Factors related to fatal injury in frontal crashes involving European cars

FACTORS RELATED TO FATAL INJURY IN FRONTAL CRASHES INVOLVING EUROPEAN CARS

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ABSTRACT

Despite considerable improvements in frontal impact crashworthiness, frontal crashes still account for a major number of front seat occupant fatalities in Great Britain. This study attempted to determine the remaining potential for further fatality reduction with passive safety improvements in frontal crashes. No evidence was found to support an increase in crash test speeds. Instead, assessment of scope for survival showed that at least 27% of all fatal drivers and 39% of all fatal front seat passengers have survival potential given attention to older occupant's chest injury tolerance and passenger compartment intrusion under 60 km/h. Considering only fatal frontal crashes that might be assessed with a barrier test, showed an estimated survival potential of at least 49% of belted drivers and 60% of belted front seat passengers. The high proportion of unbelted fatalities suggested that targeting unbelted occupant protection could have additional benefit.

FRONTAL IMPACT CRASH PROTECTION in Europe is assessed with an offset test (EU Directive 96/79/EC, 1996). That essentially examines vehicle structural performance with belted occupants. It was developed by the European Enhanced Safety of Vehicles Committee (Lowne, 1994) because 2/3 of serious and fatal injuries in frontal crashes were found to occur with intrusion (Hobbs, 1992). In addition to the directive, EURONCAP has been driving crashworthiness since its inception in 1996 (Hobbs et al, 1999). The EuroNCAP frontal test configuration is similar to regulation but run at 64 km/h, rather than 56 km/h.

The result of offset testing has been an overall improvement in crash protection in European frontal impacts as shown by Lenard et al, 1998, Frampton et al, 2000, 2002 and Langweider et al, 1997 using in-depth crash injury data. National accident data for Great Britain also reflects the overall reduction in car occupant injuries in cars manufactured from the mid 1990's onwards. In research by Frampton et al, 2002, an examination of national car to car crashes which occurred in calendar years 1997 and 1998 were used to estimate changes in mean casualty rates between cars manufactured 1988-1992 and 1993-1998. The use of just two years of data ensured that any effects of accident reduction measures were minimised. The results showed decreases in the casualty rate for newer cars. This was most pronounced with fatalities (an 18% reduction). The reduction in the killed/serious injury rate was almost as high at 15%. Because major changes to crash safety over the assessed time period was aimed at frontal crashes, it was hypothesized that gains made in injury reduction could be largely attributed to improved frontal crash protection. Those improvements are now directing attention toward the need for protection against fatal and serious injury in side crashes (Thomas and Frampton, 2003).

Nevertheless, analyses of 2004 national accident data for Great Britain (STATS19) show that frontal crashes still account for the majority of both driver (58%) and front seat passenger (53%) deaths. Currently, there is an increasing emphasis on Active Safety technology, based on the assumption that this will yield a greater return on casualty reduction compared to Passive Safety measures. Given this emphasis on Active Safety and the major gains in frontal impact crashworthiness, this study asks how much scope remains for protection against fatal injuries in frontal crashes using passive safety improvements. The last such dedicated fatality study in the UK was reported in a paper by Frampton and Mackay, 1994. Their study used 1983 – 1992 crash injury data from the East and West Midlands of England with vehicles designed to pass the full frontal barrier regulation (ECE 12, 1973) and containing no airbags or pretensioners.

METHOD

In-depth crash injury data from the UK Co-operative Crash Injury Study (CCIS) was used to examine the factors related to fatal frontal crashes. The study selects cases for investigation using a stratified random sampling procedure based on injury severity. The accident sampling covers crashes involving towed cars less than 7 years old at the time of the accident in geographical regions selected to represent urban and rural roads in Great Britain. The sampling gives a bias toward serious injury crashes because about 80% of serious and fatal crashes are covered with examination of all fatal crashes in the sample areas. For a comprehensive description of the CCIS study methodology, the reader is referred to Mackay et al, 1985.

Passenger cars from calendar years 1997 to 2005 were selected from crashes which occurred between those years in the CCIS crash injury database. The frontal crash sample was selected from all those cars where a frontal crash was the most severe impact to a vehicle in terms of injury outcome and where at least one front seat occupant died. Injury outcome was recorded using the Abbreviated Injury Scale (AAAM, 1990). Detailed injury information was available for each occupant in the study including maximum AIS by body region and maximum abbreviated injury score (MAIS). Fatally injured occupants were additionally documented with post mortem information, a requirement for accidental death in the UK.

The frontal collisions were further categorised according to a scheme developed by Frampton et al (1992). That scheme groups frontal impacts into four impact classes; Equivalent, Narrow, Underrun and Other. The Equivalent class includes collisions where the front longitudinals are significantly crushed, the type of collision that might be assessed with barrier crash tests. The Narrow class includes concentrated front damage, usually from trees or poles. Collisions with a severe underrun component, usually with struck object contact to the vehicle roof line are categorised in the Underrun class. The 'Other' class includes collisions which are unclassifiable because of the complexity of the impact.

CCIS calculates a number of measures of crash severity. In this fatal injury sample, the Equivalent Test Speed (ETS) was selected as the crash severity measure because, compared to other measures it was available for a greater number of crashes. ETS is the vehicle delta v, calculated on the assumption that deformation was caused by impact to 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. 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. Facia intrusion was known for both driver and passenger sides and was used to indicate the magnitude of compromise (intrusion) in the passenger ride-down space. It should be noted that this was static intrusion measured post crash. Actual dynamic intrusion would have been a little higher.

