HEAD AND TORSO INJURIES TO RESTRAINED DRIVERS FROM THE STEERING SYSTEM

PETE THOMAS
Accident Research Unit
Institute for Consumer Ergonomics
Loughborough, UK

BACKGROUND

The importance of the steering system as a major cause of life threatening torso injuries to unrestrained drivers in frontal impacts is well established. More recently investigations into the injuries of restrained drivers have suggested that the steering wheel is also an important source of head and face injuries. Gloyns[1] reports over 52% of restrained drivers in a serious injury sample struck the wheel with their head. In a sample of fatally injured restrained drivers he reports that torso contacts with an intruding steering wheel were also common.

Dalmotas[2] describes a sample of restrained drivers sustaining an injury of at least AIS 2 and finds that 82% of facial injuries and 40% of chest injuries are from a steering wheel contact. Similar rates of head contact are also reported by Hartemann[3]. The circumstances in which head contact with the wheel occurs has been shown to be critically dependant on vehicle design factors. Petty[4] examines tests on 6 models of car subject to identical impact characteristics where head contact with the wheel varied considerably.

STUDY STRUCTURE

In the UK there has been a law requiring the use of front seat belts since 1983. During the period to 1987 usage rates have remained above 90%. The Accident Research Units at the Institute for Consumer Ergonomics and at Birmingham University have been examining car accidents since 1983. Highly detailed data concerning the vehicle damage and the occupants injuries are combined using techniques previously described[5,6,7]. Accidents are selected for investigation using a random based stratified sampling system, most fatal and serious injury tow-away accidents are investigated together with a proportion of slight and non-injury accidents.

The relationship between the sample and the population of accidents is known where injury has occurred so weighting factors are employed to produce population estimates based on the sample. Population estimates of non-injury accidents are not yet available. Currently a sample of 1003 vehicles and 1799 occupants is available for analysis, when this data is weighted it is found that the population consists of 5118 vehicles and 9009 occupants. This data has been used to examine the relationship between the steering wheel and head and torso injuries.

In the following analysis all numbers of vehicles or drivers can be assumed to be derived from the weighted sample unless otherwise stated, this weighting may produce non-integral numbers of drivers and therefore it may be that the figures in some of the tables do not always sum to the total given. All drivers can be assumed to be restrained unless otherwise stated. Where the term "cranium" is used this represents the brain, its surrounding skeletal structures and overlying soft tissues not including the forehead. The term "face" represents the facial bones, overlying surface tissues including the forehead and the soft tissues of the mouth. "Head" refers to the cranium and face combined.

IMPACT TYPE

There were 4155 restrained drivers in the population. Of these 1737 (42%) sustained a head injury and 1301 (32%) a torso injury. 548 (33%) of those with head injuries had a contact with the steering wheel as did 233 (18%) of those sustaining torso injuries.

The most common type of impact in which these injuries were sustained were impacts to the front of the car involving directions of force between 11 and 1 o'clock. 483 (88%) of the 548 drivers with head injuries from steering systems were involved in this type of impact as were 221 (95%) of those with torso injury. In comparison only 648 (54%) of the 1189 drivers with head injuries from other sources experienced a frontal impact. 734 (69%) of the remaining 1068 torso injuries from other sources were also a result of frontal impacts. The directions of force of the most severe impact experienced by the drivers with steering wheel injuries are shown in Table 1.

