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BELTED DRIVER PROTECTION IN FRONTAL IMPACT – WHAT HAS BEEN ACHIEVED AND WHERE DO FUTURE PRIORITIES LIE?

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ABSTRACT

Examining Injuries to real people in real crashes is the ultimate way to validate improvements in crashworthiness as well as to determine where future priorities lie. Examination of U.K national statistics showed that, coincident with the introduction of airbags and better restraints there was a significant fall in the rates of killed/seriously injured car occupants as well as a significant fall in the number of car occupant fatalities.
Interrogation of the UK in-depth crash injury data for belted driver injury risk in frontal crashes showed substantial reductions in injury risk for the head in newer cars. Risk of serious injury to the chest, thigh and leg showed little change between older and newer vehicles despite controlling for occupant parameters.

Currently, there is a wealth of information available to the vehicle designer who needs to protect car occupants in crashes. Biomechanical data, anthropomorphic test devices and computer modelling of vehicle and occupant response are now an integral part of crash safety development. But the real test of successful safety design comes from examining injury outcome with real people in real crashes. Many manufacturers run a whole suite of developmental crash tests but are they enough to cover all the situations in real crashes? Indeed, regulatory and consumer crash tests rely on only one generic test to cover each major impact mode (EU Directive 96/79/EC, 1996, Hobbs et al, 1999).

Use of national accident data to evaluate vehicle crash safety can provide useful information on general trends (Transport Statistics Report, 1993). However, the detail needed to assist vehicle designers can only come from in-depth accident studies (Mackay et al, 1985, NASS, 1998). That information however, needs to be presented in such a way as to allow direct comparison with experimental procedures. The objectives of this study were therefore to explore the issues of combining national accident statistics with in-depth accident studies in order to evaluate the effectiveness of major changes in crash safety design. Additionally, to explore methods by which in-depth data could be analysed and presented which would be comparable to results from experimental analyses.

METHOD

The national accident database, STATS 19, was used to examine the gross changes in casualty patterns between newer and older cars. The police complete an accident record for each reported injury accident using a standard protocol. This includes brief details of the accident circumstances, the vehicles involved and the casualties. Details of all injured road users are recorded together with information on uninjured drivers. The data describes the population of all relevant crashes occurring in Great Britain (excluding Scotland and Northern Ireland).

Crashes occurring in the calendar years 1997 and 1998 were used to estimate trends in crashes. All vehicles were classified as cars and were in collision with other cars. The use of just two years of data means that any effects of accident reduction measures will be minimised.

The STATS 19 data records three levels of injury severity, “Fatal”, meaning death within 30 days, “slight” meaning cuts and bruises only with no hospital in-patient treatment, and “Serious” meaning every level of injury between the other two categories. Vehicles were classified into two groups, older and newer, according to their year of manufacture. A partition year of 1993 was used as it represents the year when airbags began to be fitted to large numbers of cars in the UK. Vehicles with a manufacture date before 1988 were excluded from the sub-population. It should be noted that front seat belt use in the UK remained around 90% for 1997 and 1998 (Restraint Use by Car Occupants, 1998, 1999).

In-depth crash injury data from the UK Co-operative Crash Injury Study (CCIS) was used to examine injury risk, to specific body regions of belted drivers in frontal crashes. The comparison was made between cars fitted with airbags (newer cars) and cars not fitted with airbags (older cars). A frontal crash was selected if it was the most severe impact to a vehicle in terms of injury outcome. CCIS data was available from calendar years 1992-2001. The study selects cases for investigation using a stratified random sampling procedure based on injury severity.

For a comprehensive description of CCIS, the reader is referred to (Mackay et al, 1985) CCIS.

Injury outcome was recorded using the Abbreviated Injury Scale (AAAM, 1990).

The Equivalent test Speed (ETS) was used as a measure of crash severity. ETS is the vehicle delta v, calculated on the assumption that deformation was caused by impact with a rigid barrier. The calculation assumes the force was directed through the centre of the crush area. It does not assume the vehicle was brought to rest. ETS is different to the Equivalent Energy Speed (EES) used in other in-depth studies because the EES calculation assumes the force to be through the vehicle centre of mass and that the vehicle was brought to rest. ETS is therefore always less than or equal to EES. There are a number of factors which affect the accuracy of ETS so it is best used to place crashes into groups of similar severity rather than to compare individual crashes.

