A COMPARISON OF INJURY SEVERITY AND CRASH SEVERITY DISTRIBUTIONS AND THEIR APPLICATION TO STANDARDS FOR OCCUPANT PROTECTION

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ABSTRACT

This paper looks at car occupant injury data collected in Oxfordshire over a 24 month period; both injury and non-injury accidents are included in the sample which is representative of the area in terms of impact type and severity. Accidents were reconstructed, where appropriate, with the CRASH 2 program, so that the velocity change of each vehicle could be determined. The emphasis in the analysis is on the car interior and how it relates to injury. Common sources of injury are analysed in relation to the body regions affected and the types of impact in which they occur. Front and side impacts are established as priority areas and the distributions of velocity change for these impacts are analysed in relation to injury severity so that implications of providing occupant protection at different levels of crash severity can be assessed. Finally, anthropometric dummy response is compared to injury severity for head and chest injuries to restrained occupants in frontal impacts.

DATA SOURCE

The accident data base used for this analysis covers the county of Oxfordshire, an area of 260,738 hectares with a population of 550,000. It is a representative sample of car collisions, representative that is in terms of impact type and severity (collisions with pedestrians, cycles and motorcycles are excluded). The core of the sample consists of accidents investigated on-scene with call out by the local Ambulance Service. These accidents are biased towards injury and so to fill the 'no injury' gap we also investigated those accidents reported to the Police but not involving Ambulance call out on a 48 hour follow-up basis. To ensure uniform selection, a criterion that the vehicles had to be sufficiently damaged as to require towing from the scene was adopted. The on-scene and follow-up accidents were then combined to provide a total sample with a representative cross-section of all injury severities. A total of 1076 accidents were investigated covering a collection period from April 1979 to June 1981.

ACCIDENT RECONSTRUCTION

One of the objectives in looking at priorities for occupant protection is to correlate injury severity with crash severity. For this analysis velocity change is used to measure crash severity and to ensure that it is calculated in a uniform and consistent manner each accident was reconstructed, where possible, with the CRASH 2 program (1)*. Approximately 53% of all cases were CRASHable, a detailed discussion of the reasons for not running CRASH is given in reference (2).

INJURY SOURCES FOR INJURIES OF ALL SEVERITIES

In looking at ways to improve crash protection for car occupants it is important to discover the mechanisms which most frequently cause injury. The emphasis in this analysis is on the car interior and how it relates to injury. As a starting point rather than divide injuries by types of impact, the accident sample has been analysed according to the injury sources that produced the injuries. Table A1, in the Appendix, gives the frequency of injury expressed as a percentage of all injuries, by injury source cross-tabulated with body regions affected for unrestrained (Table A1a) and restrained (Table A1b) front seat occupants; these tables were generated by including the most serious injury to each body region such that they represent numbers of injuries (rather than number of occupants) but include only one injury per body region. These figures are summarised in Tables 1 and 2 which rank the most common injury sources giving the percentage of total injury and of each body region affected. Table 1 gives figures for unrestrained and Table 2 restrained occupants. It can be argued that in trying to assess priorities for protection one should analyse the population as a whole. However legislation is scheduled for 1982 which makes belt use compulsory in the United Kingdom, so that anticipating an increase in belt use it is appropriate to look at the figures separately.

Most entries in Table 1 are self explanatory - note however that the term 'general front' is used to signify a distributed contact in which no single contact source predominates. The pattern of injury for unrestrained occupants shows the head, legs, arms and chest to be the major body regions affected with the most frequent contacts occurring to the windscreen, steering assembly, instrument panel and general front. Not surprisingly contacts with the front interior of the car are the most frequent, however the side interior ranks as the fifth most frequent source of injury and ground contact which results from occupant ejection ranks sixth.

For restrained occupants the restraint ranks as the most frequent injury source although it should be emphasized that this results from a high incidence of minor belt bruising injuries. Restraint use dramatically reduces head contact with the windscreen, and the steering assembly now appears to cause more head and face injuries although the overall frequency of steering assembly contacts is less than for unrestrained occupants. Following this trend contacts with the instrument panel, general front and parcel tray are all reduced such that restraint use obviously lowers the probability of contact with the front interior of the car. Other differences compared to unrestrained occupants are that restraint use eliminates ejection so that ground contact disappears

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* Numbers in parentheses designate references at the end of the paper.