Table 1. Directions of force on drivers with steering wheel injury

Direction of force (o/c)	Steering wheel injuries		All restrained drivers
	to head	to torso	
1	60 (11%)	45 (19%)	561 (14%)
2	25 (5%)		180 (4%)
3	23 (4%)		245 (6%)
4-8	2 (0.3%)		405 (10%)
9	0 (0%)		125 (3%)
10	13 (2%)	11 (5%)	215 (5%)
11	42 (8%)	10 (5%)	409 (10%)
12	381 (70%)	166 (71%)	1823 (44%)
Roll	0 (0%)	1 (0.5%)	159 (4%)
n/k	2 -*		34 -
Total	548 (100%)	233 (100%)	4155 (100%)

* All percentages are based on totals excluding unknown values

Table 1 shows that the most common direction of force amongst those drivers with steering system injuries was 12 o'clock. 381 (70%) drivers with head injuries and 166 (71%) drivers with torso injuries experienced such an impact compared with only 1823 (44%) of all restrained drivers. Head injuries were found to occur in all impact directions from 10 - 3 o'clock, the percentages mirroring fairly closely the distribution of impacts experienced by all drivers. Torso injuries were sustained in a more concentrated band from 10 - 1 o'clock. It is hypothesised that this difference may be a result of the asymmetric nature of the seat belt. At 2 o'clock directions of force a driver will tend to move into his seat belt and obtain maximum torso restraint thereby minimising the chance of a torso contact on the steering wheel. With forces at 10 o'clock the driver will tend to move out of the belt and be more free.

IMPACT SEVERITY

The impact severity of the vehicles in the population was assessed using the CRASH3 computer programme. The delta-v distributions for all restrained drivers in frontal impacts is shown in Table 2 together with the distributions for those with head or torso injuries.

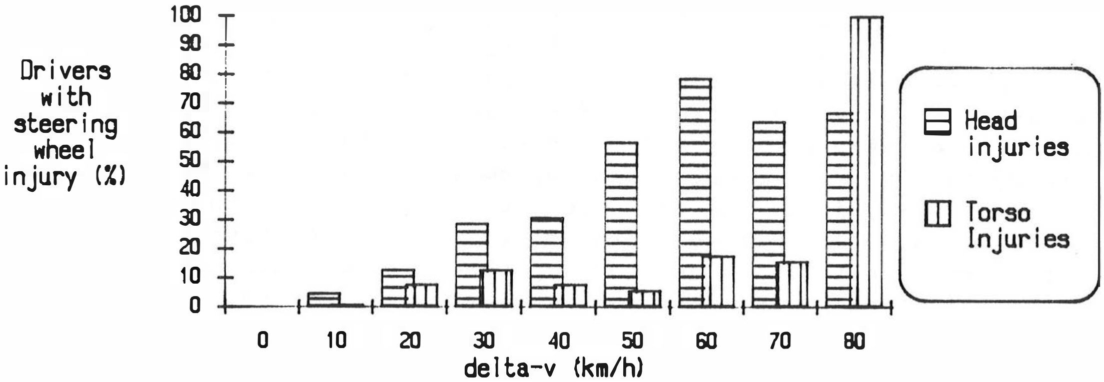
The median delta-v for all drivers was 30 km/h. For those with steering wheel contacts it was 37 km/h for both groups with head and with torso injuries. The lowest delta-V at which a restrained driver sustained head injuries was 17 km/h, it was 16 km/h for torso injuries.

Table 2. Delta-v distributions for all restrained drivers in frontal impacts and those with steering wheel injuries

Delta-v band km/h	Drivers with steering wheel		All restrained drivers in frontals
	head injuries	torso injuries	
1- 9	0 (0%)	0 (0%)	20 (1%)
10-19	15 (3%)	2 (2%)	281 (19%)
20-29	56 (12%)	35 (29%)	434 (29%)
30-39	115 (24%)	51 (41%)	397 (27%)
40-49	61 (13%)	15 (12%)	194 (13%)
50-59	56 (12%)	6 (5%)	99 (7%)
60-69	27 (6%)	6 (5%)	34 (2%)
70-79	16 (3%)	4 (3%)	25 (2%)
80+	2 (0.5%)	3 (3%)	3 (0.3%)
n/k	136 -	99 -	1160 -
Total	484 (100%)	221 (100%)	2650 (100%)

The proportion of drivers in each impact severity band who sustained a steering wheel injury is shown in Figure 1.