Linear regression was used to build predictive models of injury risk for separate body regions. This is a statistical technique which gives the predicted response of a dependent variable based on the responses to an independent (predictor) variable. In this case the dependent variable was the incidence (risk) of injury and the predictor variable was ETS. The underlying assumptions associated with the use of linear regression were validated for the data used. It should be noted that the predicted risk is valid only for the range of the predicor variable.

For the model, **R** is a measure of the correlation between the observed value and the predicted value of the dependent variable. $\mathbf{R^2}$ is the square of the R value and indicates the proportion of the variance in the dependent variable which is accounted for by the model. Essentially, R^2 is a measure of how good a prediction of the dependent variable can be made by knowing the value of the independent variable. If for example the regression produces an R^2 of 0.75 then the model has accounted for 75% of the variance in the dependent variable. Ideally an R^2 of 1 is sought, indicating an exact prediction. The p value associated with the model gives the significance of the model at the 95% confidence level. However regression is most generally assessed on the basis of the R square value.

Where results were statistically tested, the test level was set at p=0.05 for acceptance or rejection of statistical significance.

RESULTS

NATIONAL CASUALTY TRENDS - From a crash population of 655025 accidents there were 419508 cars involved in collisions with another car, the injury levels sustained are shown in Table 1. Figures 1 thru 3 show the rates of differing severities of casualty by vehicle year of manufacture. The mean injury rate is also shown between older and newer vehicles.

Table 1 - Driver Injury Levels

Injury Severity	Number
Not Injured	244,556
Slight Injuries	157,093
Serious Injuries	16,450
Fatal Injuries	1,409
Total	419,508

