LOW SEVERITY FRONTAL CRASHES THAT CAUSE INJURY TO ELDERLY OCCUPANTS

Kennerly Digges
The George Washington University, USA

Ruth Welsh, Andrew Morris
Vehicle Safety Research Centre
Loughborough University, UK

ABSTRACT

According to NASS data, for belted occupants exposed to frontal crashes, approximately 69% of the MAIS 3+ injuries are in crashes with delta-V less than or equal to 40km/h. For occupants 65 and older, 85% of the MAIS 3+ injuries and 56% of the fatalities are in these lower severity crashes. Occupants age 65 and older account for approximately 33% of fatal injuries in frontal crashes with a severity of 40km/h delta-V or lower. For elderly occupants involved in these lower severity crashes, the chest/abdomen is the most frequently injured body region, accounting for 55% of the MAIS 3+ injuries. Cases in the US and UK were examined to identify opportunities for further injury reduction. The criteria were: belted occupants age 60 and older with MAIS 3+ chest injuries; of vehicles model year 1998 and later; frontal crashes. The case review indicates that the air bags are performing well. The most frequent crash mode was a far-side corner impact (30%). Run-off-the-road and across the centerline were also frequent (22%), particularly among the older drivers. A large opportunity exists to improve safety systems by reducing injuries from crashes with inertia component toward the vehicle center. Accident avoidance features to reduce lane departure and intersection hazards could also be beneficial.

ELDERLY; ACCIDENT ANALYSIS; INJURIES; FRONTAL IMPACTS; SAFETY BELTS

NUMEROUS STUDIES HAVE SHOWN the higher vulnerability to injury and death of older occupants involved in motor vehicle crashes [Augenstein, 2001; Fildes, 2001; and Mackay 1994, 2000]. Other studies of gender differences indicate that females, like older occupants, are more vulnerable to injury that males of the same age [Lenard 2001, Welsh, 2001]. Evans found that the same physical insult was three times more likely to fatally injure a 70 year old compared with a younger person age 15 to 45. He further showed that women age 15 to 45 were 25% more likely to be killed from a similar physical insult than their male counterparts [Evans 2001, 1991].

Studies of serious injuries by body region for restrained occupants in frontal crashes have shown that for belted occupants aged 65+, the chest is the body region most frequently injured at the MAIS 3+ level [Augenstein, 2005]. Similar results were found for belted fatally injured older drivers in frontal crashes [Kent, 2005]. A further study [Welsh, 2006] showed that AIS 3+ skeletal chest injury was more prevalent among older belted front occupants (65+) than their younger counterparts and that belt loading was more frequently the injury mechanism for the older age group.

Earlier studies examined changes in chest injury propensity using cadaver testing and found a significant decrease in injury tolerance by age [Zhaou, 2001]. For frontal crashes, belt loading was found to more significantly increase the risk of injury compared with loading by air bags. When compared to 16-35 year old occupants or the “young” group, the chest injury threshold for air bag loading was reduced to 84% for the 36-65 year old age group and to 79% for the 66-85 year old age group. For belt loading, the reduction was to 47% for the 36-65 year old age group and to 28% for the 66-85 year old age group.

NHTSA’s Reports to Congress on the Effectiveness of Occupant Protection Systems have consistently shown that air bags and belt systems are less effective for elderly occupants when compared to younger occupants [NHTSA 2001]. Beginning in model year 1998 less aggressive air bags and improved belt technology were encouraged by US Standards. Manufacturers have responded by incorporating new safety technology including dual stage air bags and belts that incorporate pre-tensioning and force limiting. These systems should be beneficial in reducing injuries to occupants of all ages. A purpose of this study is to determine the characteristics of the lower severity crashes that are causing injuries to older occupants in post 1998 vehicles so that opportunities for further safety improvements can be identified.

METHODS

A statistical analysis of frontal crashes in NASS/CDS 1998-2004 was undertaken to determine the distribution of severe injuries and fatalities by crash severity and injured body region for belted front seat occupants by age groupings. This analysis confirmed the findings of several other studies that chest injuries are the most frequent injuries suffered by older occupants and that most of these injuries occur in crashes with delta-V 40km/h or less.. Of particular interest is the injury occurrence in recent model vehicles. Because of the limited data available on recent model vehicles involved in frontal crashes the approach taken was to perform a clinical review of each available case in two different databases. The two databases were: the US NASS/CDS 1998-2005 and in the UK in-depth accident database, known as the CCIS (Co-operative Crash Injury Study) database (1998-2006). Combined, these databases contain records of more than 600 occupants age 60 and older who were exposed to frontal crashes and sustained MAIS 3+ injuries. However, when filtered for belted occupants in vehicles model year 1998 and later in crashes equal to or less severe than 40km/h, the number of cases from NASS was reduced to 26. An additional 14 cases were available from the UK database. Individual cases from the two data sources were examined to determine crash patterns that were associated with MAIS 3+ chest injury. It should be noted that one case has been included where no MAIS 3+ chest injury occurred but the occupant died. His most severe injuries were an AIS 3 femur fracture attributed to the knee bolster and AIS 2 colon and mesenteric lacerations attributed to the safety belt. This case is highlighted as case 23 in Table 3.