Figure 1. Incidence of steering wheel injury



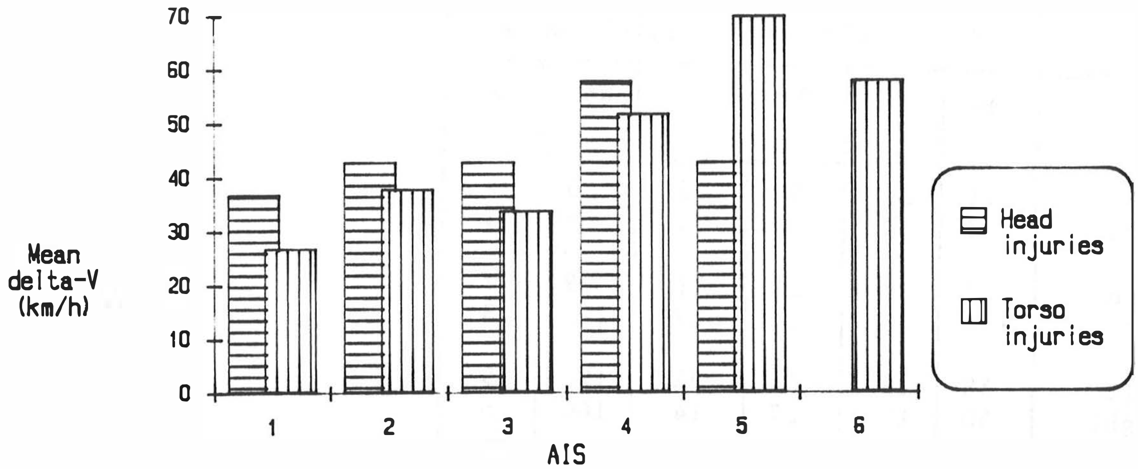
Torso injuries can be seen to be rare at most velocities. Below 80km/h typically only 10-20% of drivers in the population sustained torso injuries from the steering wheel. Table 2 shows that there were only 3 drivers in the population who experienced impacts of over 80 km/h, all of these sustained torso injuries from the wheel but the low numbers imply potential error in the last point on the graph.

Head injuries are substantially more common than torso injuries at all velocities between 30 and 60 km/h. At velocities above 50 km/h the majority of restrained drivers in frontal impacts sustain head injuries from the steering wheel.

The difference between the head and torso injury rates from the steering wheel is a direct consequence of the benefits of restraint use. Seat belts are designed to provide maximum restraint to the torso and the regulations that define seat belt performance are based on an impact at 50 km/h. Figure 1 shows this effect with the incidence of torso injury remaining below 20% up to the delta-v band 60-69 km/h. The restraining loads from a belt can only be applied to the head by transmission through the neck so the head is much more free to move forward. The head therefore will receive less benefit from restraint use and Figure 1 provides an example of this showing a far higher incidence of head injury than torso injury from steering wheels at velocities above 20 km/h.

The contrast between the relationship of injury severity and delta-v for head and torso injuries from the steering wheel provides a further demonstration of the relative benefits of restraint. Figure 2 shows the mean delta-v experienced for each severity level of head and torso injuries.

Figure 2. Mean delta-v for drivers with steering wheel injuries



There was only one driver who sustained an AIS 3 head injury from the steering wheel so the dip in the curve at this point is subject to error. The numbers of drivers in each of the other bands is shown later in Table 4. Figure 2 shows that, except at AIS 5, a head injury requires a slightly higher delta-v than a torso injury of equal AIS. This is likely to be a consequence of the greater separation between head and wheel. Other factors, however, are of at least equal importance. The AIS 1 injuries, as will be later shown, are typically bruising and cuts whether sustained by the torso or the head. It is likely that these body regions have similar tolerances to these injuries. The more severe injuries are, however, of a completely different nature. Typically an AIS 3 head injury may be either a Le fort II facial bone fracture or a cerebral contusion. An AIS 3 torso injury, on the other hand, is likely to be a pulmonary contusion with associated rib fractures. It is not at all likely that the same level of force will cause each of these sets of injuries. Further investigation of the level of the forces applied to each body area by the steering wheel is beyond the scope of this paper.

