk. Using Hu's model, Fildes, Fitzharris, Charlton and Pronk (2001) showed similar patterns of increase in fatality rates for the Australian context. These anticipated trends underscore the urgency for more

research to better understand the mechanisms of crashes involving older drivers and occupants and their particular vulnerabilities and injury patterns in order to reduce their risk and minimise injury outcomes.

The recent OECD report on Ageing and Transport (2001) claims that the most critical safety issue for older drivers and passengers relates to their increased frailty and associated increase in injury susceptibility. The frailty of older occupants has been quantified in a fragility index, which identifies the risk of an injury resulting in fatality. Evans reported that compared with drivers aged 20-50 years, fragility increases this risk by 1.75 times for drivers aged 60 years, by 2.6 times at age 70, and over 5 times for drivers aged 80 and above (Evans, 1991).. Li and colleagues also reported similar increases in fragility with advancing age. They proposed that 60-95% of the increase in death rate per distance travelled for those aged 60 and over could be accounted for by increases in fragility (Li Braver & Chen, 2003).

The fragility associated with the ageing process is thought to reduce tolerance to crash forces (Mackay, 1989; Viano et al, 1989) because of reductions in bone strength and fracture tolerance. The influence of osteoporosis particularly on females is now well established (Berthel, 1980). Nevertheless, although manufacturers have an increased awareness of the changes that take place in the ageing process, the body of knowledge upon which effective crash protection design is based is still relatively small, particularly regarding the needs of the elderly driving population (Mackay, 1989). In previous studies, Foret-Bruno (1978, 1989 (in Dejammes and Ramet, 1996)) concluded that the most elderly population could withstand a chest load of 5,000N (equating to 50mm of force-deflection on the Hybrid-III dummy) whilst

the younger population could withstand a chest load of 8,000N (equating to 80mm of force-deflection in the Hybrid-III dummy). The implications of this are that older occupants may be several times more likely to sustain a life-threatening chest injury (Padmanaban, 2001) and this can occur in a relatively moderate crash (Augenstein, 2001). The chest is clearly vulnerable as the major load bearing area for restraint systems as well as a major point of contact with the vehicle structure during a crash.

METHOD

UK in-depth crash injury data (CCIS) covering recent model cars are analysed in this study. Cases were selected for analysis based on the car's year of manufacture being post 1991. The CCIS data use a stratified sampling criterion to identify crashes to be investigated. Some 80% of 'serious' and 'fatal' and 10-15% of 'slight' injury crashes according to the UK Government's classification are investigated. Consequently, the resulting sample is biased towards the more serious crashes. In total 1,541 single impact vehicle crashes were studied.

The un-weighted sample of drivers contains information on belted drivers including 889 drivers aged between 17-39 (younger drivers), 515 aged between 40 and 64 years (middle-aged drivers) and 137 aged 65+ (older drivers – range 65 to 84 years).

The un-weighted sample of passengers contains information on belted front seat passengers, including 723 passengers aged between 13-39 years (young), 360 aged between 40-64 years (middle-aged) and 195 aged 65+ years (older passengers range 65-98).

Rear seat passengers were not considered in this study.

Data from medical records were obtained from hospitals to which the crash casualties were admitted. All vehicles in the study were less than seven years old at the time of the crash and

were towed away from the crash scene. An in-depth examination of each vehicle was made in recovery-yards and garages within a few days of the accident. The UK Government system of injury classification was used to assess and compare the severity of driver/passenger injury in the datasets. This system classifies injured drivers approximately as follows;

Fatal	Death within 30 days of the crash
Serious	Injury serious enough to warrant hospitalisation or injuries such as fractures, severe lacerations etc.
Slight	Injury requiring minor treatment at an outpatient's ward or at the roadside.
No injury	No reported or observed injury.

In addition, individual injuries were coded and described according to the Abbreviated Injury Scale 1990 revision (AAAM 1990).

RESULTS

Characteristics of Older Driver and Passenger Crashes

Initially the type and severity of impacts experienced by drivers and front seat passengers was examined. Typically 80-85% of all crashes were either frontal or struck side and consequently these scenarios were selected for the subsequent analysis. There were no significant differences in the distributions of impact type across the three age categories for drivers ($\chi^2 = 9.065$, d.f.=6, $p=n.s.$). For front seat passengers, small differences exist across the age groups with the middle age group having a higher proportion of frontal impacts and a lower

proportion of struck side impacts compared to the younger and older age categories. However, any differences between observed and expected frequencies are not highly significant, ($\chi^2=8.236$, d.f.=4, $p=0.083$).

Considering the crash severity, this has been compared among the age groups using the mean EBS (Equivalent Barrier Speed). The results are shown in table1.

Table 1 Mean EBS by impact type and occupant age

Mean EBS km/h	Driver			Front Seat Passenger		
	<40	40-64	65+	<40	40-64	65+
Frontal	33	31	35	30	29	29
Struck Side	23	26	27	24	24	26

Whilst small observational differences are apparent in the impact speeds shown in table 1, none of these are significant.

This part of the analysis has gone some way to illustrate that broadly similar crash conditions are experienced by occupants of different ages, and though not rigorously so, helps to eliminate differences in crash conditions as contributory to differences in injury outcomes.