Table 1. Ranking of Injury Sources and Body Regions affected for unrestrained front seat occupants - injuries of all severities

Injury Source \ Body Region	Head	Neck	Chest	Abdomen	Arms	Legs	Total
Windscreen	16.00*	0.65	0.05	-	2.01	-	18.71
Steering assembly	3.16	0.25	5.47	0.75	2.21	1.30	13.14
Instrument panel	0.80	0.10	1.51	0.55	1.25	6.92	11.13
General front	3.06	0.20	0.55	0.15	2.26	1.66	7.88
Side interior	1.10	0.10	1.15	0.65	1.96	0.95	5.91
Ground	1.95	0.30	0.80	0.25	0.85	0.75	4.90
Parcel tray	0.05	-	0.05	-	0.05	4.26	4.41
Window glass	2.00	0.40	-	-	0.60		3.00
Mirror	1.91	0.30					2.21
Front header	2.06	0.10					2.16
Knobs/keys etc	0.05				0.15	1.86	2.06
Non-contact		1.56					1.56
A pillar	0.90	0.05			0.25	0.05	1.25
Total N = 1993	33.04	4.01	9.58	2.35	11.59	17.75	78.34

* % of all injuries

Table 2. Ranking of Injury Sources and Body Regions affected for restrained front seat occupants - injuries of all severities

Injury Source \ Body Region	Head	Neck	Chest	Abdomen	Arms	Legs	Total
Restraint	0.11*	0.42	14.63	4.96	2.21	0.21	21.79
Steering assembly	6.21	0.42	1.89	0.11	1.37	1.68	11.68
Instrument panel	1.16	0.32	0.32	0.11	0.63	6.63	9.16
Non-contact		8.11			0.21		8.32
Windscreen	4.42	0.32			1.47		6.21
General front	1.68	0.11	0.11	0.11	1.47	2.21	5.68
Side interior	0.84	0.11	0.95	0.42	2.42	0.74	5.47
Window glass	2.74	0.11	0.11		0.84	0.11	3.89
Parcel tray						2.21	2.21
Foot controls						2.00	2.00
Roof	1.26				0.21		1.47
Other occupants	0.84	0.21			0.21		1.26
A pillar	1.05				0.21		1.26
Total N = 950	20.31	10.13	18.01	4.96	11.25	15.79	80.40

* % of all injuries

and non-contact injuries (almost exclusively to the neck) are more frequent.

Having established the common sources of injury the next step in defining a strategy for crash protection is to look at the types of impact in which they occur. Table 3 gives the common injury sources by type of impact for unrestrained front seat occupants. It is clear from the four most frequent sources of injury that head-on impacts predominate. Not surprisingly side interior and window glass contacts generally result from side impact and ground contact from rollover accidents where the likelihood of ejection is high. Non-contact injuries which predominately involve the neck most frequently occur in rear end impacts.

Table 4 gives the corresponding figures of common injury sources by type of impact for restrained front seat occupants. The pattern is similar to that for unrestrained occupants; frontal impacts are the predominant cause of injury except for side interior and window glass contacts which result from side impact. Also although a significant number of non-contact injuries occur in rear impacts for restrained occupants they appear most frequently in frontal impacts; these injuries are in general minor and almost exclusively to the neck.

INJURY SOURCES FOR INJURIES OF SEVERITY AIS 3 OR GREATER

In looking at injuries from the point of view of improving protection it is difficult to know how to optimize the effects of both frequency and severity. One approach (3) is to weight injuries according to cost and use the resulting distribution of weighted injuries, however this has the limitation that the distributions of minor and serious injuries cannot be compared directly. A more basic approach, used here, is to analyse the distributions separately.

Table 5 gives the ranking of injury sources for unrestrained front seat occupants for injuries of severity AIS 3 or greater, together with the percentage of serious injury they represent and the body regions involved. Comparing this with Table 1 for unrestrained occupants the predominant injury sources remain although their order is revised. Thus if the emphasis is on reducing serious injury the priority areas are the instrument panel and steering assembly in front impacts, side interior in side impacts and reduction in ground contacts resulting from ejection in rollovers. For restrained occupants (Table 6) although their ranking is revised the predominant injury sources for serious injury are the same as those for all injuries with the exception of non-contact injuries which drop out and A pillar injuries which assume the higher rank of sixth rather than thirteenth. Comparison with unrestrained occupants shows that restraint use eliminates ground contacts by preventing ejection and also reduces contact with the front interior since the percentages of serious injury from both instrument panel and steering assembly contacts are reduced. The latter reduction has the effect of elevating the side interior to rank highest in terms of producing serious injury with the restraint system itself ranking second. Thus for restrained occupants priority areas for reducing serious injury are side interior contacts from side impact and restraint system, instrument panel, general front and steering assembly contacts in frontal impacts. Note also that the predominant body areas affected are the chest, head, abdomen and legs unlike unrestrained occupants where head injury is more prominent.