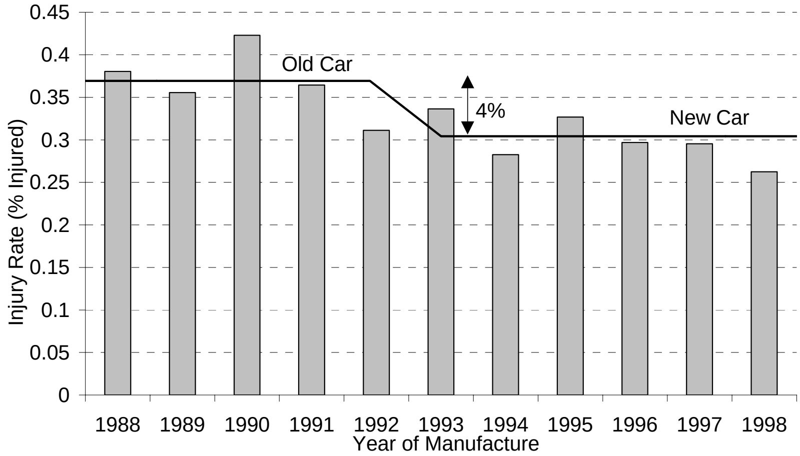

Figure 1 - Injury Rate for Car Drivers

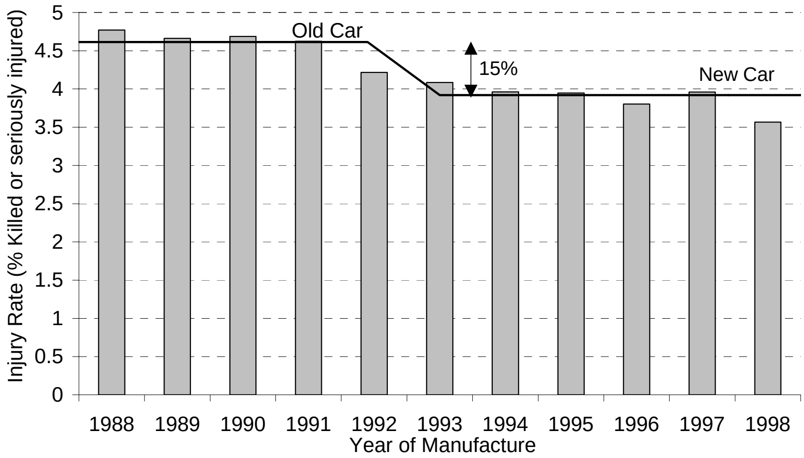

Figure 2 - Killed/Serious Injury Rate for Car Drivers

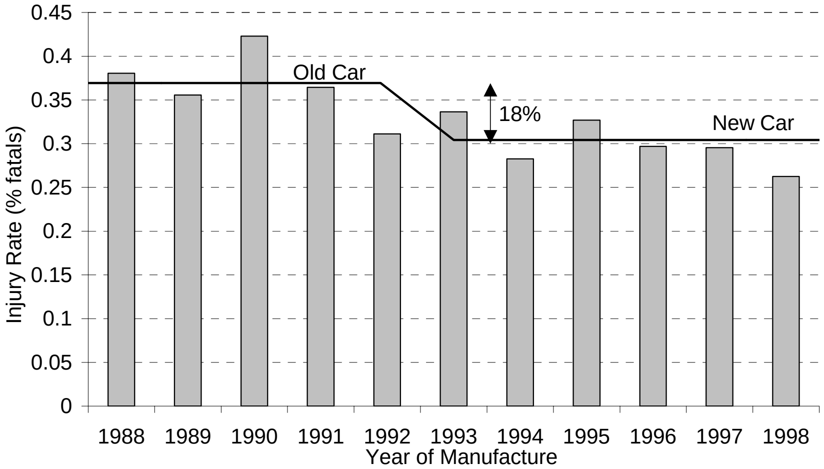

Figure 3 - Fatality Rate for Car Drivers

The national casualty figures show decreases in the casualty rate in newer cars. This is most pronounced with fatalities (an 18% reduction). The reduction in the killed/serious injury rate is almost as high at 15%. This is noteworthy as there are many more seriously injured survivors than fatalities in the injured population. The reduction in total numbers of injured occupants however is just 4%. Because major changes to crash safety over the time period was aimed at frontal crashes, it is reasonable to hypothesize that gains made in injury reduction can be attributed, at least in part to improved frontal crash protection. The UK in-depth crash injury data was examined to determine what changes had occurred in injury risk to belted drivers in frontal crashes.

CCIS IN-DEPTH SAMPLE CHARACTERISTICS - The in-depth data contained 3732 vehicles in the older car category and 1514 in the newer car category.

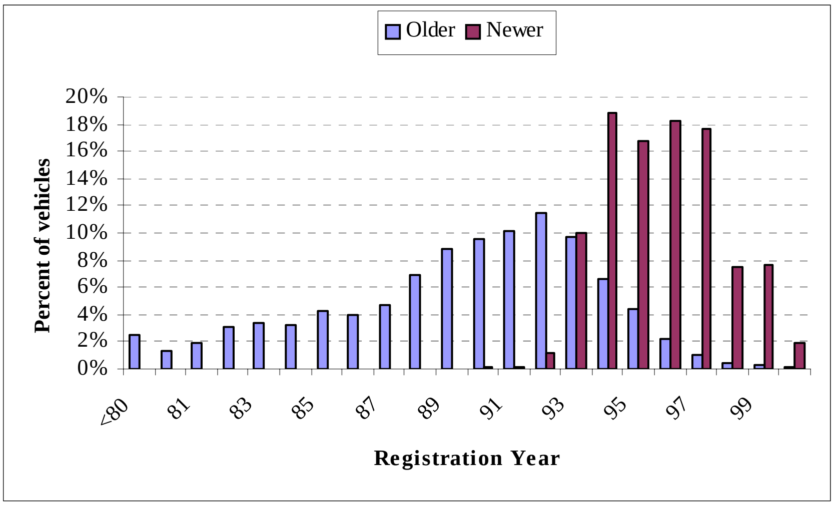

Figure 4 - Registration Year

Figure 4 shows the distribution of frontal crash older and newer cars by registration year. Older cars show an interquartile range of registration year from 1987-1992 with a median year of 1990. The corresponding values for the newer cars are 1994-1997 and 1996 respectively. This approximates to the older/newer car split used to examine national casualty trends. Only 8% of the older vehicles were known to have seat belt pretensioners while 76% of the newer vehicles were so fitted. In 1% of older cars, fitment was unknown and this was the case for 3% of newer cars.

Seat belt use was confirmed for 2708 drivers in the sample of older cars and for 1194 drivers in newer cars. These drivers formed the basis for further in-depth analysis. It should be noted that not all vehicle/occupant information was known in all cases. Where totals differ from the base sample the new totals are shown.

BELTED DRIVER HEAD AND CHEST INJURY SEVERITY: IN-DEPTH SAMPLE CHARACTERISTICS - Any major changes to vehicle safety systems, such as the introduction of seat belt pretensioners and airbags in newer cars would be aimed primarily at reducing threat to life. Consequently addressing injuries to the head and chest. Table 2 shows the injury severity distributions for the head and chest in older and newer cars.