Injury Severity and Driver Age

Figures 1 and 2 show injury outcomes (according to the UK Government’s classification of crashes) in frontal impacts for the three groups of drivers and passengers respectively. Observationally, it is apparent that both older drivers and passengers have a higher proportion of ‘Fatal’ injury outcome for frontal impacts and thus have a lower proportion of less severe injury when compared to the younger and ‘middle’ aged groups. It is also apparent that the

'middle' age group has a lower proportion of slight injury outcome than the younger age group. Chi-square tests ($\chi^2 = 34.8$, d.f. = 6, $p < 0.001$ for drivers and $\chi^2 = 66.770$, df = 6, $p < 0.001$ for passengers) confirm that differences exist in the distribution of injury severity even though as was shown above, the nature and severity of crashes do not vary significantly among the age groups.

Figure 1

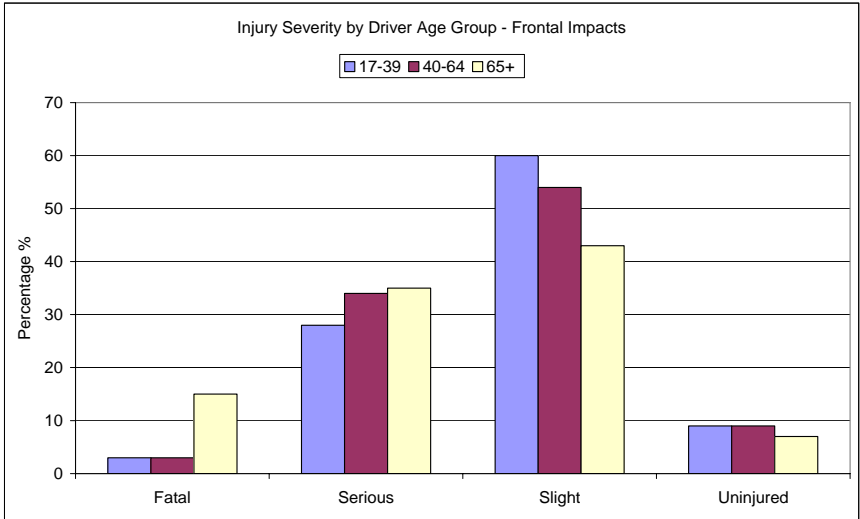


Figure 2

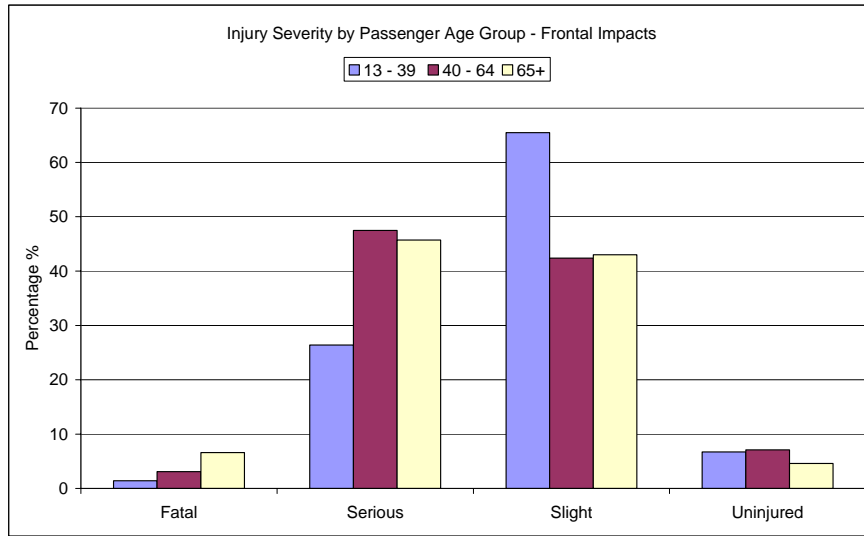
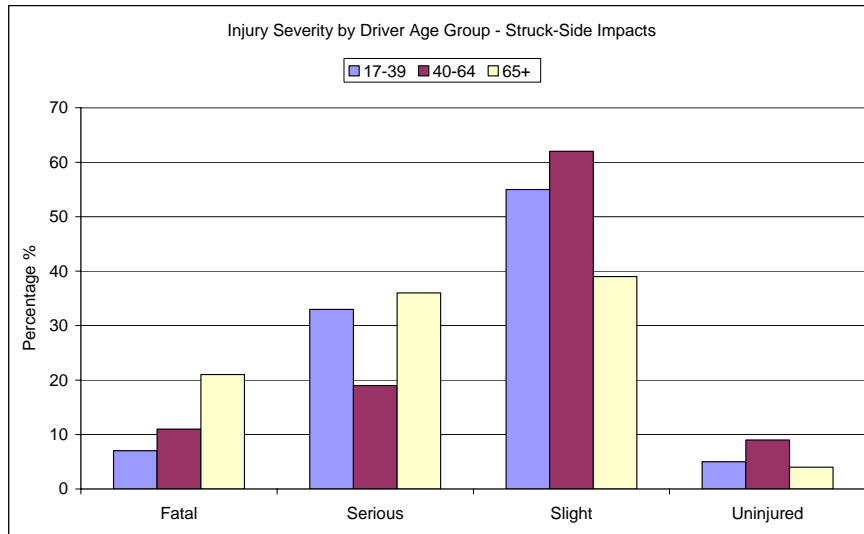