STEERING SYSTEM INTRUSION

Steering system intrusion was observed to play a significant role in the incidence of head and torso injuries although the degree of intrusion is related to impact severity. The direction of intrusion of those wheels that caused injury is compared in Table 3 with all steering wheels in frontal impacts.

Table 3. Steering wheel movement in frontal impacts

Direction	Head injury		Torso injury		All wheels	
	No	%	No	%	No	%
up	111	26	66	35	253	9
down	2	0.4	2	1	69	3
fore	7	21.0	21	11	39	2
aft	134	31	58	29	205	8
left	58	13	56	28	120	5
right	50	11	27	14	160	6

The displacement of each steering wheel was measured along 3 perpendicular axes. Table 3 shows the number of wheels that moved along each direction, the percentage of all wheels in that group with known movement and the mean displacement along that direction. Of the wheels that caused head injury 111 (26%) moved upwards and 134 (31%) moved rearwards, only 253 (9%) and 205 (8%) of all steering wheels in frontal impacts moved up or rearwards. Wheel movement to either left or right was also more common amongst those wheels that caused head injury.

The steering wheels that caused torso injury were also more likely to have moved upwards, forwards, rearwards and to the right than the population of wheels.

Table 3 shows no clear relationship between the direction of movement and injuries with the exception of downward movement. There is a tendency however for injuries to be associated with a steering wheel that has moved regardless of direction. The direction and degree of steering wheel movement is dependent on both the impact severity and the steering system layout. A steering column with a forward mounted steering rack and a rigid column will have different intrusion characteristics to one with a bulkhead mounted rack and 2 universal joints. It is clear that head and torso injuries are related to both impact severity and intrusion separately, but these last two variables are also related to each other. It is beyond the scope of this analysis to discriminate between the effects of each.

INJURY SEVERITY

Within the population studied there were 1737 restrained drivers that sustained a head injury; 548 (33%) of these were from the steering wheel. There were 1319 drivers who sustained a torso injury, 233 (18%) from the steering wheel. Although steering wheel injuries to the head were more common they tended to be slightly less severe than those from all other sources. Torso injuries from the steering wheel on the other hand, tended to be slightly more severe than those from other sources, and substantially more severe than the corresponding head injuries. Table 4 compares the severity distribution of these 4 groups of injuries.

Table 4. Severity of head and torso injuries from steering wheel and other sources. All impact directions.

AIS	Head injuries		Torso injuries	
	Steering wheel	Other sources	Steering wheel	Other sources
1	403 (74%)	783 (66%)	191 (82%)	841 (79%)
2	130 (24%)	323 (27%)	17 (7%)	136 (13%)
3	1 (0.2%)	42 (4%)	12 (5%)	59 (6%)
4	11 (2%)	10 (0.8%)	6 (3%)	12 (1%)
5	3 (1%)	20 (2%)	4 (2%)	15 (1%)
6	0	12 (1%)	3 (1%)	5 (0.4%)
Total	548 (100%)	1189 (100%)	233 (100%)	1086 (100%)

Of the 548 head injuries from the steering system only 15 (3%) were of AIS 3 or above. Amongst the 1189 head injuries from other sources, 84 (7%) were of AIS 3 or above. In contrast 25 (11%) of the torso injuries from steering wheels were of AIS 3 or above compared with 91 (8%) of the 1086 from all other sources. The steering system was more often the cause of severe life threatening injuries to the torso than to the head. Of the 35 head injuries that were AIS 5 or 6 only 3 (9%) were caused by the steering system; however amongst those 27 drivers with AIS 5 or 6 torso injury 7 (26%) were caused by the steering system.