As a final note the comparison of injury sources for all injuries and for

Table 3. Injury Source by Type of Impact
- unrestrained front seat occupants

Injury Source \ Impact Type	Head-on	Side	Rollover	Sideswipe	Rear	Total
Windscreen	15.10*	0.80	1.35	1.25	0.10	18.60
Steering assembly	11.09	1.00	0.60	0.45	0.10	13.24
Instrument panel	8.63	1.25	0.65	0.30	0.20	11.03
General front	6.07	0.55	0.40	0.85		7.87
Side interior	1.15	3.71	0.75	0.20	0.10	5.91
Ground	0.30	1.20	3.26	0.15		4.91
Parcel tray	3.56	0.30	0.15	0.20	0.10	4.31
Window glass	0.15	2.01	0.55	0.05	0.25	3.01
Mirror	1.56	0.40	0.15	0.10		2.21
Front header	2.06	0.05	0.05	0.00		2.16
Knobs/keys etc	1.81	0.15	0.0	0.05	0.15	2.16
Non-contact	0.65	0.15	0.25	0.15	0.70	1.90
A pillar	1.05	0.15	0.05	0.05		1.30
Total N = 1993	53.18	11.72	8.21	3.80	1.70	78.61

* % of all injuries - these figures correspond to those in Table 1, the same body regions are used so that the total number of injuries remains the same.

Table 4. Injury Source by Type of Impact
- restrained front seat occupants

Injury Source \ Impact Type	Head-on	Side	Rollover	Sideswipe	Rear	Total
Restraint	17.05*	1.79	0.95	1.58	0.42	21.79
Steering assembly	9.05	1.47	0.74	0.32	0.11	11.69
Instrument panel	6.63	0.95	0.53	0.42	0.63	9.16
Non-contact	4.84	0.95	0.42	0.53	2.42	9.16
Windscreen	4.74	0.32	0.74	0.32	0.11	6.23
General front	4.95	0.21		0.32	0.21	5.69
Side interior	0.95	3.47	0.84		0.21	5.47
Window glass	0.95	1.68	0.63	0.63		3.89
Parcel tray	1.79		0.11	0.21	0.11	2.22
Foot controls	0.95	0.42	0.42	0.21		2.00
Roof	0.11	0.21	0.32	0.95		1.59
Other ccupants	0.74	0.53				1.27
A pillar	1.05	0.21				1.26
Total N = 950	53.80	12.21	5.70	5.49	4.22	81.42

* % of all injuries - these figures correspond to those in Table 2, the same body regions are used so that the total number of injuries remains the same.

Table 5. Ranking of Injury Sources for serious injuries (AIS≥ 3) and body regions affected for unrestrained front seat occupants

Injury Sources \ Body Region	Head	Neck	Chest	Abdomen	Arms	Legs	Total
Instrument panel	0.44*		3.93	3.06	3.06	7.42	17.91
Steering assembly	1.75		8.30	3.49	1.31	0.44	15.29
Side interior	2.18	0.44	4.37	2.68	2.62	1.75	13.98
Ground	5.24	0.44	3.06	1.31		0.87	10.92
General front	1.75	0.87	0.87	0.44	1.31	0.44	5.68
Exterior surface	3.49	0.44	0.44	0.44		0.44	5.25
Windscreen	3.49	0.44			0.44		4.37
Parcel tray						3.93	3.93
Intruding object	0.87		0.44	0.87	0.44	0.87	3.49
Total N = 229	19.21	2.63	21.41	12.23	9.18	16.16	80.82

* % of all serious injuries

Table 6. Ranking of Injury Sources for serious injuries (AIS≥ 3) and body regions affected for restrained front seat occupants

Injury Sources \ Body Region	Head	Neck	Chest	Abdomen	Arms	Legs	Total
Side interior	1.32*	1.32	3.95	2.63	3.95	1.32	14.48
Restraint			6.58	6.58			13.16
Instrument panel	1.32		2.63	1.32	1.32	3.95	10.53
General front	1.32		1.32	1.32	2.63	3.95	10.53
Steering assembly	1.32		6.58				7.89
A pillar	5.26						5.26
Windscreen	1.32	2.63					3.95
Floor						3.95	3.95
Roof side rails	2.63	1.32					3.95
Total N = 76	14.49	5.27	21.06	11.85	7.90	13.17	73.70

* % of all serious injuries

serious injuries suggests similar areas for crash protection although the ranking of the components is slightly different. Accordingly if one were to apply a weighting to injury severity according to cost one would expect the priorities to be similar to those already proposed.