Figure 3

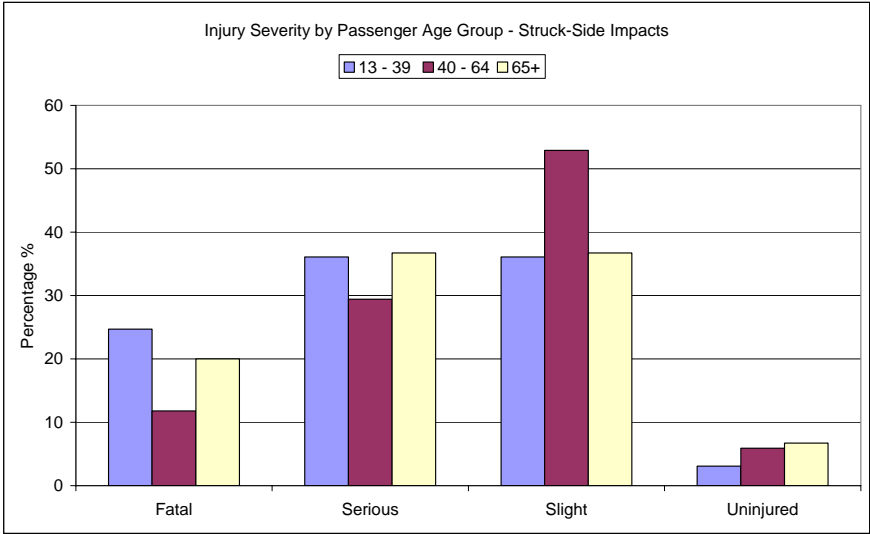


When struck-side impacts were considered, a significant relationship was found for drivers between age group and injury severity ($\chi^2 = 14.05$, d.f. = 6, $p < 0.05$). Observationally (figure 3) the fatality rate among the older drivers is 3 times that of the younger drivers and twice that of the 'middle' age group. The serious injury rates are similar for the younger and older

drivers but 15% lower for the ‘middle’ age group. Clearly the older driver age group has the lowest proportion of slight injury outcome in struck side crashes

In struck-side impact crashes for passengers (Figure 4) a different pattern emerges. Observationally, it is the ‘Younger’ passengers who are marginally more likely to be fatally injured in the event of a side impact crash although a Chi-square test on the overall distribution does not show any statistically significant differences ($\chi^2= 5.184$, $df = 6$, $p = 0.520$).

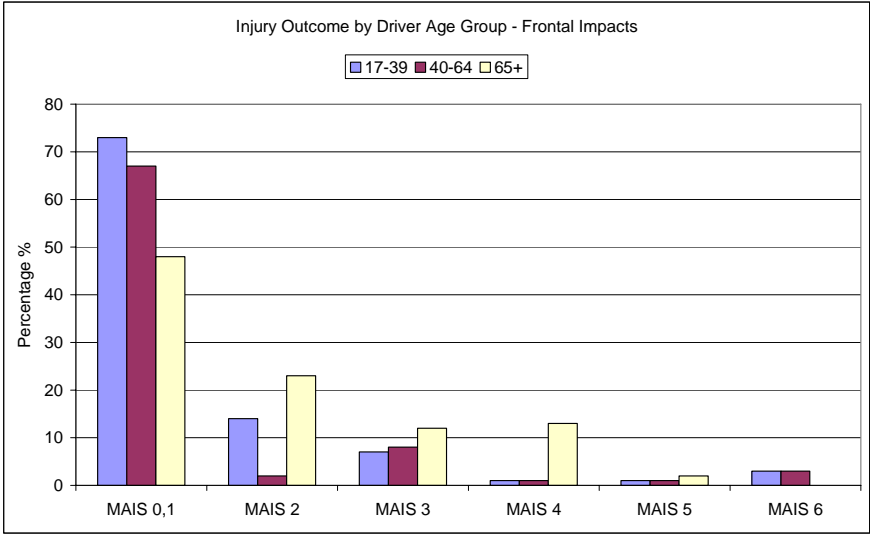
Figure 4



Figures 5, 6, 7 and 8 show the injury outcome according to the Maximum Abbreviated Injury Scale Score (MAIS). Statistical tests for differences in the distributions have not been carried out as in many cases in the higher MAIS scores the cell counts are too low for confident results. Accordingly the observed data suggest trends but these are not conclusive.

Figure 5 illustrates the MAIS outcome in frontal impacts according to driver age. The results suggest that the older driver age group are over-represented particularly at the MAIS 4 level although they are also over-represented at the MAIS 2 and MAIS 3 level .

Figure 5



A similar observation was made for older drivers in side impact crashes (figure 6). In this analysis, the older drivers appear over-represented at all levels of injury severity from MAIS 3 and above.