Table 2 – Head and Chest Injury Severity

	Head Injury Severity		Chest Injury Severity	
	Older	Newer	Older	Newer
AIS 0	61%	72%	54%	55%
AIS 1+	39%	27%	44%	45%
AIS 2+	13%	5%	11%	9%
AIS 3+	5%	2%	4%	4%
N	2704	1194	2706	1193

Table 2 shows a different pattern of injury severity between the head and chest in newer and older vehicles. The head is uninjured more often in newer cars and there appear to be substantial reductions in AIS 2+ and 3+ injury. There is also a reduction in AIS 1+ injury which, together with increases in non injury cases, suggest that more severe injury is not being replaced with minor injury.

By contrast, the distribution of chest injury severity appears little changed between older and newer cars. The table suggests a slight reduction in the incidence of AIS 2 injury because there is no difference in the proportions of AIS 3+ injury.

These results needs careful consideration before they can be attributed to improved vehicle safety. For example, crash severity may be different between vehicle types. Occupant parameters also need to be addressed. A higher proportion of females in one type of vehicle may mean drivers who are sitting closer to the forward interior structures. And older drivers are known to have decreased tolerance to blunt trauma, especially regarding rib cage strength. Curves of AIS 2+ injury risk by crash severity were derived in order to quantify risk and introduce a measure of control on crash severity between older and newer cars. Occupant parameters such as age and gender were also investigated.

HEAD INJURY RISK MODEL - Head injury was defined as any injury to the skull, brain or face. In the sample of belted drivers, there were 2704 with known head injury severity in older cars, 348 of whom had an AIS 2+ head injury. In newer cars, the corresponding numbers were 1194 and 68 respectively. ETS was known for 1863 drivers of older cars of which 238 had AIS 2+ head injury. The corresponding numbers in newer cars were 854 and 46 respectively. Figure 5 shows the risk of AIS 2+ head injury in older and newer cars. The negative risk shown is a product of the straight line fit.

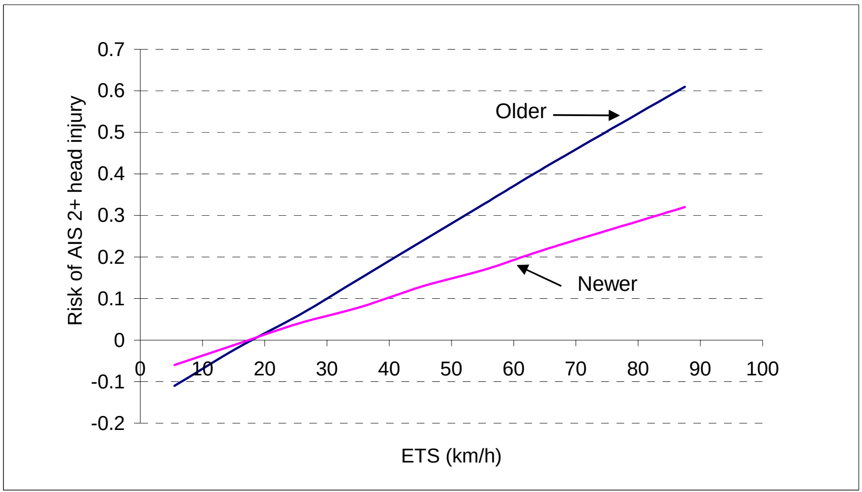

Figure 5 - AIS 2+ Head Injury Risk
Older-R^2=0.917, sig of regression p=0.000
Newer-R^2=0.731, sig of regression p=0.007

AIS 2+ head injury risk increased with crash severity in both older and newer cars. The risk in newer cars was about half that in older vehicles across the full range of ETS. At 60 km/h for example the risk in newer cars was 20%, but nearly 40% in older cars. The effectiveness of improved safety for the head therefore increased with crash severity.

Table 3 - Driver Age in Older and Newer Cars – AIS 2+ Head Injury

	Older Cars	Newer Cars
Inter quartile Range (yrs)	25-51	28-48
Median (yrs)	36	36
Mean (yrs)	40	39
N	343	67

t-test on mean (equal variances not assumed) p=0.855

Table 4 - Driver Gender in Older and Newer Cars – AIS 2+ Head Injury

	Male	Female	N
Older Cars	66%	34%	348
Newer Cars	71%	29%	68

(χ^2 = 0.59, d.f. = 1, p<0.444)

Comparison of age and gender for drivers with AIS 2+ head injury showed no statistical differences between those in older and newer cars. Although the majority in both types of vehicle were male.