CRASH SEVERITY DISTRIBUTIONS

Having established that priority areas for crash protection are in front and side impacts the next step is to look at the distribution of crash severity in these impacts. Because the accident data base is a representative sample of car collisions, it is meaningful to present distributions of impact severity. Table 7 gives distributions of velocity change for front and side impacts. For frontal impacts the mean velocity change was 13.6 mph and 95.6 % of all impacts occurred at a velocity change of less than 30 mph. For side impacts the mean velocity change is 14.5 mph and 92.4% of all impacts occurred at less than 30 mph. This slightly higher mean velocity change occurs because the distribution of frontal impacts includes the striking cars from rear impacts, which have low values of velocity change, so that their inclusion depresses the mean of the overall distribution. Although these distributions provide an indication as to the speeds that should be adopted for crash testing, to provide a complete picture we require to know the level of injury severity associated with particular velocity changes.

Table 7. Distributions of Velocity Change for Front and Side Impacts

	Front		Side	
ΔV mph	N	%	N	%
1-5	54	10.6	10	7.6
6-10	142	27.8	40	30.3
11-15	149	29.2	35	26.5
16-20	73	14.3	20	15.2
21-25	39	7.6	13	9.8
26-30	31	6.1	4	3.0
31.40	14	2.7	6	4.5
41-50	7	1.4	3	2.3
50+	1	0.2	1	0.8
	510	100.0	132	100.0
Not CRASHed	259	33.7	71	35.0
Mean ΔV	13.6 mph		14.5 mph	

INJURY SEVERITY VERSUS CRASH SEVERITY FOR FRONTAL IMPACTS

Since the velocity change has been calculated for each vehicle a velocity change can be associated with each injury; if each injury is scored on AIS then a pattern of AIS versus ΔV can be constructed. It is important to note that AIS is a discrete ordinal variable such that it is incorrect to assume anything about the interval between specific values. Thus it is incorrect to compute mean AIS versus ΔV. However,since ΔV is a continuous variable mean ΔV's can be calculated for each AIS level. Accordingly mean ΔV's were calculated for each MAIS level for front seat occupants involved in frontal impacts and these are given in Table 8. Mean ΔV's have also been calculated separately for drivers and front seat passengers.

The effectiveness of seatbelts is clearly demonstrated in that the mean ΔV's for belted occupants are considerably higher at every level of severity; this means that for a given level of injury the restrained occupant can tolerate a higher ΔV, for example the mean ΔV for injuries of AIS 3 or greater is 28.3 mph compared to 23.6 mph if unrestrained.

Comparing unrestrained drivers and front seat passengers the latter have a lower mean ΔV at every level of severity. This can be explained by the ride down that the driver derives from the steering assembly. Interestingly this benefit for the driver disappears at lower severities when both occupants are restrained because there appears to be no difference in the mean ΔV's, at the AIS 1 and 2 levels of severity, for restrained drivers and front seat passengers. However, for injuries of severity AIS 3 or greater the mean ΔV for front seat passengers is higher (31.5 mph) than for drivers (27.1 mph) which suggests that restraint system effectiveness is compromised by the presence of the steering assembly.

Table 8. Mean Velocity Change (mph) for each MAIS Level - Frontal Impacts

MAIS	Front Seat Occupants: Unrestrained $\Delta\bar{V}$	Unrestrained N	Restrained $\Delta\bar{V}$	Restrained N
1	11.8	188	13.9	101
2	13.1	99	18.9	28
≥3	23.6	49	28.3	19

MAIS	Drivers: Unrestrained $\Delta\bar{V}$	N	Drivers: Restrained $\Delta\bar{V}$	N	Front Seat Passengers: Unrestrained $\Delta\bar{V}$	N	Front Seat Passengers: Restrained $\Delta\bar{V}$	N
1	12.0	134	13.6	72	11.2	54	14.6	29
2	13.6	66	19.3	20	12.2	33	18.1	8
≥3	24.9	31	27.2	14	21.4	18	31.5	5

Head Injuries in Frontal Impacts

The analysis of injuries by source and body region showed that the most prevalent injuries, particularly from the point of view of severity, were to the head and chest. Accordingly, to explore these injury mechanisms further, head and chest injuries have been analysed as a function of velocity change.