Figure 6

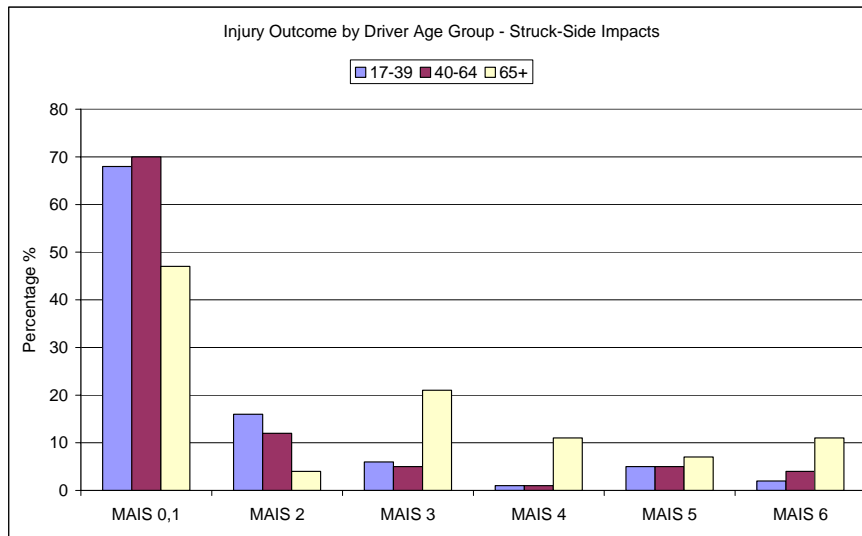
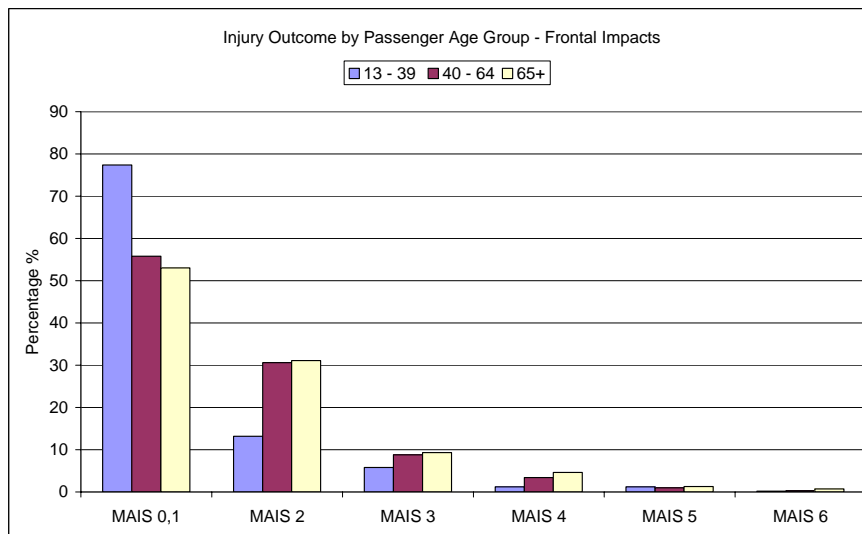


Figure 7



In Figure 7, passengers in frontal impacts are considered. Observed differences in injury outcomes exist with ‘Younger’ occupants more likely to sustain MAIS 0 and 1 injuries compared to ‘Middle-aged’ and ‘Older’ occupants. However, older occupants appear almost three times more likely to sustain MAIS 4+ injuries compared to ‘Younger’ occupants.