CHEST INJURY RISK MODEL - In the sample of belted drivers, there were 2706 with known chest injury severity in older cars, 336 of whom had an AIS 2+ chest injury. In newer cars, the corresponding numbers were 1193 and 113 respectively. ETS was known for 1864 drivers of older cars of which 252 had AIS 2+ chest injury. The corresponding numbers in newer cars were 854 and 89 respectively. Figure 6 shows the risk of AIS 2+ chest injury in older and newer cars. The negative risk shown is a product of the straight line fit.

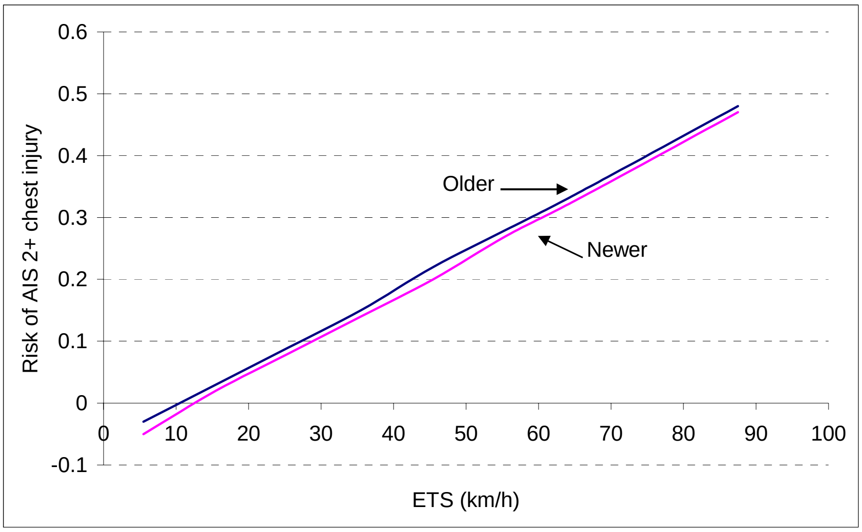

Figure 6 - AIS 2+ Chest Injury Risk
Older-R^2=0.913, sig of regression p=0.000
Newer-R^2=0.859, sig of regression p=0.001

AIS 2+ chest injury risk increased with crash severity in both older and newer cars. The risk in both types of vehicle was very similar across the full range of ETS. At 60 km/h for example the risk in both newer and older cars was 30%.

Table 5 - Driver Age in Older and Newer Cars – AIS 2+ Chest Injury

	Older Cars	Newer Cars
Inter quartile Range (yrs)	34-64	36-64
Median (yrs)	48	48
Mean (yrs)	48	50
N	332	113

t-test on mean (equal variances not assumed) p=0.504

Table 6 - Driver Gender in Older and Newer Cars – AIS 2+ Chest Injury

	Male	Female	N
Older Cars	61%	39%	336
Newer Cars	73%	27%	113

(χ^2 = 4.659, d.f. = 1, p=0.031)

Comparison of age for drivers with AIS 2+ chest injury showed now statistical differences between those in older and newer cars. Drivers in newer cars were more likely to be male compared to those in older cars ($p<0.05$). Although the majority of drivers in both vehicle types were male.

THIGH INJURY RISK MODEL - In the sample of belted drivers, there were 2706 with a maximum known thigh injury severity in older cars, 117 of whom had an AIS 2+ thigh injury. In newer cars, the corresponding numbers were 1194 and 42 respectively. Of drivers in older cars with AIS 2+ thigh injury 112/117 (96%) had sustained femur fracture. The corresponding figure in newer cars was 39/42 (93%). ETS was known for 1864 drivers of older cars of which 81 had AIS 2+ thigh injury. The corresponding numbers in newer cars were 854 and 35 respectively. Figure 7 shows the risk of AIS 2+ thigh injury in older and newer cars. The negative risk shown is a product of the straight line fit.