Table 9 gives mean velocity change versus head injury severity for drivers and front seat passengers. As a general observation the mean ΔV's appear to be higher for a given level of injury severity than the overall injury ΔV's of Table 7.

Comparing drivers and front seat passengers, unrestrained, the mean ΔV's for AIS 1 and 2 level injuries are similar although for AIS ≥ 3 the mean ΔV for passengers is lower than for drivers. This suggests that unrestrained drivers derive a ride down benefit from the steering assembly in terms of risk of head injury. For restrained occupants the pattern is reversed front seat passengers have a higher mean ΔV for AIS ≥ 3 injuries than drivers although there is little difference at the lower severity levels. This suggests that seat belts are more effective for front seat passengers than drivers at higher severities, because the absence of the steering wheel and assembly allows the restrained passenger to move forward without contact.

Table 9. Mean Velocity Change (mph) for each AIS Level - Head Injuries - Frontal Impacts

	Front Seat Occupants			
AIS	Unrestrained		Restrained	
	$\Delta\bar{V}$	N	$\Delta\bar{V}$	N
1	11.8	105	17.3	25
2	17.4	85	22.2	28
≥3	23.5	14	37.5	5

	Drivers				Front Seat Passengers			
AIS	Unrestrained		Restrained		Unrestrained		Restrained	
	$\Delta\bar{V}$	N	$\Delta\bar{V}$	N	$\Delta\bar{V}$	N	$\Delta\bar{V}$	N
1	11.8	68	17.3	20	11.4	37	17.5	5
2	17.5	59	22.6	21	18.9	26	21.1	7
≥3	31.2	6	35.0	2	18.8	8	39.2	3

Chest Injuries in Frontal Impacts

Table 10 gives mean velocity change versus chest injury severity for frontal impacts. The overall figures for front seat occupants show little difference in the mean ΔV's irrespective of belt use. However, this must be due to the overriding influence of driver effects because the number of front seat passengers in the sample is considerably smaller. For drivers there appears to be little difference in mean ΔV's irrespective of belt use, however by comparison, unbelted front seat passengers suffer injury at a lower mean ΔV for every level of severity which tends to reiterate the benefit of the steering assembly for the driver. Belted front seat passengers have higher mean ΔV's than their unbelted counterparts and at higher severities (AIS ≥ 3) appear to derive a belt benefit not seen by drivers.

Table 10. Mean Velocity Change (mph) for each AIS Level - Chest Injuries - Frontal Impacts

	Front Seat Occupants			
AIS	Unrestrained		Restrained	
	$\Delta\bar{V}$	N	$\Delta\bar{V}$	N
1	16.5	76	16.7	74
2	16.7	4	15.0	2
≥3	27.7	17	32.3	8

	Drivers				Front Seat Passengers			
AIS	Unrestrained		Restrained		Unrestrained		Restrained	
	$\Delta\bar{V}$	N	$\Delta\bar{V}$	N	$\Delta\bar{V}$	N	$\Delta\bar{V}$	N
1	18.1	63	16.9	52	14.4	13	16.8	22
2	12.5	3	15.0	2	12.5	1	-	-
≥3	32.6	11	29.2	5	19.2	6	37.5	3

INJURY SEVERITY VERSUS CRASH SEVERITY FOR SIDE IMPACTS

Table 11 gives mean velocity change for each MAIS level of severity for unrestrained and restrained occupants involved in side impacts. Note that occupants seated on the struck side have been separated from those seated opposite. Looking at unrestrained occupants for a given MAIS level those seated on the struck side are injured at a lower mean ΔV than those seated opposite. This is because the occupant seated opposite will travel across the passenger compartment before striking the side of the car and the vehicle's velocity will have been reduced accordingly so that a given injury severity will occur at a higher measured ΔV. A similar trend holds for restrained occupants however this effect results from the restrained occupants seated opposite to the side struck being held in position and deriving some ride down benefit from the vehicle. Similarly by comparison with unrestrained occupants seated opposite, restrained occupants show a higher mean ΔV for each level of severity which confirms that there is a definite benefit from belt use for occupants seated away from the struck side of the vehicle. Interestingly enough even for occupants on the struck side the mean ΔV's are higher with belt use particularly at the lower injury severities. This confirms earlier work (4) which suggested that in impacts where significant intrusion did not occur occupants seated on the struck side derived a benefit from belt use.