The results of this study predominantly use descriptive analyses, however, where appropriate, the Chi-Square test for statistical significance was used. The null hypotheses of no difference between groups was rejected if the probability (p) associated with the test statistic was less than 0.05.

RESULTS

INJURY SEVERITY AND SEAT BELT USE IN FRONTAL CRASH SAMPLE - Table 1 shows front seat occupants in the frontal crash sample by seat belt use and injury outcome.

Table 1. Seat Belt Usage Rates by Injury Outcome for Frontal Crash Sample (N=3187)

	Front Seating Position		
Injury Outcome	Driver	Front Seat Passenger	Driver and Passenger
All Survivors	88% (N=2336)	87% (N=725)	88% (N=3061)
MAIS 3+ Survivors	79% (N=205)	78% (N=54)	79% (N=259)
Fatalities	72% (N=103)	74% (N=23)	72% (N=126)
All Injury Severities	87% (N=2439)	87% (N=748)	87% (N=3187)

Accident data often shows lower belt use than in the general traffic population due to the nature of the sampling bias toward injury crashes. Here, the belt use for front seat occupants of all injury severities is 87% compared to an average of 93% in UK national roadside surveys shown in various Transport Research Laboratory reports (Restraint Use by Car Occupants, 1997-2005). There is little difference in belt use between drivers and passengers with the same injury status. Belt use for all front seat occupant fatalities (72%) is significantly lower than for all survivors (88%) [Chi squared=25.54, df=1, p=0.000] and much lower than the general U.K average of 93%. 28% of the sample of front seat occupant fatalities were unbelted. This is important to note because frontal impact occupant protection in Europe is based around a belted occupant. The scope for preventing fatalities to unbelted occupants would require a dedicated study due to the complex kinematics involved. In all probability, that scope would be more limited than that for belted occupants.

BELTED FRONT SEAT OCCUPANT FATALITIES IN ALL FRONTAL CRASHES - In the frontal impact sample of 126 fatally injured front seat occupants, 91 were belted of which 74 were drivers and 17 were front seat passengers.

Overall Injury Severity for Belted Front Seat Occupants

Table 2 shows the maximum AIS sustained by the 91 belted front seat occupant fatalities in all frontal crashes.

Table 2. MAIS – Belted Front Seat Occupant Fatalities (N=91)

MAIS	**N**	**Percentage**
<4	10	12%
4	34	37%
5	33	36%
6	14	15%
Total	91	100%

Most fatalities (88%) sustained a MAIS of 4+. Multiplicity of injury is an important factor with fatalities (Mackay et al, 1992), however, the MAIS is still a good reflection of fatality risk. For example, in the whole frontal impact sample from which these fatalities were drawn, there were 214 front seat occupants with MAIS 3, of whom 98% survived the crash. Of 164 occupants with MAIS 4+ however, only 32% survived.

Impact Class and Struck Object for Belted Front Seat Occupants

Table 3 shows the impact classes and struck objects for the 91 fatally injured and belted front seat occupants in frontal crashes.

Table 3. Frontal Impact Class and Struck Object – Belted Front Seat Occupant Fatalities (N=91)

	Object Struck						
Impact Class	Car	Light Truck	Heavy Truck	Pole/ tree	Wide Object	N/K	(%)
Equivalent	39	7	7	-	13	1	74%
Narrow	-	-	-	3	2	-	5%
Underrun	1	2	16	-	-	-	21%
Other	-	-	-	-	-	-	0%
(%)	44 %	10%	25%	3%	17%	1%	100%

In terms of impact class, most (74%) were impacts with substantial involvement of the vehicle frontal structures with 21% of impacts being the underrun type with direct impact to the vehicle windshield and A-pillars. Narrow crash configurations were relatively rare comprising 5% of the belted fatal sample.

44% of occupants were involved in a car to car collision, while 25% were involved in collisions with heavy trucks. 70% of heavy truck impacts resulted in substantial underrun. 17% of occupant's vehicles collided with wide off road objects such as walls and bridge parapets. Only 3% of fatal impacts were to narrow objects like trees and poles. In only 1% of cases was the object struck not known (N/K).

<u>Injury Patterns for Belted Front Seat Occupants in Underrun Versus Non Underrun Crashes</u>

Of the 91 fatally injured and belted front seat occupants, 19 were involved in impacts with substantial underrun of the vehicle structure. Figure 1 compares the body regions where AIS 4+ injury occurred for those cases against the 72 occupants in impacts without a major underrun component (termed "non underrun").

Non Underrun (N=72) Underrun (N=19)