To effect a further comparison the weighting factors developed as a measure of Harm by Malliaris[8] were used. The weighting factors employed are based on the economic cost of an injury if the injury occurred in the US. While it is not accepted that the absolute values of the weights would be the same in the UK it is considered that the relative values from one AIS level to the next are likely to be closely similar. Therefore the Harm scale can be employed to compare the overall severity of sets of injuries but cannot be used to compare the total economic cost of injuries from one country to another. The Harm scale also takes no account of the long term effects of injuries. It is still, however, a useful guide in comparing groups of injuries. The contribution of the steering wheel to the total Harm of head and torso injuries is shown in Table 5.

Table 5. Total Harm of head and torso injuries from steering wheels and other sources

Body area	Contact point		Total Harm (row total)
	Steering wheel	Other point	
Head	2003 (16%)	10299 (84%)	12302 (100%)
Torso	2360 (25%)	7032 (75%)	9392 (100%)
Total Harm (column total)	4363 (20%)	17331 (80%)	21694 (100%)

The total Harm to the head caused by the steering wheel was 2003 units, this represented 16% of the total head Harm of 12302 units. The torso Harm caused by the steering wheel was slightly higher amounting to 2360 units, representing 25% of the total torso Harm.

The use of the Harm scale suggests, therefore, that the torso injuries that result from steering wheel contact are of slightly greater economic consequence than the head injuries.

Head injuries

When the severity of a particular injury is coded it is assigned an AIS value and is categorised as being a surface, skeletal or internal injury. Injuries to the head are also coded as being sustained by the cranium, or the face.

The distribution of the severity of the injuries of each of these areas shows that most injuries to the head are sustained by the face. These distributions are shown in Table 6 and compared with the overall severity of head injury, being the highest AIS of the cranium and face, taken from Table 4.

Table 6. Severity of the most severe cranium, face and head injuries from steering wheels

AIS	Cranium injury	Face injury	Most severe injury to head
0	388 (71%)	22 (4%)	0 (0%)
1	43 (8%)	457 (84%)	403 (74%)
2	111 (20%)	58 (11%)	130 (24%)
3	0 (0%)	2 (0.4%)	1 (0.2%)
4	3 (0.6%)	8 (2%)	11 (2%)
5	3 (0.5%)	-	3 (0.5%)
Total	548 (100%)	548 (100%)	548 (100%)

Of the 548 restrained drivers with a head injury from the steering wheel 160 (29%) had a cranium injury and 525 (96%) sustained a face injury. There were therefore 137 drivers who sustained both cranium and face injuries. 111 (69%) of the cranium injuries were AIS 2 whereas 457 (87%) of facial injuries were of AIS 1. The numbers within each group sustaining AIS 3+ injuries were, however, similar there being 6 such cranium injuries and 10 such face injuries.

The total Harm of the cranium injuries was 1231 units compared with 966 units for facial injuries. Therefore the use of harm to establish the importance of injuries to each part of the head suggests that the reduction of cranium injuries should have a slightly higher priority than facial injuries. The Harm weighting factors employed, however, give fixed weights to each level of AIS regardless of body area. They are not sensitive to the particular potential for long term disfigurement and the associated emotional disability of facial bone fractures and soft tissue lacerations.

The position of the wheel contact on the head was determined by the location of the associated surface injury. 22 drivers received a cranium contact alone, 508 a face contact alone and 18 contacted the wheel with both parts of their head. The nature of the most severe injuries that resulted from each type of contact is shown in Table 7.

Table 7. Most severe cranium or face injury from steering wheel contact

Contact with cranium alone	
Injury type	No
Surface - AIS 1	21
unconsciousness-AIS 2	1
Total	22

Face and cranial contact	
Injury type	No
Surface - AIS 1	15
Unconsciousness-AIS 2	3
Total	18

Face contact	
Injury type	No
Surface - AIS 1	254
AIS 2	32
Nose or tooth fracture	116
Other face fracture	21
Fractured skull alone	12
Unconsciousness -AIS 2	66
-other	7
Total	508

These 508 face contacts most commonly resulted in facial bruising or lacerations but there were 116 (23%) drivers with minor facial bone fractures - broken noses or teeth. Face contacts frequently resulted in cranial injury; 66 drivers were unconscious for 15 mins or less but a further 31, who sustained AIS 2 facial injuries in addition sustained AIS 2 facial injuries in addition sustained AIS 2 unconsciousness. An additional 7 (1%) drivers sustained more severe brain injury. One driver struck the wheel with his jaw, he sustained a comminuted mandible fracture with a fractured base of skull and a subarachnoid and petechial brain haemhorrhage.