Table 11. Mean Velocity Change (mph) for each MAIS Level - side impacts

	Occupants on Side Struck				Occupants Opposite to Side Struck			
AIS	Unrestrained		Restrained		Unrestrained		Restrained	
	$\Delta\bar{V}$	N	$\Delta\bar{V}$	N	$\Delta\bar{V}$	N	$\Delta\bar{V}$	N
1	9.2	23	13.0	15	12.2	18	14.6	17
2	10.5	10	20.0	13	17.1	4	22.5	2
	}17.4		}18.6		}19.8		}25.5	
≥3	23.7	10	17.5	6	25.8	5	27.5	3

CORRELATION OF INJURY SEVERITY WITH ANTHROPOMETRIC DUMMY RESPONSE

Since a velocity change can be associated with each injury scored on AIS, then providing a relationship between anthropometric dummy response and velocity change can be established, the anthropometric dummy response appropriate to each AIS level can be calculated. Figure 1a gives a schematic diagram of AIS versus ΔV showing the distribution of ΔV's associated with each AIS level. The next stage is to translate the ΔV distributions to dummy response distributions using a response curve such as that shown in figure 1b. Obviously if the response were linear then a direct conversion of means would be possible but assuming a non-linear relation transformation has to be done prior to computing the means. That is for each data point the velocity change is transformed to the appropriate dummy response using the Severity Index (SI)=f(ΔV) relation and mean dummy response then computed from the resulting distribution.

Fig. 1a

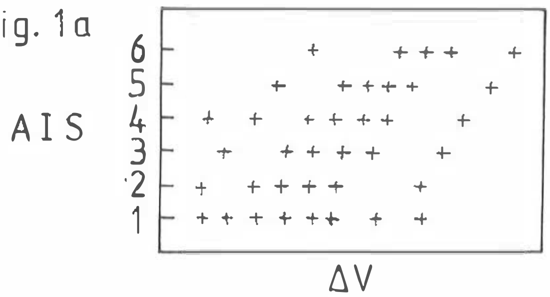
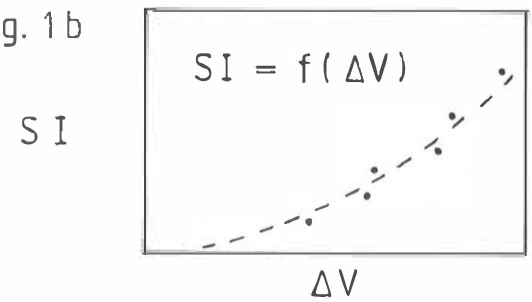


Fig. 1b



Head Injury Criterion (HIC) - Restrained Occupants in Frontal Impacts

Table 9 gave mean ΔV's versus AIS for head injuries in frontal impacts. The next step is to relate this distribution to an appropriate dummy response curve. For head response the commonly used parameter is Head Injury Criterion (HIC). The Transport and Road Research Laboratory (5) generated a HIC versus ΔV curve using a sled with deceleration pulses chosen to be representative of typical frontal impacts for European cars. The experimental set up was such that the anthropometric dummy was restrained with a 3-point belt and no head contact occurred. Their HIC versus ΔV relationship follows a power function of the form $HIC = 0.0319\ \Delta V^{2.863}$. Then this function was used to transform the ΔV's to HIC's and allow mean HIC's to be computed for each AIS level. Table 12 gives the mean HIC values for head injuries of severity AIS 1,2 and 3, the standard deviation for each distribution is also given. By way of comparison mean HIC's were also calculated using the HIC versus ΔV curve constructed by Langweider (6) which approximates to the power function $HIC = 0.1764\ \Delta V^{2.369}$. It can be seen that the effect on AIS level 3, the onset of serious injury, is minimal.

Table 12. Mean HIC versus AIS - Restrained Front Seat Occupants

HIC/ΔV Function	$0.0319\ \Delta V^{2.863}$		$0.1764\ \Delta V^{2.369}$	
AIS	Mean	St dev	Mean	St dev
1	181	188	209	187
2	423	494	420	413
3	869	568	809	439

It should be noted that one can argue such an analysis lacks validity because the HIC vs ΔV relationships are derived without head contact whereas our data shows that, even for restrained occupants, all head injuries had some degree of contact recorded. However, in the absence of a more suitable parameter to measure head severity the analysis has been included on the basis that the results are useful indicators. Interestingly the mean HIC of 870 estimated for serious injury (AIS3) suggests that some degree of head contact reduces the tolerance level from the quoted standard of 1000 (7).