Figure 8

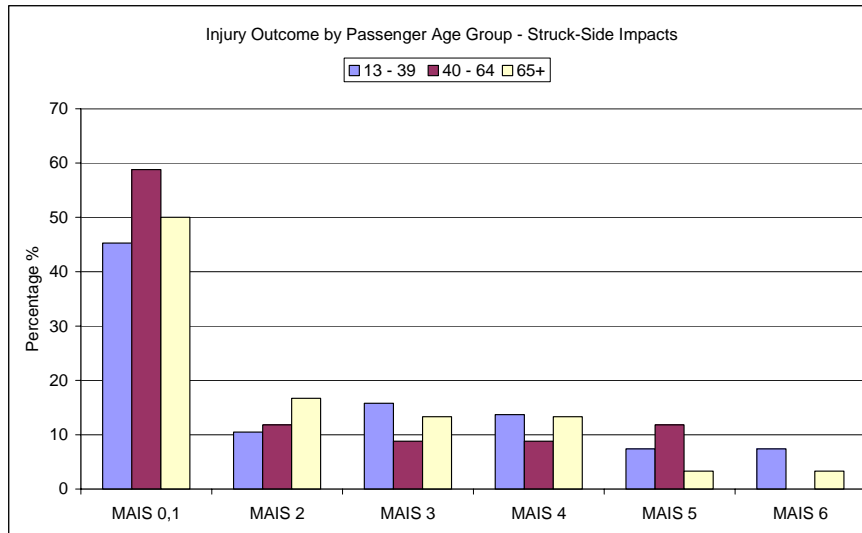


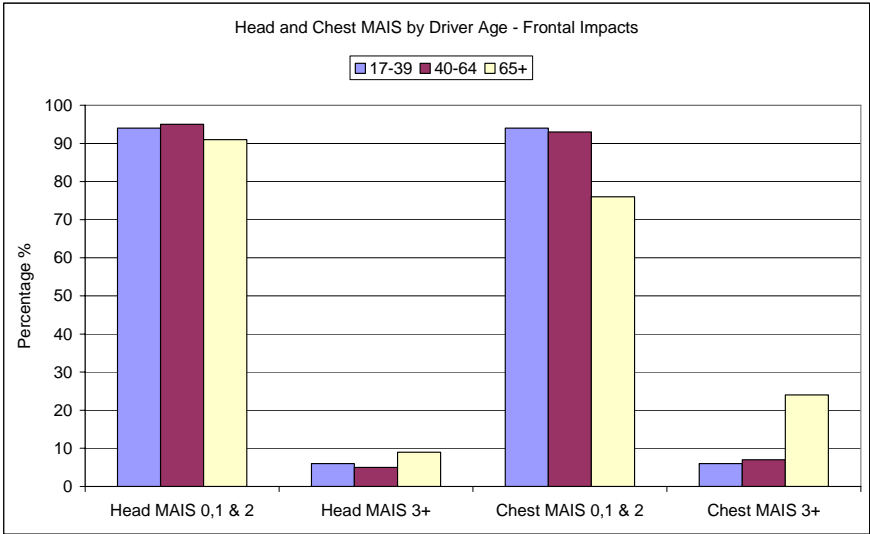
Figure 8 shows the MAIS outcome for passengers in struck-side crashes. Here the relationship between occupant age and injury outcome was much less clear-cut. ‘Younger’ occupants are observed to sustain a higher proportion of injuries at the MAIS 4+ level, with the ‘middle’ age group having the highest rate of MAIS 5 injury.

Injured Body Region and Occupant Age

Given the differences in MAIS outcomes in both frontal and right-side impacts, the data were analysed further to look at injuries to specific body regions. All body regions were examined but the differences in the injury rates in most of the body regions were NOT statistically significant across each of the 3 age groups.

The head and chest regions were then further considered, as these were the most frequently injured body regions. Figures 9 and 10 show the head and chest MAIS outcomes according to crash type and driver age group. The results show that for frontal impacts, there was no statistical difference in head injury rates across driver age groups ($\chi^2 = 1.83$, d.f. = 2, $p=n.s.$) However when chest injuries were considered, major differences in injury rates were observed and the older driver age-group sustained a higher proportion of injuries to the chest region at the MAIS 3+ level when compared to the other age groups. Differences in the overall distribution are supported by a chi-square test ($\chi^2 = 45.55$, d.f. = 2, $p<0.0001$).

Figure 9



A similar result was found for drivers involved in right-side crashes. Here, the driver head injury rates did not differ statistically between the three groups of drivers. However, when chest injuries were considered, the older driver age group was found to have a higher proportion of injuries at the MAIS 3+ level (Figure 10). Observed differences in the overall distribution of chest injury rates are supported by a significant chi-square test ($\chi^2 = 15.49$, d.f. = 2, $p<0.001$)

Figure 10

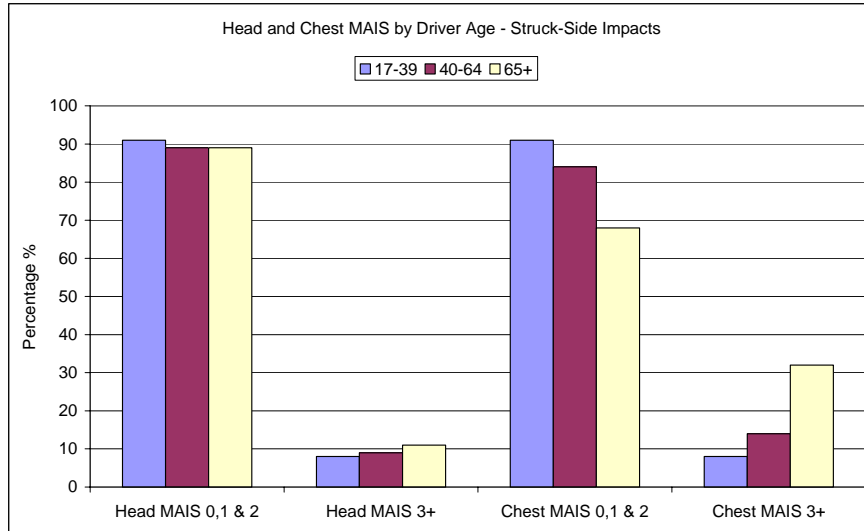


Figure 11 shows the Head and Chest MAIS outcomes in frontal impacts according to passenger age group. A chi-square test found that the overall distributions for head injury outcomes across the three age groups in frontal crashes did not differ ($\chi^2 = 0.824$, $df = 2$, $p = 0.662$). However when chest injuries were considered, differences in the overall distribution were supported by chi-square analysis ($\chi^2 = 32.754$, $df = 2$, $p = 0.0001$). Observationally, the rate of serious chest injury shows a positive relationship with the defined age categories.