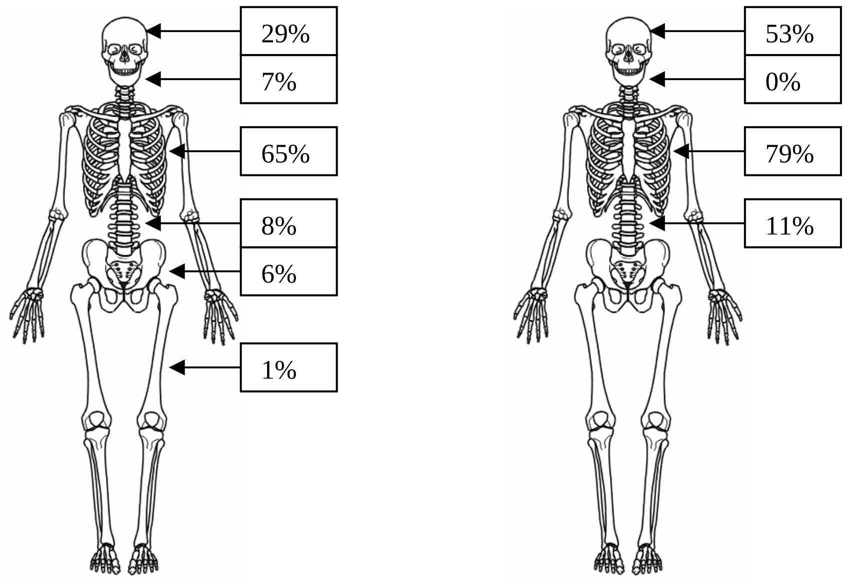

Figure 1. Belted Occupant AIS 4+ Injury Rates by Body Region - Non Underrun Versus Underrun Fatal Frontal Crash Configurations

The AIS 4+ injury rates for head, neck, chest, abdomen, pelvis and thigh are shown for cases with and without underrun. The head and chest were the body regions most at risk of AIS 4+ injury in both types of crash configuration. AIS 4+ abdominal injuries showed a relative increase of 38% in underrun crashes, the chest showed a relative increase of 22% while the head showed a relative increase of 83%. This was, in most cases due to direct head impact on the heavy truck or the windshield header rail supported by the truck. Care should be taken when interpreting these results due to the small sample of underrun crashes, however, the general trend is clear in that AIS 4+ injury rates were higher for the head, chest and abdomen when an underrun occurred. In particular, the increased risk of serious head injury is emphasized. The scope for passenger car design to prevent fatality in severe underrun crashes is likely to be very limited even when occupants are belted.

BELTED FRONT SEAT OCCUPANT FATALITIES IN NON-UNDERRUN FRONTAL CRASHES - Current European frontal barrier tests aim to improve crashworthiness by engaging the vehicle front structures in a demanding offset impact condition, promoting improved performance in both car to car and car to narrow object impacts. Two belted Hybrid III dummies assess the injury risk. This section explores the factors related to fatal injury in real world crashes targeted by the frontal tests.

In this study, 72 fatally injured and belted front seat occupants were exposed to an impact with significant structural engagement and no major underrun. Of those, 93% were in Equivalent impacts and 7% in narrow object impacts. These 72 occupants formed 79% of the belted front seat occupant fatalities and 57% of all front seat occupant fatalities (both belted and unbelted). Drivers and front seat passengers were separated for the analysis because the steering wheel and other vehicle control components in front of the driver can have a marked effect on the type and severity of injuries received. There were 57 drivers and 15 front seat passenger fatalities to be examined.

<u>Belted Drivers and Front Seat Passengers in Non-underrun Crashes - AIS 4+ Injury Rates by Body Region</u>

The rates of AIS 4+ injury by body region are shown in figure 2 for fatally injured belted front seat occupants in non-underrun crashes. Figure 2 shows the AIS 4+ driver head injury rate to be lower than that for the front passenger despite the presence of the steering control mechanism. That illustrates the effectiveness of the driver airbag. It should be noted that 8/57 drivers had no airbag whilst 11/15 front passengers had no airbag. Care should be taken when interpreting the front passenger results due to the small sample size. Nevertheless, the general injury trends are clear. For both drivers and passengers the head and chest sustained the highest rates of AIS 4+ injury, with the chest being the body region most often injured at AIS 4+ by a large margin. One driver sustained an AIS 4+ thigh injury due to traumatic amputation above the knee.

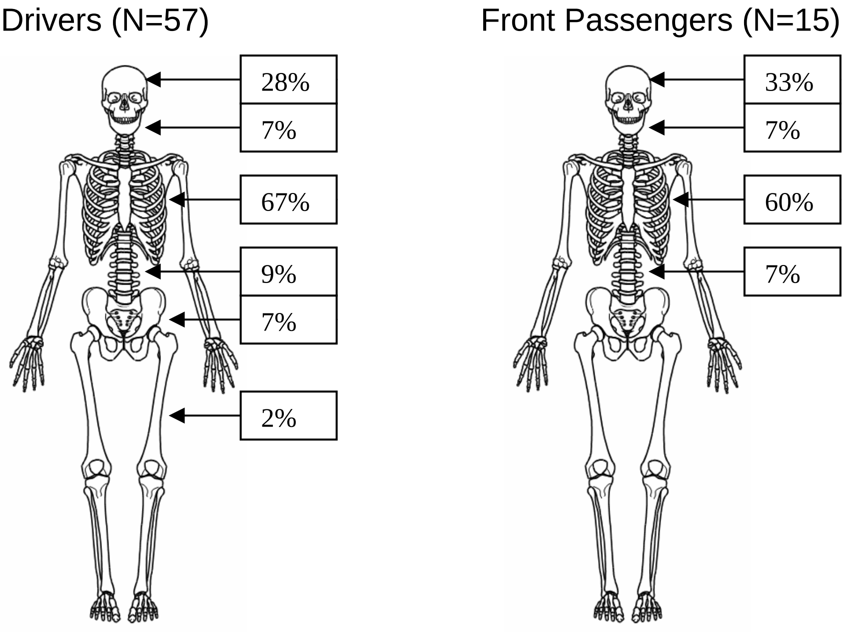

Figure 2. AIS 4+ Injury Rates by Body Region - Belted Drivers and Front Passengers in Fatal Non-Underrun Crashes

<u>Belted Drivers with Airbags and ETS - Crash Severity</u>

Figure 3 shows the distribution of crash severity for fatally injured belted drivers with airbags.