ANALYSIS OF NASS CDS

NASS 1998-2004 contains 20,801 belted front seat occupants exposed to frontal crashes equal to or less severe than 40 km/h. Of these occupants 1,265 suffered MAIS 3+ or fatal injures (MAIS 3+F). When expanded by NASS weighting factors, the population becomes 11,228,238 front seat occupants with 125,396 MAIS 3+F injured. The distribution of the weighted occupants with MAIS 3+ injuries and fatalities by age group is shown in Table 1.

It may be noted from Table 1 that only 3% of the MAIS 3+ injured are age 65+ and in crashes more severe than 40 km/h. Consequently, the injury rates for this group are less reliable than for the other groups. However, the injuries suffered by this group are much more likely to be fatal.

The NASS database was further queried to determine the injury distribution by body region for belted front seat occupants age 65+ in 1998 and later model year vehicles involved in frontal crashes equal to or less severe than 40 km/h. The result was that 55% of the MAIS 3+ injuries were to the chest/abdominal region.

Table 1; Belted Front Seat Occupants in Frontal Crashes by Delta-V and Age Group – Distribution of MAIS 3+ Injured Occupants, Fatalities and Injury Rates.

MAIS 3+ INJURIES	**Age**	**Age**	**Age**	
Crash Severity km/h	**16-35**	**35-65**	**65+**	**All**
Less than or equal 40	28%	24%	17%	69%
Greater than 40	15%	13%	3%	31%
Total	43%	37%	20%	100%
FATAL INJURIES	**Age**	**Age**	**Age**	
Crash Severity km/h	**16-35**	**35-65**	**65+**	**All**
Less than or equal 40	10%	11%	18%	41%
Greater than 40	17%	28%	14%	59%
Total	27%	39%	33%	100%
INJURY RATE	**Age**	**Age**	**Age**	
Crash Severity km/h	**16-35**	**35-65**	**65+**	
Less than or equal 40	0.90	1.30	2.60	
Greater than 40	14.50	21.30	18.50	

CLINICAL REVIEW OF NASS/CCIS CASES

To better understand the nature of the crashes in which elderly occupants are injured, a case by case review of NASS/CCIS cases was undertaken. As shown by the analysis of NASS field data, the largest opportunity for reducing elderly fatalities for belted occupants is in frontal crashes with a severity less than or equal to 40 km/h. In these crashes, chest injuries were found to be the body region with the most frequent MAIS 3+ injuries. It was desired to investigate the performance of newer vehicles with second generation air bags. The criteria for selecting cases for detailed review was as follows: Belted front seat occupants, age 60 and older with MAIS 3+ chest injuries in vehicles model year 1998 and later that were in frontal crashes with delta-V 40 km/h and below. One case where a fatality resulted from an AIS 2+ abdominal injury was also included. The query produced 40 cases within the two data sets – 15 male and 25 female. Twelve of the 25 drivers were male. There were 12 female and 3 male front passengers. The distributions of these occupants and injury severity by occupant age and vehicle delta-V are shown in Table 2. In Table 2, the "All" column includes all MAIS 3+ injured and the one MAIS 2 fatality.

Table 2; Distributions of NASS/CCIS Cases that Met the Search Criteria

Age Group	All		Fatals		MAIS 3+		Delta-V	All		Fatals		MAIS 3+	
	US	UK	US	UK	US	UK		US	UK	US	UK	US	UK
60-69	8	9	2	4	5	4	10-19 km/h	7	2	1	0	3	0
70-79	8	4	3	2	4	3	20-29 km/h	10	3	3	1	4	2
80-89	10	1	3	1	4	1	30-39 km/h	9	9	4	6	6	6
Total	40		15		21		Total	40		15		21	