Figure 11

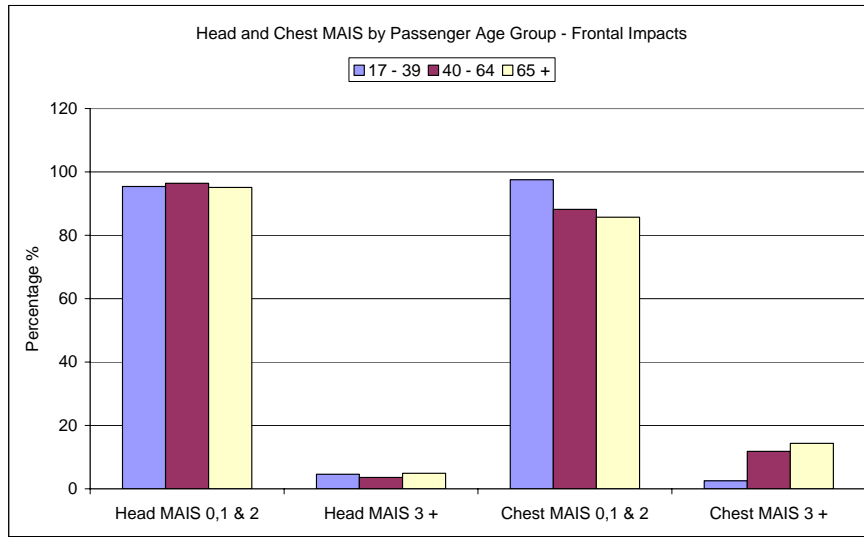
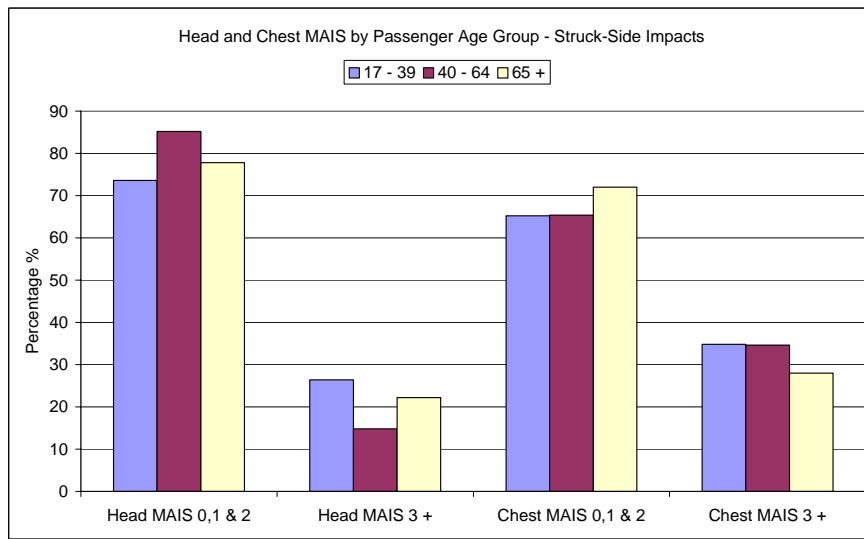


Figure 12



A somewhat different result was found for passengers involved in left-side crashes (Figure 12). There was no evidence to suggest that the passenger head injury rates differed between the three age groups of passengers ($\chi^2 = 1.578$, $df = 2$, $p = 0.454$). However, when chest injuries were considered, there were also no significant differences in the overall distribution ($\chi^2 = 0.424$, $df = 2$, $p = 0.809$). Both the middle-aged and older age group were observed to have a higher albeit non-statistically significant rate of injuries at the MAIS 3+ level compared to the younger age-group of passengers.

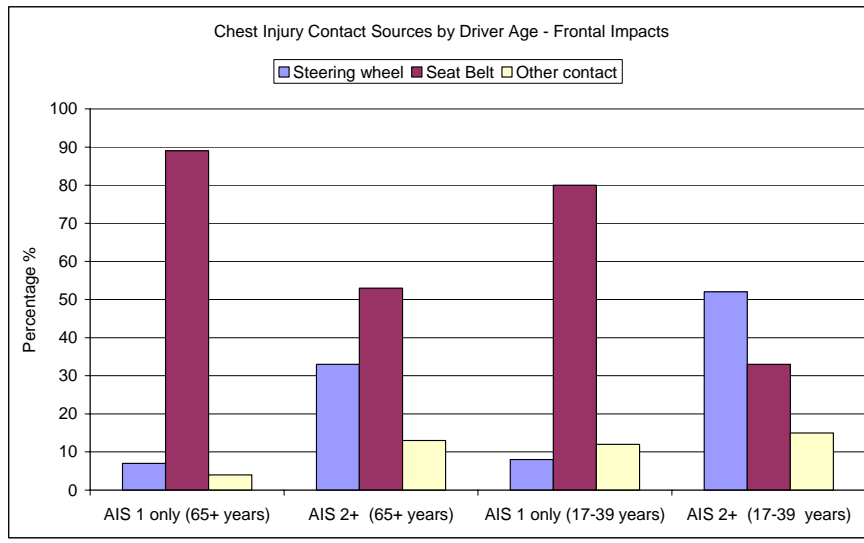
Injury outcomes and contact sources (drivers)

In this section only drivers are considered; the results for passengers are not yet available but intuitively the issues will be similar. The most striking results are also apparent when comparisons are made between the distinctly older and younger age categories and these are presented here. In this section, the cell counts become too low for statistical tests for significance to be carried out and accordingly the results should be seen as indicative rather than conclusive.

In both frontal and side impacts, the data in this study suggest that the chest is the most vulnerable body region for the older driver age group. In the sample studied, 20% or more of older drivers in frontal crashes (regardless of airbag deployment) and 32% of older drivers in right-side impact crashes sustained injuries at the MAIS 3+ level. Given the risk of chest injury to older drivers in both frontal and side impacts, the nature and source of injuries were examined.

Figure 13 shows the source of injuries to drivers by Abbreviated Injury Scale (AIS) score in the younger and older groups only.