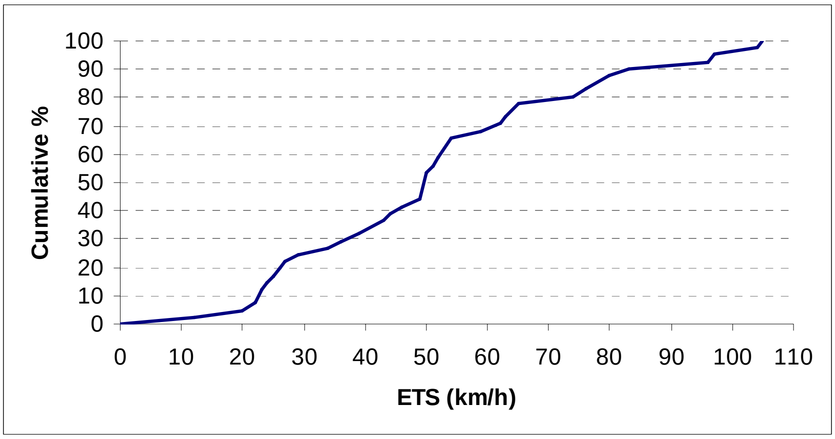

Figure 3. ETS Distribution for Fatally Injured Belted Drivers with Airbags (N=41)

The median ETS was 50 km/h with an interquartile range of 32 to 65 km/h. 78% of these drivers died with an ETS below 66 km/h (consistent with the EuroNCAP crash severity) while 68% died with an ETS below 60 km/h (consistent with the crash severity for EU Directive 96/79/EC). This is not overwhelming evidence to support the raising of frontal crash test speeds, especially with the attendant implications for “stiffening” of vehicle structures. Those who died below 60 km/h equate to 28/103 (27%) of fatally injured belted and unbelted drivers and 28/126 (22%) of the whole population of fatal front seat occupants.

Belted Drivers with Airbags and ETS - Intrusion and Crash Severity

For the 41 belted drivers with known ETS, facia static intrusion was known in 37 cases.

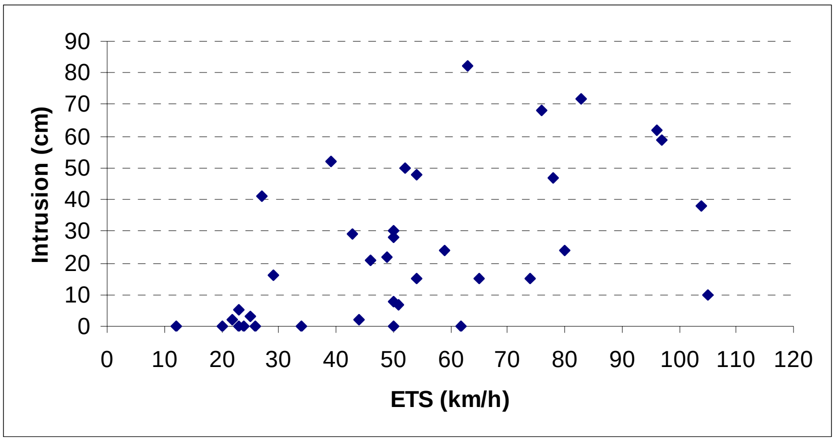

Figure 4. Intrusion and ETS for Fatally Injured Belted Drivers with Airbags (N=37)

Figure 4 shows that facia intrusion was generally high in the 12 crashes above 60 km/h. Only 2 showed facia intrusion below 10cm and the average intrusion was 41cm. Additionally, 8 of the 12 crashes were in excess of 75 km/h, well into the crash severity spectrum where crash protection becomes uncertain. Figure 3 showed that only 20% of drivers with belts, airbags and known ETS experienced crashes in excess of 75 km/h.

Of the 25 crashes below 60 km/h however, the level of facia intrusion was more evenly split with 13 cases below 10cm and 12 $\geq$ 10cm. The average intrusion was 16cm. Vehicles designed to pass offset tests at 56 km/h should at least be capable of preventing serious injury (AIS 3+) to the head, chest abdomen and thigh in real world crashes below and up to 60 km/h and with no fatalities. Additionally, it would be expected that intrusion in excess of 9cm should be unlikely at speeds up to that assessed in the regulation.

Here, when ETS was below 60 km/h and intrusion below 10cm, the average intrusion was 2cm. When ETS was below 60 km/h and intrusion $\geq$ 10cm, the average intrusion was 31cm.

Belted Drivers with Airbags and ETS - Injury Patterns by Crash Severity

Table 4 shows AIS 3+ injury rates for belted drivers with airbags for crash severities below and above 60 km/h. For crashes below 60 km/h, intrusion levels are also considered. The head and chest were the body regions most often injured to AIS 3+ across all crash conditions. AIS 3+ Thigh, abdomen and pelvis injury rates were highest in the most severe crash condition (condition A). Serious thigh injury rates were much higher in conditions A and C than in condition B. This is likely due to the higher levels of facia intrusion in conditions A and C. Abdominal injury rates were also much higher in conditions A and C compared to condition B. This may be associated with higher levels of steering column intrusion but need further investigation. In Condition C, almost all drivers sustained AIS 3+ chest injury which may also be associated with steering column intrusion. That chest injury rate is a cause of some concern given that the crash severity is below 60 km/h. In condition B, the causes of AIS 3+ head and chest injury is of concern given crash severity below 60 km/h and low levels of intrusion. No AIS 3+ foot/ankle injuries were evident in any of these crash conditions.