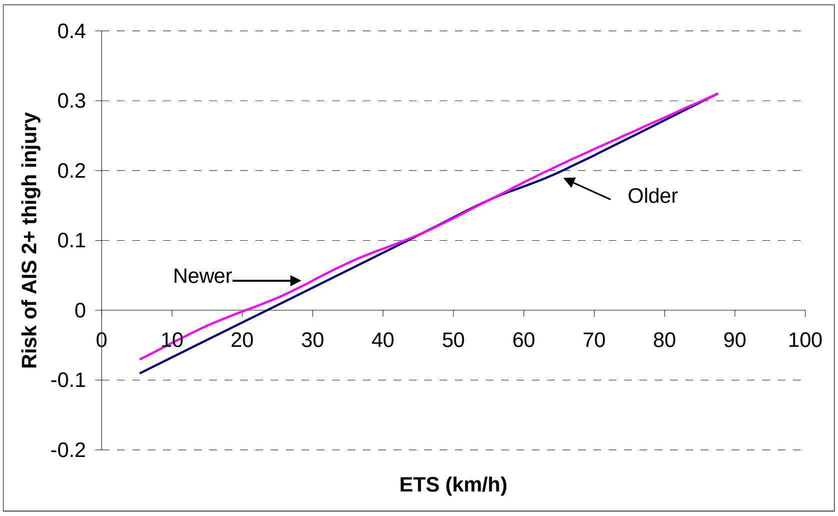

Figure 7 - AIS 2+ Thigh Injury Risk
Older-R^2=0.825, sig of regression p=0.002
Newer-R^2=0.825, sig of regression p=0.002

AIS 2+ thigh injury risk increased with crash severity in both older and newer cars. The risk in both types of vehicle was very similar across the full range of ETS. At 60 km/h for example the risk in both newer and older cars was 18%.

Table 7 - Driver Age in Older and Newer Cars – AIS 2+ Thigh Injury

	Older Cars	Newer Cars
Inter quartile Range (yrs)	25-50	28-50
Median (yrs)	36	36
Mean (yrs)	39	40
N	113	41

t-test on mean (equal variances not assumed) p=0.835

Table 8 - Driver Gender in Older and Newer Cars – AIS 2+ Thigh Injury

	Male	Female	N
Older Cars	60%	40%	117
Newer Cars	64%	36%	42

(χ^2 = 0.258, d.f. = 1, p=0.611)

Comparison of age and gender for drivers with AIS 2+ thigh injury showed no statistical differences between those in older and newer cars. Although the majority in both types of vehicle were male.

BELOW KNEE INJURY RISK MODEL - In the sample of belted drivers, there were 2704 with a maximum known below knee injury severity in older cars, 190 of whom had an AIS 2+ below knee injury. In newer cars, the corresponding numbers were 1193 and 80 respectively. In older cars, 74/190 drivers with AIS 2+ below knee injury had sustained leg fracture (39%) while 129/190 sustained ankle/foot fracture (68%). In newer cars, 36/80 drivers with AIS 2+ below knee injury had sustained leg fracture (45%) while 56/80 sustained ankle/foot fracture (70%). The majority of drivers with below knee injury had therefore sustained ankle foot fracture, in both groups.

ETS was known for 1862 drivers of older cars of which 142 had AIS 2+ below knee injury. The corresponding numbers in newer cars were 853 and 62 respectively. Figure 8 shows the risk of AIS 2+ below knee injury in older and newer cars. The negative risk shown is a product of the straight line fit.

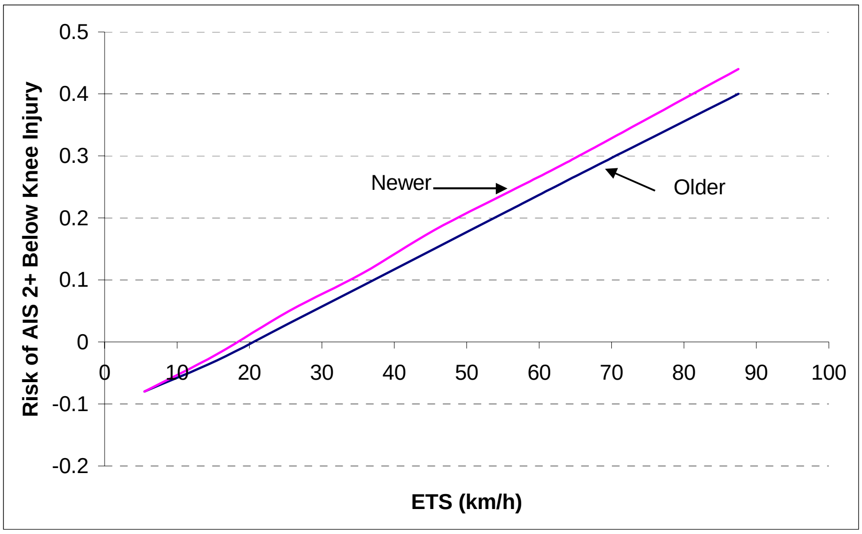

Figure 8 - AIS 2+ Below Knee Injury Risk
Older-R^2=0.851, sig of regression p=0.001
Newer-R^2=0.905, sig of regression p=0.000

AIS 2+ below knee injury risk increased with crash severity in both older and newer cars. The risk in newer cars was slightly higher than in older cars across the full range of ETS. At 60 km/h for example the risk in newer vehicles was 26% and 23% in older cars.