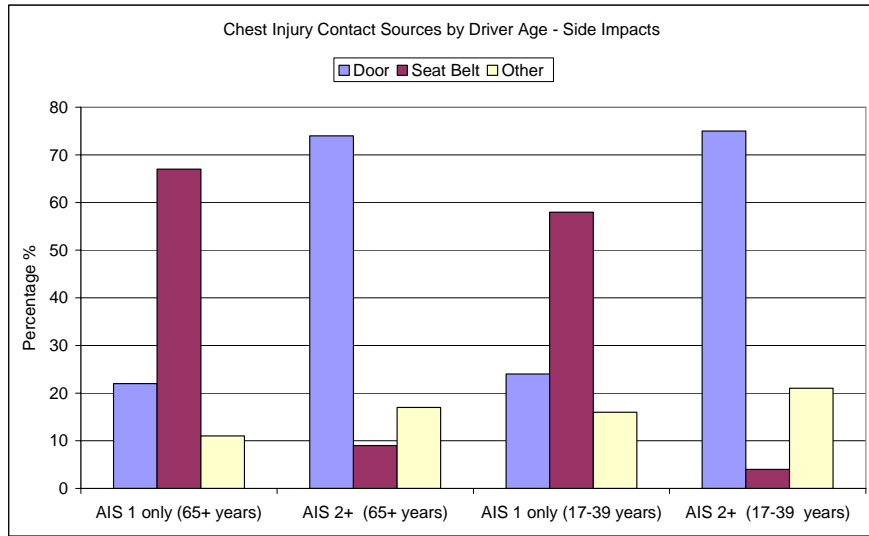
Figure 13



It was found that the seat belt and the steering wheel make up the majority of chest injury contact sources in frontal impacts. For both groups (younger and older), the main source of injury at the AIS 1 level was the seat belt. However, when injuries at the AIS 2+ level were considered, the seat belt became the main source of contact for the older group. In contrast, the seat belt is a less important source of injury for the younger age group and the steering wheel assumes a greater significance for this group. The influence of the airbag in this analysis was considered but the data could not provide conclusive or informative findings due to paucity of data.

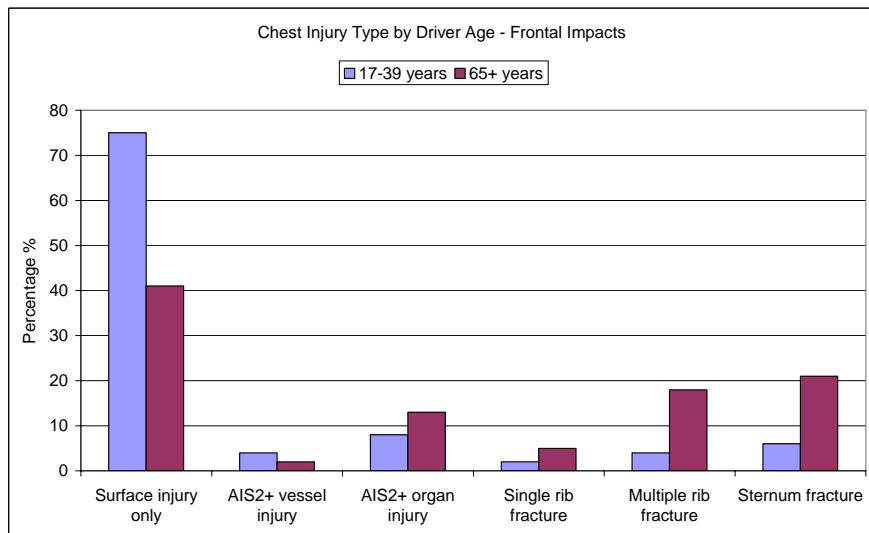
Figure 14 shows the injury contact source by AIS for drivers in right-side crashes.

Figure 14



Here the injury contact sources are roughly equivalent with the door as the main source of contact at all injury levels for both age groups of drivers. This is an intuitive finding given the likely proximity of the driver to the door in the event of a crash.

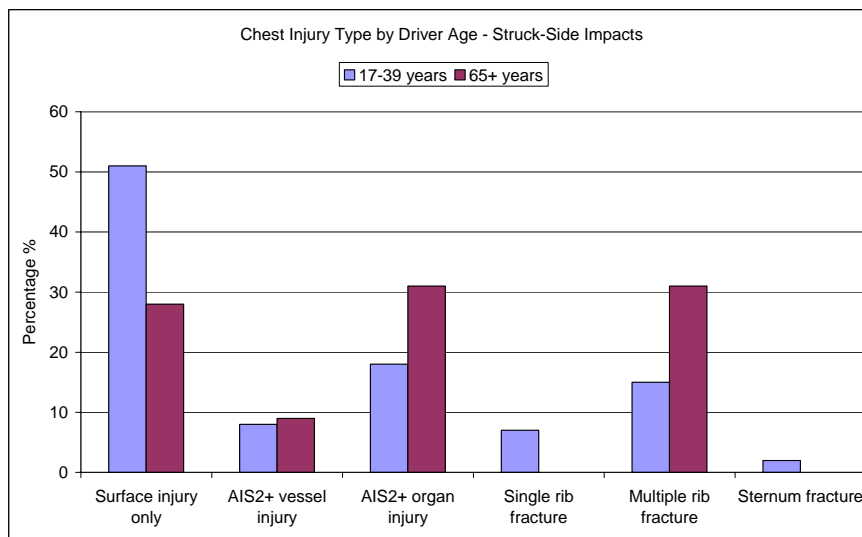
Figure 15



Figures 15 and 16 show the injury types in frontal and side impact crashes respectively by driver age group (younger or older).