Chest Severity - Restrained Occupants in Frontal Impacts

A similar procedure was adopted to correlate chest injury with the Chest Severity Index (CSI). In the same series of tests used for head response TRRL measured peak spine deceleration as an indicator of chest severity and arrived at a Severity Index versus ΔV relation which approximates to a power function of the form $CSI = 0.1332\ \Delta V^{2.1805}$. Table 10 gave mean ΔV's versus AIS for chest injuries in frontal impacts. Then transforming the distributions of ΔV for each AIS level to distributions of Severity Index and computing the means gives the figures in Table 13. By way of comparison mean CSI's were also calculated using the CSI versus ΔV curve constructed by Langweider (6),

Table 13. Mean CSI versus AIS - Restrained Front Seat Occupants

CSI/ΔV Function	$0.1332\ \Delta V^{2.1805}$		$0.00204\ \Delta V^{3.3118}$	
AIS	Mean	St dev	Mean	St dev
1	82	94	51	89
2	109	67	61	52
3	251	155	215	200

which approximates to the power function $CSI = 0.00204\ \Delta V^{3.3118}$, it can be seen that this curve predicts slightly lower mean severity indices.

CONCLUSIONS

Common Sources of Serious Injury

For unrestrained occupants the most frequent sources of serious injury (AIS $\geq$ 3) ranked:

(i) the instrument panel involving the legs and chest in frontal impacts.
(ii) the steering assembly involving the chest and abdomen in frontal impacts.
(iii) the side interior involving the chest and abdomen in side impacts.
(iv) the ground involving the head and chest in rollovers.
(v) the 'general front' involving the head in frontal impacts.

The windscreen (head) and parcel tray (legs) were also frequent sources of injury but were also of lower severity.

For restrained occupants the most frequent sources of serious injury (AIS ⩾ 3) ranked:

(i) the side interior involving the chest, arms and abdomen, in side impacts.
(ii) the restraint involving the chest and abdomen in frontal impacts.
(iii) the instrument panel involving the legs and chest in frontal impacts.
(iv) the 'general front' involving the legs and arms in frontal impacts.
(v) the steering assembly involving the chest in frontal impacts.

Restraint use eliminated ground contacts by preventing ejection and also reduced contact with the front interior of the vehicle.

Crash Severity

For frontal impacts the mean velocity change was 13.6 mph with 95.6% of all impacts occurring below 30 mph.

For side impacts the mean velocity change was 14.5 mph with 92.4% of all impacts below 30 mph.

Injury Severity Versus Crash Severity

(a) Frontal Impacts

Restrained occupants had mean ΔV's substantially higher than unrestrained occupants; for injuries of AIS ⩾ 3 the mean ΔV for restrained occupants was 28.3 mph compared to 23.6 mph if unrestrained.

Unrestrained front seat passengers had a lower mean ΔV than drivers at each level of severity, suggesting that drivers derive some benefit of ride down from the steering assembly e.g. for injuries of AIS ⩾ 3 the mean ΔV for front seat passengers was 21.4 mph compared to 24.9 mph for drivers.

For restrained occupants there was little difference in mean ΔV's between front seat passengers and drivers at lower severities, although front seat passengers had a higher mean ΔV for AIS ⩾ 3 injuries.

The pattern for head injuries was similar to that for all injuries. Unrestrained drivers had a higher mean ΔV (for injuries of AIS ⩾ 3) than unrestrained front seat passengers due to a ride down benefit from the steering assembly. However, although the mean ΔV's for restrained drivers were higher than if unrestrained the mean ΔV for AIS ⩾ 3 injuries was lower than that for front seat passenger suggesting that interaction with the steering assembly compromises belt effectiveness.

Chest injuries showed a similar trend. The mean ΔV's for unrestrained drivers were higher than for unrestrained passengers but similar to those for restrained drivers. Restrained front seat passengers had higher ΔV's than restrained drivers.

(b) Side Impacts

For unrestrained occupants those seated on the struck side were injured at a lower mean ΔV than those seated opposite, irrespective of belt use. There was a definite belt effect for occupants seated on the opposite side in that their mean ΔV's were higher with belt use. There was some indication of a belt effect at low severities (AIS 1 and 2) for occupants on the struck side.

Injury Severity Versus Anthropometric Dummy Response

Experimentally established functions of dummy response versus velocity change were used to transform distributions of velocity change to distributions of dummy response for given AIS levels of injury severity. The resulting distributions were then used to compute mean dummy response for each AIS injury level.

For head injury to restrained front seat occupants in frontal impacts HIC was used to measure dummy response; a mean HIC value of 870 was predicted for injuries of severity AIS 3.