The degree of facial disfigurement that results from these injuries is highly dependent on the nature of the injury and its treatment. An AIS 1 facial laceration may result in a more visible change of features than a fractured zygoma or mandible. The more severe facial injuries, which have potential for long term disfigurement were relatively rare. There were 32 (6%) drivers with an AIS 2 surface injury and 21 (4%) with a serious facial bone fracture.

Cranium contacts with the steering wheel most commonly resulted in surface injuries. 15 of the 18 cranium and face contacts resulted in surface injury, there were also 3 drivers who were briefly unconscious.

TORSO INJURIES

The chest was the most common site of torso injury from the steering wheel although the small numbers of abdomen injuries were more severe. Of the 233 restrained drivers with torso injury from the steering wheel 227 (97%) sustained a chest injury and 16 (7%) an abdomen injury. 10 drivers sustained injuries to both body areas from the wheel. The severity distribution is shown in Table 8 compared with the overall torso severity from Table 4. Of the 227 drivers with a chest injury 21 (9%) sustained an injury of AIS 3 or above, however 13 (81%) of the 16 abdomen injuries were of this severity. The total harm represented by the chest injuries was 1830 units, that of the abdomen was 1428 units. The nature of the torso injuries sustained showed that only 3 (19%) of the 16 abdomen injuries may have been caused by fractured ribs, the remainder were clearly a result of an abdomen contact by the wheel. Steering wheel designs that mitigate the consequences of steering wheel injuries to the chest therefore will not automatically provide equal benefits to abdomen injuries. The reduction of abdomen injuries from the steering wheel must therefore still be seen as an important target.

The most common injury to the chest amongst the restrained drivers was an AIS 1 surface injury, the most common abdominal injury on the other hand was to the liver. Table 9 shows the nature of these injuries.

Amongst the chest injuries 179 (78%) were AIS 1 surface injuries. Of the remaining 51, 29 (57%) were skeletal and 16 (43%) were internal. The internal injuries were frequently but not invariably accompanied by less severe skeletal injuries.

Table 8. Severity of the most severe injuries to the torso, chest and abdomen from steering wheels

AIS	Chest injuries	Abdomen injuries	Most severe injury to torso
0	6 (3%)	218 (93%)	0 (0%)
1	188 (81%)	3 (1%)	191 (82%)
2	18 (8%)	0 (0%)	17 (8%)
3	11 (5%)	4 (2%)	12 (5%)
4	5 (2%)	4 (2%)	6 (3%)
5	2 (1%)	5 (2%)	4 (2%)
6	3 (1%)	N/A	3 (1%)
Total	233 (100%)	233 (100%)	233 (100%)

Table 9. Torso injuries from the steering wheel

Most severe chest injury	
Description	**No**
Surface	
AIS 1	179 (78%)
AIS 2	7 (3%)
Skeletal	
AIS 1 rib #	13 (6%)
AIS 2 rib #	4 (2%)
AIS 2 sternum #	6 (3%)
AIS 3 sternum #	6 (3%)
Internal	
AIS 3 lung injury	3 (1%)
AIS 4 lung injury	2 (1%)
AIS 5 lung injury	2 (1%)
Haemothorax	2 (1%)
Heart and vessel injury	6 (3%)
Total	230 (100%)

Most severe abdomen injury	
Description	**No**
Surface	
AIS 1	3 (19%)
Internal	
Torn mesentary	2 (13%)
Ruptured spleen	1 (6%)
AIS 3 liver	2 (13%)
AIS 4 liver	3 (19%)
AIS 5 liver	5 (31%)
Total	16 (100%)

Only 3 (19%) of the 16 abdominal injuries were to the surface, of the remainder 10 (63%) were to the liver and 3 (19%) were to other organs. Of the 13 non-surface injuries all but 2 can be seen to be injuries to the upper abdomen.