In frontal impacts it was found that older drivers tended to sustain higher rates of AIS 2+ organ injuries (including particularly injuries to the lungs, heart and myocardium) both single and multiple rib fractures and sternum fractures.

Figure 16



In right side impacts the same effect is observed. However there is an even higher rate of AIS2+ organ injuries and multiple rib fractures in the older driver group compared to the younger driver group.

DISCUSSION

This study has found that, given similar crash conditions, older drivers and passengers appear to be more at risk of sustaining fatal and serious injuries in both frontal and struck-side crashes compared to younger occupants. The body region most prone to injury is the chest. When injury rates to all other body regions are examined, there is no discernible difference in

injury rate. However, when the chest region is considered, the older occupants sustain significantly higher rates of injury of a more serious level in both the frontal and struck-side crash conditions. If predictions for the shift in population age distributions prove accurate, they indicate a need for intervention through vehicle design. Chest injury mitigation devices such as driver airbags, side airbags and load-limiting seat belt systems may be beneficial in this respect. However, given the type and source of the chest injuries, there may also be a requirement to further refine seat belt systems so that biomechanical variation in tolerance to impact (due to age) is taken into account. Methods for providing for such variability could include load limiting or discretionary web-lock mechanisms, which could be calibrated for specific occupant characteristics such as age, sex, weight and height as Mackay (1994) suggests. It will also be important to monitor how effectively recent safety systems such as door and seat-mounted side airbags afford protection, particularly to the elderly vehicle occupant.

More data from real world crash analyses may help with the understanding of injury patterns and outcomes specific to crashes involving older adults and the relative protective influences of vehicle size and design features. Specifically, it would be most useful to know about the relative frequency and severity of injuries occupants of different age groups involved in various configurations of crash types and vehicle design features. This type of analysis would better enable the identification of features associated with crash protection and would be useful for advising older occupants on specific aspects of vehicle safety.

Given the need to encourage older drivers to use and/or purchase vehicles with modern safety features, priority needs to be given to promoting awareness of vehicle safety issues amongst

older people. The OECD report on Ageing and Transport (2001) notes that “older drivers need information on the implications of ceasing to drive, on the physical and cognitive changes experienced as part of the ageing process, and on the choice of safer vehicles”.

Recent surveys commissioned by the Australian Automobile Association (AAA) reported a continuing belief amongst drivers that stronger and bigger cars offer more protection, whereas smaller ones were seen as less robust (AAA, 1997). In addition there was no consensus that new cars were generally any safer than older cars although new expensive cars were seen as having superior safety features. The study also reported age-related differences in awareness and attitudes about crashworthiness and specific safety features. For example, when asked about “*what aspects or features of a car help to make it safe in a crash*”, only 51% of drivers aged over 55 years spontaneously responded that specific safety features (such as airbags and seatbelts) were important, compared to over 75% of drivers in the age groups 18-24 and 25-33 years. Other more recent research (Charlton et al, 2002) also shows that older people had a poor understanding of some safety features designed to improve occupant protection in a crash. Two key areas of misinformation amongst older people were found to be airbags and vehicle structure including the value of modern crumple zone design.

Therefore, there is also clearly much scope for promoting awareness of vehicle safety features across all age groups of drivers and particularly amongst the older population. This is likely to have a positive influence on safer vehicle purchasing patterns with better crash protection levels and demonstrable occupant safety benefits.

CONCLUSIONS

- For similar crash characteristics, older occupants (65 years and older) have a significantly higher rate of fatality in frontal impacts. This is also the case for older drivers in struck-side impacts.
- The MAIS outcome is more severe for older drivers in both frontal and struck-side impacts than for their younger counterparts. A similar observation is apparent for front seat passengers in frontal impacts, but this is not the case for struck-side impacts.
- MAIS 3+ head and chest injury is more prevalent for older drivers in both frontal and struck-side impacts compared with younger drivers. The result is statistically significant for chest injury but not for head injury. For front seat passengers, no significant differences are apparent in the rate of head and chest injury for passengers of different ages.
- For drivers in frontal impacts, serious chest injury is associated more often with seat belt loading for older drivers whilst more frequently with steering wheel for younger drivers. The older drivers sustained a higher rate of multiple rib fracture, sternum fracture and AIS 2+ internal organ injury than the younger drivers.
- In struck-side crashes, the injury contact source for chest injury most prevalent for drivers of all ages is contact with the side door. However, the older drivers have a higher rate of multiple rib fracture and AIS 2+ internal organ injury than the younger drivers.
- The difference in the rate and type of injury, particularly to the chest, for occupants of different ages indicates a need to consider the restraint system in relation to the variance in injury tolerance apparent in the car occupant population.

- Continued collection and study of in-depth accident data is needed in order to further develop an understanding of the different crash protection requirements for the varying population, and also in order to monitor the real effect of any design interventions.

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Further information on CCIS can be found at <http://www.ukccis.org>