A summary of the crash data from the 40 NASS/CCIS cases is shown in Table 3. The first three columns identify the case in the NASS/CCIS file by the year, PSU (primary sampling unit - numbers indicate NASS cases, letters indicate CCIS cases), and case number NO within that unit. The next four columns provide data on the injured occupant. The Age is in years, the Height (Hgt) is in centimeters, and the weight (Wgt) is in kilograms. In addition the body mass index (BMI – Quetelet, c1869) of the occupant is calculated. The BMI is calculated as a person's weight divided by their height squared. A BMI value less than 18.5 is underweight. A BMI above 25 is overweight and over 30 is obese. In the table, underweight occupants are shown in italics and obese are shown in bold. The column 'OP' indicates the occupant's position – driver (D) or front passenger (P). The Offset column summarizes the location (Driver's side (D), Passenger's side (P) or Center (C)) of the damage to the vehicle front and the estimated distance in percentage that the direct damage extended across the front of the vehicle. The Nr Imp column indicates the number of impacts to the case vehicle. In a number of cases an offset-frontal crash was followed by a side slap between the two vehicles. This type of crash would be documented as 2 impacts. There are two columns that designate the change in velocity or delta-V expressed in km/h. The first column shows the longitudinal or frontal component of delta-V. The second shows the lateral or side component. Two of the last three columns deal with the chest/abdominal injury suffered by the occupant. The AIS column is the severity of the most severe chest injury (except for the single AIS 2 abdominal injury). In this column, fatally injured occupants are designated by bold, underlined numbers. In some cases there were other injuries that may have contributed to the fatality. However, the chest or abdominal injury was also a major influencing factor in all these cases. The contact for the most severe chest (and the AIS 2 abdominal injury) is shown in the penultimate column. The final column lists the crash factors that provide insight into opportunities for countermeasures. These are grouped and prioritized by; run off road / crossing centerline, near/far corner impact and high/low BMI where these are possible contributing factors.

Table 3; Crash Data from 40 NASS/CCIS Cases

	Year	PSU	NO	Age	Hgt cm	Wgt kg	BMI	OP	Offset	Nr Imp	DV front	DV side	AIS	Chest Contact	Crash Factors
1	2002	2	14	68	196	122	**31.8**	D	50% D	6	-17	3	**4**	A/B Steer C	Run off left
2	2004	82	164	80	175	88	28.7	D	100% C	2	-33	0	5	Airbag	Run off left
3	2001	L	13384	60	n/k	n/k	n/k	D	100% C	1	-37	10	3	Steering Wheel	Run off left
4	2001	L	13384	61	158	77	**30.8**	P	100% C	1	-37	10	**4**	Safety belt	Run off left
5	2004	K	86118	61	160	64	25.0	D	24% P	1	-27	0	3	Unknown	Run off left
6	2000	79	13	83	158	66	26.4	P	10%P	2	-35	6	**4**	Safety belt	Run off right
7	2003	73	176	66	183	91	27.2	D	80% P	2	-32	0	4	Safety belt	Over centerline
8	2004	2	62	81	178	77	24.3	D	50% D	1	-22	4	**5**	Safety belt	Over centerline
9	2004	50	147	80	157	54	21.9	D	40% D	1	-35	0	**5**	Steering C	Over centerline
10	2004	79	244	70	175	136	**44.4**	D	95% P	3	-39	0	**3**	Safety belt	Over centerline
11	2003	L	15118	61	n/k	n/k	n/k	D	23% D	1	-38	0	**5**	Steering wheel	Over centerline
12	2003	B	34122	71	178	92	29.0	D	n/k	1	-19	0	3	Safety belt	Junction judgment
13	2002	74	11	79	183	91	27.2	D	5%D	1	-8	14	4	Left interior	Near corner
14	2004	72	173	67	165	79	29.0	D	10%D	1	-16	14	4	Left interior	Near corner
15	1998	73	106	70	155	54	22.5	P	50% D	2	-14	37	3	Safety belt	Far corner
16	2001	41	106	79	157	60	24.3	D	10% P	2	-11	-4	3	Safety belt	Far corner
17	2002	78	39	87	163	54	20.3	D	75% P	2	-26	-22	**4**	Steering C	Far corner
18	2002	73	188	63	165	68	25.0	P	50% D	2	-29	17	3	Trans. Lever	Far corner
19	2003	49	186	85	178	82	25.9	D	50% P	1	-24	0	3	Steering C	Far corner
20	2004	13	161	87	178	64	20.2	D	40% P	1	-36	-13	3	Right interior	Far corner
21	2004	13	172	80	173	79	26.4	D	40% P	2	-33	-12	3	Safety belt	Far corner
22	2004	79	18	82	173	82	27.4	D	10% P	1	-21	-17	3	Steering C	Far corner
23	2005	45	196	69	n/k	102	n/k	D	80% P	1	-37	-7	**2**	Safety belt	Far corner
24	2002	W	70668	69	178	87	27.5	D	29% P	1	-18	0	3	Safety belt	Far corner
25	2002	L	13411	72	n/k	n/k	n/k	P	77% D	1	-26	-7	5	Safety belt	Far corner
26	2002	D	75680	69	183	98	29.3	P	n/k	1	-31	0	3	n/k	Far corner
27	2003	W	70856	60	170	64	22.1	P	29% D	1	-38	0	4	Safety belt	Far corner
28	2005	L	15734	66	n/k	n/k	n/k	P	69% D	1	-37	0	**5**	Safety belt	Far corner
29	2001	48	62	83	160	41	***16.0***	P	100% C	1	-22	-8	3	Safety belt/airbag	Low BMI
30	2003	D	76009	69	178	44	***13.9***	D	100% C	1	-37	0	3	Safety belt	Low BMI
31	2004	B	34441	87	183	50	***15.0***	P	100% C	1	-30	0	**5**	Safety belt	Low BMI
32	2002	78	2	73	152	77	**33.3**	P	80% D	1	-12	4	3	Safety belt	High BMI
33	2005	73	162	68	163	91	**34.3**	D	80% C	1	-27	5	3	Steering C	High BMI
34	2005	2	54	60	168	136	**48.2**	D	10% D	1	-26	0	4	Steering C	Near Corner High BMI
35	2005	41	39	78	147	75	**34.7**	D	20% D	1	-34	0	**5**	Airbag	Far Offset High BMI
36	2005	50	175	66	165	77	28.3	D	100% C	2	-32	18	3	Safety belt	Frontal/Rotation
37	2002	75	53	71	150	54	24.0	P	80% D	3	-22	8	**3**	Safety belt	2 Frontals
38	2001	2	51	75	n/k	n/k	n/k	P	100% C	1	-24	-9	3	Safety belt	Frontal
39	2000	B	32868	70	175	n/k	n/k	P	100% C	1	-27	0	**4**	Safety belt	Frontal
40	2004	B	34441	79	190	87	24.1	D	100% C	1	-30	0	**5**	Steering wheel	Frontal