For chest injury to restrained front seat occupants in frontal impacts CSI was used to measure dummy response; a mean CSI value of 250 was predicted for injuries of severity AIS 3.

ACKNOWLEDGEMENTS

The authors would like to thank Mary L. Wood, Kathie Lawrence and Steven Humm of the Clinical Team and Andy Tippett, Hugh Pollard and Peter Jennings of the Engineering Team for all their help and assistance in collecting and processing the accident data. Thanks also to the Thames Valley Police and Oxfordshire Ambulance Authority without whose cooperation we would not have been able to collect the accident data.

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APPENDIX

Table A1a. Percentage distribution of injuries according to injury source and body region - unrestrained, front seat occupants

Injury Source	Total	Body Region					
		Head*	Neck	Chest	Abdomen	Arms	Legs
Windscreen	18.71	16.00	0.65	0.05		2.01	
Steering assembly	13.14	3.16	0.25	5.47	0.75	2.21	1.30
Instrument panel	11.13	0.80	0.10	1.51	0.55	1.25	6.92
General front	7.88	3.06	0.20	0.55	0.15	2.26	1.66
Parcel tray	4.41	0.05		0.05		0.05	4.26
Knobs/keys etc	2.06	0.05				0.15	1.86
Front header	2.16	2.06	0.10				
Mirror	2.21	1.91	0.30				
A pillar	1.25	0.90	0.05			0.25	0.05
Foot controls	1.15						1.15
Add-on equipment	0.25						0.25
Roof	0.95	0.80	0.10			0.05	
Floor	0.45					0.05	0.40
Other front objects	0.05	0.05					
Side interior/ Side general	5.91	1.10	0.10	1.15	0.65	1.96	0.95
Side arm rest	0.50	0.15		0.10	0.10	0.05	0.10
Window glass	3.00	2.00	0.40			0.60	
Window frame	0.65	0.50				0.15	
B pillar	0.40	0.25	0.10			0.05	
Roof side rails	0.50	0.50					
Gear lever	0.15					0.15	
Other occupants	1.15	0.45	0.05	0.35	0.20	0.10	
Intruding objects	0.60	0.20	0.05	0.05	0.10	0.05	0.15
Exterior surface	1.00	0.60	0.10	0.10	0.05	0.10	0.05
Ground	4.90	1.95	0.30	0.80	0.25	0.85	0.75
Non-contact	1.91	0.35	1.56				
Other miscellaneous	0.60	0.20		0.10	0.10	0.10	0.10
Unknown	12.83	4.41	0.25	1.20	0.45	4.01	2.51
Total (N = 1993)	100.00	41.50	4.66	11.48	3.35	16.45	22.46

* includes face

Table A1b. Percentage distribution of injuries according to injury source and body region - restrained front seat occupants

Injury Source	Total	Body Region					
		Head*	Neck	Chest	Abdomen	Arms	Legs
Windscreen	6.21	4.42	0.32			1.47	
Steering assembly	11.69	6.21	0.43	1.89	0.11	1.37	1.68
Instrument panel	9.17	1.16	0.32	0.32	0.11	0.63	6.63
General front	5.69	1.68	0.11	0.11	0.11	1.47	2.21
Parcel tray	2.21						2.21
Knobs/keys etc	0.95						0.95
Front header	0.95	0.53	0.42				
Mirror	0.63	0.42	0.21				
A pillar	1.26	1.05				0.21	
Foot controls	2.00						2.00
Add-on equipment	0.32						0.32
Roof	1.47	1.26				0.21	
Floor	0.84						0.84
Other front objects	0.21						0.21
Side interior/ Side general	5.48	0.84	0.11	0.95	0.42	2.42	0.74
Side arm rest	0.32						0.32
Window glass	3.91	2.74	0.11	0.11		0.84	0.11
Window frame	0.22	0.11				0.11	
B pillar	0.32	0.11				0.21	
Roof side rails	1.05	0.95	0.11				
Gear level/tunnel	0.32						0.32
Other occupants	1.26	0.84	0.21			0.21	
Intruding objects							
Exterior surface	0.43	0.32				0.11	
Restraint	21.79	0.11	0.42	14.63	4.21	2.21	0.21
Ground	0.44	0.11	0.11				0.11
Non-contact	9.16	0.84	8.11			0.21	
Other miscellaneous	1.59	0.53		0.32	0.11	0.21	0.42
Unknown	10.11	3.68	0.21	0.95	0.32	3.16	1.79
Total (N = 950)	100.00	28.00	11.20	19.39	5.39	15.05	21.07

* includes face