Table 4. Fatally Injured Belted Drivers with Airbags and ETS - AIS 3+ Injury Rates by Crash Severity

	Crash Condition		
Body Region	A ETS > 60km/h (N=12)	B ETS <= 60km/h, intrusion <10cm (N=13)	C ETS <= 60km/h, intrusion >=10cm (N=12)
Head	6 (50%)	5 (39%)	7 (58%)
Neck	1 (8%)	3 (23%)	1 (8%)
Upper Limbs	2 (17%)	-	1 (8%)
Chest	10 (83%)	8 (62%)	11 (92%)
Abdomen	4 (33%)	1 (8%)	3 (25%)
Pelvis	3 (25%)	1 (8%)	1 (8%)
Thigh	6 (50%)	1 (8%)	4 (33%)
Knee	-	-	1 (8%)
Legs	3 (25%)	1 (8%)	1 (8%)

Belted Drivers with Airbags and ETS - Occupant Age/Gender by Crash Severity

Table 5 shows the gender split and ages of belted drivers with airbags for crash severities below and above 60 km/h.

Table 5. Fatally Injured Belted Drivers with Airbags and ETS - Occupant Age and Gender by Crash Severity

	Crash Condition		
	A ETS > 60km/h (N=12)	B ETS <= 60km/h, intrusion <10cm (N=13)	C ETS <= 60km/h, intrusion >=10cm (N=12)
Age (years)	Median=57: Range=36 - 66	Median=65: Range=48 - 76	Median=48: Range=26 - 61
Gender	Male=75% Female=25%	Male=77% Female=23%	Male=67% Female=33%

Table 5 sheds some light on the causes of serious chest injury in condition B. The occupants were older in that condition compared to conditions A and C (median age 65 years, interquartile range 48-76 years). So that, despite low intrusion and crash severities under 60 km/h, serious chest injuries likely occurred due to seat belt loads. The gender split (77% male) also suggests that it is not only older women who are at risk from belt loads.

Belted Drivers with ETS and no Airbag

Six drivers fell into this category. Despite being post 1997 vehicles they were not fitted with driver airbags. European driver airbags have a considerable influence on head injury reduction and can also reduce some chest loads. It was therefore not considered appropriate to examine crash conditions and occupant injury patterns further due to the vehicles not having the full compliment of current safety features.

Belted Front Seat Passengers with Airbags and ETS

Table 6 shows for belted front seat passengers with airbags, the maximum body region AIS, occupant age and gender together with vehicle ETS and static facia intrusion. There was not enough data to draw a cumulative frequency chart of ETS.

Table 6. Fatal Belted Front Seat Passengers with Airbags – Body Region Maximum AIS, Age, Gender and Crash Severity (N=3)

Maximum Body Region AIS	**Front Passenger Number**		
	1	**2**	**3**
Head	1	0	4
Neck	0	0	1
Chest	4	5	3
Abdomen	1	2	0
Thigh	0	0	0
Leg	0	1	0
Age (years)	70	66	89
Gender	F	F	F
ETS (km/h)	31	35	18
Intrusion (cm)	0	0	0

All of the three occupants shown in table 6 were elderly women in crashes of low severity and no facia intrusion. All had sustained serious chest injury with one occupant sustaining a serious head injury also. The cause of AIS 4 head injury is unknown and should be further investigated, given the low crash severity (18 km/h) and no facia intrusion, there is a suggestion of head to airbag interaction. The conditions of low intrusion and low crash severity suggest scope for appropriate seatbelt load limiting to reduce chest injury severity. These crashes were all well below the crash severity used in regulation testing and should be at least survivable. These three situations equate to 3/23 (13%) of fatally injured belted and unbelted front seat passengers and 3/126 (2%) of the whole population of fatal front seat occupants.

<u>Belted Front Seat Passengers with ETS and no Airbag – Intrusion and Crash Severity</u>

Vehicles sold in the UK were slow to include front seat passenger airbags unlike equivalent vehicles sold in other European countries, due to differing marketing demands and strategies. This accounts for the relatively large passenger sample without airbags in this study. Unlike the situation for drivers however, the benefits of front seat passenger airbags has been debated for the condition where front passengers are belted. It was therefore felt necessary to examine belted fatal front seat passengers without airbags in this study. It should be noted that all 10 passengers in this section were in vehicles with driver airbags and therefore improved frontal crash structures.

For the 10 belted front seat passengers with no passenger airbag and known ETS, facia static intrusion was known in all cases. 10 data points were considered insufficient to produce a valid cumulative frequency chart of ETS, however, a scatter plot of facia intrusion versus ETS was considered to be helpful. Figure 5 shows how facia intrusion and ETS varied for the fatally injured front seat passengers with no airbag.