DISCUSSION

The discussion to follow applies to belted front seat occupants in frontal crashes. Referring to Table 1, the NASS analysis shows that approximately 69% of the MAIS 3+ injuries are in crashes equal to or less severe than 40 km/h delta-V. For occupants 65 and older, 85% of the MAIS 3+ injuries and 56% of the fatalities are in these lower severity crashes. Occupants age 65 and older account for approximately 33% of the fatal injuries in frontal crashes equal to or less severe than 40 km/h. For elderly occupants involved in these lower severity crashes, the chest/abdomen is the most frequently injured body region, accounting for 55% of the MAIS 3+ injuries.

A summary of the occupant ages and crash severity by injury severity for the 40 clinical NASS/CCIS cases is shown in Table 2. Whilst the largest grouping is the 60-69 year olds, of these over a quarter are octogenarians. There are differences in the age distributions between the US and UK cases; 10 of the 11 occupants aged over 80 were from the NASS data (38% of NASS cases) with just 1 from the CCIS data (7% of CCIS cases). Whilst the rate of AIS 4+ chest injury among the chest

MAIS 3+ occupants is comparable for the UK and US cases, the fatality rate is higher for the CCIS cases (50%) compared to the NASS cases (28% excluding the AIS 2 abdominal injury case). The majority of the CCIS fatal cases (85%) occurred where the delta-V was greater than 30 km/h whereas 50% of the fatal NASS cases had a delta-V less than 30 km/h.

Rib fractures were present in the majority of the clinical cases with MAIS 3+ chest/abdominal injuries. The rib fractures were generally accompanied by MAIS 2+ soft tissue injuries, with lung contusion being the most frequent. However there were 7 cases where lung contusions occurred without documented rib fractures. There were also 2 cases with AIS 3+ bowel injuries without AIS 3+ rib fracture.

The crashes in Table 4 have been grouped according to common crash factors that may have contributed to the crash or the injury. The run-off and over-centerline (and a case of junction judgment) constitute the initial group of twelve. The largest group is the next grouping of 18 that involve offset or corner crashes, sometimes with significant lateral delta-V. These crashes frequently involve secondary side-slaps that may contribute to the injury. In 15 of the 18 crashes, the injured occupant was on the far-side of the crash. The occupant may have been subjected to an inertia component that was not straight forward. In these cases the crash vector included a lateral component directed toward the vehicle far-side. In some cases a side slap may have also provided an additional lateral component. In the two cases with a near-side lateral component, the chest injury was caused by contact with the vehicle near-side interior.