Table 9 - Driver Age in Older and Newer Cars –AIS 2+ Below Knee Injury

	Older Cars	Newer Cars
Inter quartile Range (yrs)	27-53	29-54
Median (yrs)	39	38
Mean (yrs)	41	42
N	186	80

t-test on mean (equal variances not assumed) p=0.577

Table 10 - Driver Gender in Older and Newer Cars – AIS 2+ Below Knee Injury

	Male	Female	N
Older Cars	56%	44%	190
Newer Cars	59%	41%	80

(χ^2 = 0.136, d.f. = 1, p=0.712)

Comparison of age and gender for drivers with AIS 2+ below knee injury showed no statistical differences between those in older and newer cars. Although the majority in both types of vehicle were male.

INTRUSION AND LOWER LIMB INJURY - Passenger compartment deformation (intrusion) is a response to how the front end structures absorb crash energy and is also an outcome of crash severity. Figure 9 shows the intrusion associated with AIS 2+ lower limb injury.

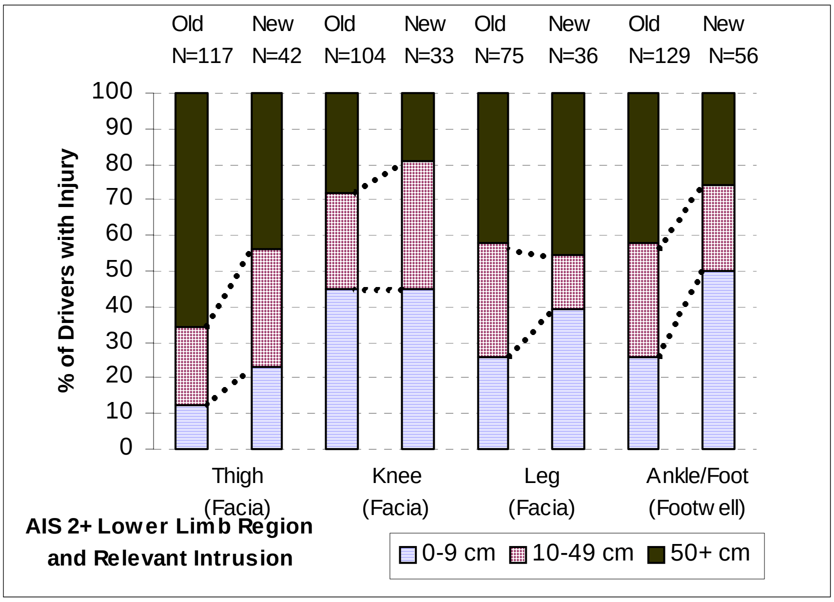

Figure 9 - Intrusion and AIS 2+ Lower Limb Injury

In newer cars, Femur fractures and fractures of the ankle/foot regions were less often associated with severe intrusion (50+ cm) than in older cars. Of note is that while 26% of drivers in older cars received ankle foot injury with <10 cm of footwell intrusion, this intrusion level accounted for 50% of drivers with those injuries in newer cars. In both vehicle types, AIS 2+ knee injuries were those least often associated with severe intrusion. Overall, AIS 2+ lower limb injuries appear to have occurred with lower levels of intrusion in newer vehicles, despite a similar risk by crash severity to older vehicles.

DISCUSSION

UK national casualty figures from 1997 and 1998 show a general reduction in injury rates for drivers of newer cars. Those reductions were greatest for serious and fatal injuries. It is likely this can be attributed to improvements in crashworthiness, since the trend coincides with the year in which vehicles with driver airbags and more effective restraints were introduced to the UK (Lenard et al, 1998). Those measures were specifically targetted at reducing moderate to serious injuries. Additionally, it is unlikely that there were significant changes in emergency medical care or accident rates over the two year period studied. For future work, the national casualty figures might be combined with make and model data, so that the contribution of specific designs to the casualty reduction figure can be assessed. In that way, best practice in safety design could be evaluated against the population of injury accidents.

Only driver injuries were assessed on account of the under-representation of uninjured passengers in the data. It is possible, although unlikely, that the protection offered in modern vehicles has the effect of taking a driver, who was previously seriously or fatally injured, out of the injury population altogether. However, typically a casualty recorded with any injury will have injuries to four body regions even at a minor level so it is most probable that an injured driver will remain injured albeit at a less severe level.