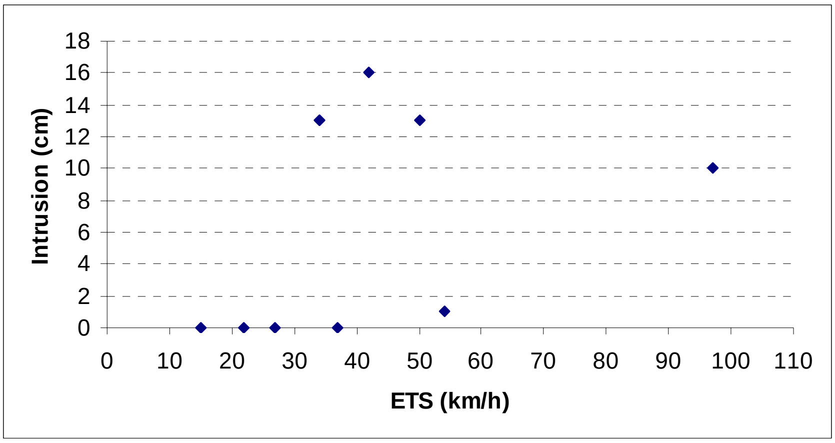

Figure 5. Intrusion and ETS for Fatally Injured Belted Front Seat Passengers Without Airbags (N=10)

The median ETS was 36 km/h with an interquartile range of 26 to 51 km/h. There were two cases with an ETS of 34 km/h and 13cm of intrusion represented by only one marker on the chart. Almost all of these passengers were fatally injured below 60 km/h. The one exception being an extremely severe impact at 97 km/h. 5 of the cases below 60 km/h showed virtually no facia intrusion but there were 4 cases with intrusion between 12 and 16cm.

Belted Front Seat Passengers with no Airbag in Crashes <= 60 km/h

Table 7 shows for belted front seat passengers without airbags and ETS below 60 km/h, the maximum body region AIS, occupant age and gender together with vehicle ETS and static facia intrusion.

Two occupants sustained AIS 3+ head injury, 2 sustained AIS 3+ neck injury, 1 sustained AIS 3+ abdominal injury, 1 sustained AIS 3+ thigh injury and 1 sustained AIS 3+ leg injury. Seven of the nine sustained AIS 4+ chest injury. In only two cases could it be argued that a passenger airbag may have been effective in reducing serious head injury (passenger numbers 3 and 8). In case number 3, reduction of chest injury alone would likely not have avoided the fatality because of an AIS 5 neck injury. In six of the nine cases however, reducing the chest injury may have avoided the fatality. That equates to 6/23 (26%) of fatally injured belted and unbelted front seat passengers and 6/126 (5%) of the whole population of fatal front seat occupants.

Those six occupants were all elderly (all over 70, except one at 61) and female. All their chest injuries were caused by seat belt loading. Passenger 9 only received abdominal abrasions from the seat belt. He was 58 years old and developed a left side pneumothorax requiring insertion of a chest drain. He died in hospital two days post crash but the exact cause of death is unknown.

Table 7. Fatal Belted Front Seat Passengers without Airbags – Body Region Maximum AIS, Age, Gender and Crash Severity in Crashes <=60 km/h (N=9)

Maximum Body Region AIS	**Front Passenger Number**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Head	0	1	3	1	1	1	0	5	0
Neck	1	1	5	2	3	0	2	0	0
Chest	4	4	4	4	4	6	4	0	0
Abdomen	2	4	0	2	2	2	1	0	1
Thigh	0	0	0	3	0	0	0	0	0
Leg	0	1	1	1	0	3	0	0	0
Age(years)	81	61	21	80	86	80	74	17	58
Gender	F	F	F	F	F	F	F	F	M
ETS(km/h)	54	42	34	50	15	34	37	27	22
Intrusion (cm)	1	16	13	13	0	13	0	0	0

<u>Belted Drivers and Front Seat Passengers with no ETS</u>

Twelve fatal front seat occupants fell into this category, 10 drivers and 2 front seat passengers. Static facia intrusion was known for 11 occupants but it was considered inappropriate to examine crash conditions and occupant injury patterns further with no objective measure of crash severity (ETS) available. It should be noted however that one 19 year old female driver, with no intrusion, sustained an AIS 4 injury to the head and no injury to any other body region. In this case, an airbag was present but did not deploy.

ESTIMATES OF POTENTIAL SURVIVABILITY – What is the remaining potential for survival in frontal impacts? The answer to this question can involve subjective analysis, open to debate. For reasons of objectivity, it was decided to define a “passive safety envelope” for survival potential in the cars used in this study. These cars were assumed to have improved frontal crash structures and restraints compared to the sample examined in the 1994 Frampton and Mackay work.

The crash severity level (56 km/h) employed in the current European frontal test regulation (EU Directive 96/79/EC, 1996) was used as a "benchmark" to define the boundary of the "passive safety envelope." Real world crashes falling within the safety envelope were those where the crash severity was less than 60 km/h, the vehicle structure was engaged (and not significantly underrun) and the occupants were belted and provided with airbags. Some front seat passengers without airbags were assumed to fall within the envelope where the vehicle had improved frontal crash structures and where the passenger received no serious head injury (which may have been prevented with an airbag). Table 8 shows the number of fatal front seat occupants in the sample who fell within the safety envelope.