The number of large and/or obese people among the injured occupants was higher than expected; this was particularly noticeable in the NASS cases. Of the 33 occupants with known weight and height, 21 were overweight, 7 of whom were obese. There were two passengers, cases 29 and 31 (aged 83 and 87) and one driver aged 69 (case 30) who were underweight. In these cases an underlying frailty may have contributed to the injury outcome.

The heavy individuals pose a challenge to the restraint systems. Two of the high BMI individuals (cases 10 and 34) weighed over 130 kg. For each, their injury was from the steering assembly, suggesting that they may have exhausted the energy absorption capability of the restraint system. Another was only 147 cm tall (case 35), but with a high BMI and a build requiring a belt extender.

The final six cases in the table involve a variety of crash types. One involved a 90-degree rotation prior to the frontal crash. A second involved multiple frontal crashes. The third was a low severity crash with a male passenger and a female driver. Only the passenger was injured and the injury was an AIS 3 rib fracture. This case was unremarkable. The remaining two cases were also un-remarkable.

The air bag was listed as a source of injury in 2 cases. One involved a run-off-the-road crash in which the driver appeared to be inactive and possibly incapacitated (case 2). The other involved a very short (147cm) female (case 35) who was obese and required a belt extender. The steering system was the source of injury in two cases of head-on crashes involving occupants with weight above the 95th percentile (cases 33 and 34). The steering system was also frequently a source of injury in the far-corner offset crashes. However, the belt system was the most frequent injury source; 22 of 38 cases with known contact (58%).

The most frequent crash mode was a corner impact – either to the far front or to the near front. Nine cases involved corner impacts or impacts with high to moderate lateral delta-V. Five of these cases displayed a far corner impact. The most frequent pre-crash event was making a turn across traffic, with an associated front corner impact from oncoming traffic. Four cases involved drivers aged 80 or older making turns across the traffic flow. This was the most common pattern that emerged from the analysis.

Multiple impacts were present in about 30% of the cases of NASS cases but none of the CCIS cases. However, in most cases the second impact was a sideswipe that had little influence on the outcome. There were four cases in which the multiple impacts may have been significant. Three of these cases involved fatal injuries. The types of impacts in these cases were multiple frontal impacts and frontal impacts followed by a side slap. This type of crash is highly complex and requires additional investigation to assess the types and sequence of crashes that offer opportunities for introducing countermeasures.

Another pattern that emerged, particularly from the CCIS cases was the high exposure of females in the front passenger position. The UK data had one case in which sleep or a medical condition may have contributed to the crash and a close-in occupant may have contributed to the chest injuries.

CONCLUSIONS

The analysis of the NASS/CDS data system shows that the largest opportunity for reducing elderly occupant fatalities is in frontal crashes of severities at or below 40 km/h. About 85% of MAIS 3+ injuries and 56% of the fatalities suffered by belted occupants 65 years and older in frontal crashes are at severities of 40 km/h or lower.

Front corner impacts and/or crashes with a significant lateral velocity component were the most frequent in elderly NASS and CCIS frontal low severity crashes with MAIS 3+ chest injuries. About 35% of the cases had inertia components that directed the occupant toward the vehicle far-side. Another 5% had inertia components that directed the occupants toward the vehicle near-side. These cases suggest opportunities for restraint systems with improved protection in oblique and low-overlap-offset crashes. Similarly, the high proportion of injuries attributed to the belt system (58%) indicates a need to incorporate biomechanical knowledge of the reduced tolerance of elderly occupants into the restraint design.

Crashes during turns across traffic were a common problem for the elderly. In the US cases 12 of the 26 cases involved elderly drivers being hit by an oncoming vehicle during a left turn across an active traffic lane. A right corner impact was the result. Systems to warn drivers of hazardous conditions prior to the turn or to prevent turns under hazardous conditions could be highly beneficial to elderly drivers.

Another condition frequently observed was the failure to take action to prevent driving across the centerline or running off the near-side of the road. At least 7 such cases were present in the US data and 4 in the UK data. The inattention may have been the consequence of drowsiness or a sudden medical condition. These conditions were present in about 22% of the cases. Among drivers 80 years and older, these conditions were present in 40% of the cases. An opportunity exists for crash avoidance countermeasures to address the lane departure problem for older drivers.

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