It is reasonable to assume that, since new vehicles introduced in 1993 contained improvements primarily aimed at frontal crash protection, then improvements in those crashes have contributed significantly to the reduction in casualties in the national data. One limitation of the national data is that it does not show what injuries are being reduced and under what crash conditions.

Using in-depth accident data, predictive risk models were developed for AIS 2+ injury to belted drivers in frontal crashes. For each model developed, there was a good, statistically significant fit to the data. Although it should be noted that, accuracy at very low levels of crash severity (where drivers are more likely to be uninjured) may be compromised because the CCIS sampling system specifically targets injured occupants.

There was a substantial reduction in the predicted risk of AIS 2+ head injury for belted drivers in newer cars. This was an intuitive finding based on the presence of an airbag and has been shown before in European studies (Lenard et al, 1998, Frampton et al, 2000, Langweider et al, 1997). The result does however validate the method used to develop the injury risk models. It indicates the effectiveness of the airbag in reducing head injury, especially as the risk of AIS 2+ injury in newer cars was consistently half that in older cars, across a broad spectrum of crash severity.

AIS 2+ injury risks to the chest, thigh and below the knee were very similar between older and newer cars, occurring at similar crash severities. A number of driver parameters were investigated to ensure that driver populations were similar and not affecting the results. This was because chest injury rates are shown to be highly correlated to occupant age (Morris et al, 2002). Generally, there is a reduction in tolerance to blunt trauma with increasing age. Additionally, there is good evidence which suggests that femur strength also decreases with age (Dejeammes and Ramet, 1996). In terms of gender, women, who are generally smaller than men might stand a higher chance of striking the vehicle interior due to closer proximity to the steering wheel and other interior structures.

Overall, gender and age distributions were very similar for drivers with AIS 2+ head, chest, thigh and below knee injuries in older and newer cars which illustrates no confounding occupant factors relating to injury risk. One exception concerned the higher proportion of males with AIS 2+ chest injury in newer vehicles. If newer vehicles were better at protecting the chest, but injuries occurred at similar crash severities to older cars, this could be due to a higher proportion of females in newer cars, sitting closer to the steering wheel. Since this is not the case, the conclusion that AIS 2+ chest injury risk is not reduced between vehicle types, remains valid.

AIS 2+ below knee injury risk by crash severity remained unchanged between old and new vehicles. However, there were indications that such injuries occurred at lower levels of intrusion in newer cars, especially to the ankle foot. It is likely that the newer cars were more resistant to intrusion generally, although it is not known how many were designed for offset testing. This could be usefully followed up in a future study. Nevertheless, the relationship between intrusion and injury risk is certainly not clear. Thomas and Bradford (1995) showed that when controlling for crash severity, intrusion still dictated the risk for the lower limbs. This current study suggests that the issue of the crash pulse may be as pertinent. Crandall et al (1995) have already shown from crash tests that loading of the lower extremity can be higher in cars with lower levels of intrusion. This issue is important to address due to the highly impairing nature of many of these injuries.

Clearly there are still major issues to consider in the area of frontal crash protection. Overall, this study has demonstrated a reduction in injury, coincident with the introduction of new safety measures. At a detailed level, it suggests that those reductions are likely due to the attenuation of head injuries in frontal crashes. The risk of AIS 2+ injuries to the chest, thigh and below knee still need to be addressed. The effect of seat belt pretensioners in reducing occupant loads and forward movement appears questionable considering this unchanged risk.

The viability of producing predictive injury risk models from accident data has been shown. They will allow future comparison of injury risk in different generations of vehicle. Further, as well as quantifying injury risk in accidents, the use of such models allow a more direct comparison of accident data to output from ATD's in crash tests or computer simulations.

Whilst the predictive risk from real crashes is extremely useful to vehicle safety designers, further work is needed to determine the mechanisms of injury in newer cars. They may not be the same as in older cars. For example, what is the relationship between the structural response (intrusion) and crash severity (input)? Even though there are clear benefits to the head, it can be seen that there is still a risk of head injury in newer cars with airbags. To further improve protection, causation mechanisms need to be investigated.

The effect of changes in vehicle design need to be evaluated for occupants in other seating positions also. Because front seat passengers and rear passengers are exposed to a different environment than drivers. That may well affect the way in which they are injured and the subsequent development of protective measures.

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National (STATS 19) road accident data is collated by the Department of Transport, Local Government and the Regions (DTLR) and supplied to the Vehicle Safety Research Centre in electronic form by the UK Data Archive at

Essex University. Those who originally collected the data bear no responsibility for the further analysis or interpretation of it.