Table 8. Fatally Injured Front Seat Occupants in Frontal Crashes – Numbers Within Safety Envelope

	N	**Within Safety Envelope**
Unbelted Occupants	35	No
Severe Underrun Impacts	19	No
Belted Occupants in Non Underrun Impacts		
DVR + bag. ETS < 60 km/h	28	Yes
DVR + bag. ETS >= 60 km/h	13	No
DVR + no bag	6	No
FSP + bag. ETS < 60 km/h	3	Yes
FSP + no bag. ETS >= 60 km/h	1	No
FSP + no bag. ETS < 60 km/h. AIS 4+ chest injury - from belt. No AIS > 1 head injury	6	Yes
FSP + no bag. ETS < 60 km/h. No AIS 2+ injury	1	Not Known
FSP + no bag. ETS < 60 km/h. Serious head/neck injury	2	No
DVR + FSP. No ETS	12	Not Known
Total	126	

Unbelted occupants and those involved in severe underrun crashes fell outside the safety envelope because these conditions are not specifically addressed in European vehicle design. There were some cases where insufficient detail was available to make a judgement on survival potential because ETS was unknown or cause of death was uncertain due to very minor injuries. Therefore, table 8 may underestimate the number of cases falling within the safety envelope. Using the results from table 8, table 9 shows the number of fatalities with potential for survival as a proportion of various front seat occupant groups.

Table 9. Fatally Injured Front Seat Occupants in Frontal Crashes – Potential for Survival in Relation to Front Seat Occupant Groups

Fatality Group	Potential for Survival
Belted/unbelted – All Frontals	
Front seat occupants N=126	29%
Drivers N=103	27%
Front seat passengers N=23	39%
Belted Only – All Frontals	
Front seat occupants N=91	41%
Drivers N=74	38%
Front seat passengers N=17	53%
Belted Only – Non Underruns	
Front seat occupants N=72	51%
Drivers N=57	49%
Front seat passengers N=15	60%

Overall, the greatest potential appears to be for front seat passengers. The belted only – non underrun condition represents most closely the crash conditions that might be assessed with crash tests. 57% of all fatally injured front seat occupants were in that type of crash. In that condition, this research indicates that half of the drivers and 60% of the front seat passengers had potential for survival.

DISCUSSION

The introduction of new regulation and consumer frontal crash tests in Europe from 1996 onward, resulted in improvements to the frontal crashworthiness of cars. The risk of serious and fatal injury has shown a substantial decline in the UK, in part due to newer vehicle designs. Nevertheless, fatal injuries still occur to car occupants with a significant number occurring in frontal crashes. This study has examined the factors related to front seat occupant fatalities in frontal crashes, using cars from calendar years

1997-2005, in an attempt to assess the potential benefits which still remain from improved passive safety measures.

In front crashes, the seat belt is the primary restraint and, in Europe at least, crash protection is optimised for the belted occupant. Given the high proportion of unbelted occupants in this UK fatal frontal crash sample (28%), it may be time to reconsider unbelted occupant protection. Especially since the UK has one of the highest belt usage rates in Europe and there are regions in other European countries where belt use is significantly lower. It would be correctly argued that seat belts should always be used, however, it could also be argued that pedestrians should not step into the path of on-coming cars, yet pedestrian protection is now of importance in the design of European vehicles.

15% of all fatally injured front seat occupants were belted and involved in severe frontal collisions with underrun to the windscreen and A-posts. The impacted object was commonly a heavy truck. AIS 4+ head, chest and abdominal rates were higher in those underrun crashes compared to those without underrun. In particular, the AIS 4+ head injury rate was far higher because of direct head impact to the incoming vehicle. Those underrun crashes were severe and currently beyond the threshold where occupants might be expected to survive because the structural integrity is so severely compromised. Improved protection likely lies with the design of heavy truck underrun guards. Regulations governing those guards have been in place in the UK since 1983 (Motor Vehicles Construction and Use Regulations, 1983) but there is clearly more that can be done to increase their efficiency.

57% of all fatal front seat occupants were belted and involved in a crash with no major underrun component. The type of condition assessed in frontal barrier tests and termed “non underrun impacts” in this study. Injury outcomes in these crashes were compared to those from similar fatal frontal crashes with older car designs, studied by Frampton and Mackay in 1994. For drivers, the AIS 4+ head injury rate is down from 40% in the ’94 analysis to 28% in this study. Perhaps an indication of airbag effectiveness. The AIS 4+ chest injury rate is similar, 67% compared to 69% in the ’94 study. The Abdominal injury rate is down from 19% in ’94 to 9%. For front passengers, the AIS 4+ head injury rate is up on the ’94 study from 12% to 33% while the chest injury rate is down from 77% to 60%. The Abdominal injury rate is down from 18% in ’94 to 7% in this study. It should be noted that the median crash speeds for fatalities in this study are lower than those found in the ’94 analysis. In that analysis, the median speeds for drivers and passengers were 61 km/h and 50 km/h respectively. In this current study they were 50 km/h for drivers and 36 km/h for front seat passengers. Care should be exercised when comparing the absolute values for front seat passenger samples due to their small size. Nevertheless, the generally lower speeds in this current study may be due to newer vehicles providing better protection at higher crash severities (thus contributing to the overall reduction in fatalities), whilst leaving the lower speed crashes unaddressed. Additionally, the increased stiffness of newer vehicles may contribute to raising the crash pulse and hence affect the number of deceleration injuries. These issues should be investigated further. Especially as there have been recent calls in Europe for a “restraint test” to supplement the offset barrier assessment.

Chest injuries remain the most frequently injured body region to AIS 4+ for both belted driver and front seat passenger fatalities. AIS 4+ chest injuries to the driver in particular occurred at the same rate to that in the ’94 study, despite the lower crash speeds in the newer vehicles. Indeed, several studies, Frampton et al, 2000, 2002 and Langweider et al, 1997 all show no major gains in driver chest protection in European vehicles manufactured after the mid 1990’s, despite the presence of airbags and pre-tensioners. The causes of those driver chest injuries deserve detailed further research.

In non underrun impacts, where crash speed was known, more than two thirds (68%) of belted drivers with airbags died under 60 km/h, the approximate crash severity of the European regulation frontal test. Almost 80% died under 66 km/h, the approximate crash severity of the EuroNCAP frontal test. This is not supportive of an increase in crash test speeds. In about half of the cases where ETS was less than 60 km/h, excessive intrusion likely contributed to the fatality, in the other half (with low intrusion) the driver age and seat belt loads were the more likely contributory factors, although the cause of some serious head injuries in that low intrusion condition warrant further investigation. Almost all front seat passengers with known crash speed died under 60 km/h with the major contributory factor being age and seat belt loads resulting in AIS 4+ chest injuries. A similar finding was reported by Mackay and Frampton in 1994 and still appears to be an issue. The decreasing impact tolerance of the chest with age has been well documented in work by Morris et al, 2002. In this study, there was 1 belted front seat passenger with an AIS 4 head injury at very low (18 km/h) crash severity with no intrusion. That case warrants further examination for possible head to airbag interaction.

The crash severity level employed in European frontal test regulations was used as a “benchmark” to define the “safety envelope” under which potential existed for fatality prevention. In real frontal crashes this translated into impacts with a crash severity less than 60 km/h, structural engagement without significant underrun, where the occupants were belted and provided with airbags. The airbag criteria was dropped for front seat passengers where it was concluded that a bag would have had no demonstrable effect on injury outcome.

For the whole sample of fatal frontal crashes, including underruns and unbelted occupants, it was estimated that there was survival potential for at least 29% of all front seat occupant fatalities, 27% of all driver fatalities and 39% of all front seat passenger fatalities.

Considering only non underrun crashes allowed an assessment of the real world crash conditions directly targeted by frontal crash tests. The results indicated survival potential for 51% of belted front seat occupants. Almost half (49%) of fatal belted drivers had potential for survival. About half of those experienced significant intrusion at less than 60 km/h. Vehicles designed to pass offset deformable tests should not exhibit significant intrusion below 60 km/h. These crashes should be examined in further detail to determine the reasons for intrusion. Perhaps with an eye on issues of Compatibility. The other half of drivers experienced very little intrusion at less than 60 km/h but were elderly, most with AIS 4+ chest injuries, likely to have been seatbelt related.

It was also estimated that 60% of belted front seat passengers in non underrun crashes had potential for survival, given attention to age and seat belt loading issues. Smart restraint systems such as BOSCOS (Hardy et al, 2005) which use ultrasound to detect occupant bone strength and modify belt load limiting could have a large impact on fatality reduction.

It should be emphasized that survival potential was not assessed for 37% of all fatal front seat occupants due to non-use of the seat belt or a lack of information concerning crash severity. The assessments of potential survivability in this study are therefore very likely to be underestimates.

The current emphasis on Active Safety technology is important. Preventing crashes happening in the first place is the best way to prevent injury, however, the technology is still in development. Future accident prevention measures will also include more automatic control of the driving task. That is, however, some distance away. This study has shown that, in the meantime, fatalities in frontal crashes do not all occur as a result of extremely severe crash conditions. Indeed, many occur at crash severities well below those assessed with crash tests. As such, there is still potential for improved protection against fatal injury using a passive safety approach.

CONCLUSIONS

- Frontal crashes still account for a major number of car occupant fatalities in Great Britain.
- The number of fatally injured unbelted occupants suggests it may be timely to consider unbelted occupant protection in frontal crashes.
- 15% of fatal frontal crashes were severe underruns, beyond the limits of passive safety protection.
- In non underrun frontal crashes, fatalities occurred at lower crash severities in newer cars. Possibly due to a reduction of casualties at higher crash severities.
- No evidence was found to support an increase in frontal crash test speeds.
- Intrusion is still an issue for driver fatalities under 60 km/h as is the chest injury tolerance of older drivers.
- The chest injury tolerance of older female front seat passengers is a major issue for fatalities under 60 km/h.
- The chest remains the body region most frequently injured to AIS 4+ for both belted drivers and front seat passengers who died.
- Considering all fatally injured front seat occupants in frontal crashes, there is an estimated survival potential for 27% of drivers and 39% of front seat passengers, given improved passive safety.
- Considering belted, fatally injured front seat occupants in frontal crashes, with no significant underrun, shows an estimated survival potential for 49% of drivers and 60% of front seat passengers, given improved passive safety.
- Values of potential for survival are likely to be underestimated in this study.

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ACKNOWLEDGEMENTS

This paper uses accident data from the United Kingdom Co-operative Crash Injury Study (CCIS). CCIS is managed by TRL Ltd on behalf of the Department for Transport (Transport Technology and Standards Division) who fund the project with Autoliv, Ford Motor Company, Nissan Motor Europe and Toyota Motor Europe. The data were collected by teams from the Birmingham Automotive Safety Centre of the University of Birmingham, the Vehicle Safety Research Centre at Loughborough University, and the Vehicle & Operator Services Agency of the Department for Transport. Further information on CCIS can be found at http://www.ukccis.org

National (STATS 19) road accident data is collated by the UK Department for Transport 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.