TORSO INJURY SOURCE

As has been shown the impacts which result in torso injuries, particularly the more serious injuries, tend to be of a relatively high delta-v. All of the drivers in this study were restrained and many of the restraints showed load markings. These restraints therefore clearly applied some loads to the driver and could conceivably have contributed to the torso injuries. There were 75 restrained drivers in the population who sustained torso injuries from the steering wheel and also had a restrained front seat passenger sitting adjacent. The severity of the drivers torso injuries allocated to the steering wheel are shown cross-tabulated in Table 10 with the torso severity of the front passenger in the same car.

Table 10. Severity of torso injury of restrained front seat occupants in the same car. Drivers with torso injury from steering wheel

Driver torso severity - AIS	Passenger torso severity - AIS				
	0	1	2	3	4
1	27	31	2	6	0
2	1	2	0	0	0
3	0	1	0	0	2
4	0	0	0	0	1
5	1	0	1	0	0
Total	29	34	3	6	3

Of the 75 pairs of occupants there were 33 where the driver sustained more severe torso injuries than the adjacent passenger. There were 10 pairs where the front passengers sustained more severe torso injuries than the drivers and the remaining 32 pairs received injuries of equal severity. Confounding factors, such as rear loading, obesity and seat belt failure, were observed to play a major role in the torso injuries of all of the more severely injured front passengers and in only 3 of the 35 more severely injured drivers. Such factors also applied to the pair that received AIS 4 torso injuries. It should be noted that Table 10 does not control for differences in intrusion between drivers and front passenger.

The torso injuries that these drivers sustain are regularly more severe than those of the adjacent restrained front seat passenger. All of the passengers sustained their torso injury, if any, from their seat belt so the difference in the injury experience of the 2 seating positions may be due to the loads from the steering wheel.

HEAD CONTACTS ON THE STEERING WHEEL

The 548 drivers with head injury had 751 separate contacts with the steering wheel. The hub was the part most frequently struck and also the part most commonly associated with facial bone fractures.

Drivers who were unconscious after the impact tended to hit the hub more frequently than those who remained conscious. Table 11 shows the contact distributions.

Table 11. Contact points of drivers with head injury from the steering wheel, drivers with facial bone fractures, conscious and unconscious drivers

Contact point	All head injuries		Facial bone fractures		Conscious drivers		Unconscious drivers	
rim	172	(39%)	60	(38%)	125	(46%)	46	(28%)
spoke	11	(3%)	11	(7%)	11	(4%)	0	(0%)
hub	222	(51%)	80	(49%)	125	(46%)	96	(57%)
rim/spoke join	33	(8%)	11	(7%)	8	(3%)	25	(15%)
n/k part of wheel	313	-	79	-	201	-	109	-
Total contacts	751		241		470		276	
Total drivers	548		137		329		120	

Of the 438 drivers with a head contact with an identified part of the wheel, 222 (51%) struck the hub and 172 (39%) the rim. The distribution of contact points for those 169 drivers with a facial bone fracture was similar, 80 (49%) with the hub and 60 (38%) with the rim. Table 7 shows that 137 of the facial injuries were skeletal. However the similar contact distributions of Table 10 suggests that all parts of the wheel are sufficiently stiff to cause skeletal injuries.

Facial bone fractures and cranium injury involve different injury mechanisms and this is reflected in the contact distributions shown in Table 11. 329 drivers remained conscious after striking the wheel with their heads, they sustained 470 contacts and the location within the wheel was known for 276 (58%) contacts. 125 (46%) of these located contacts were with the hub and 125 (46%) were with the rim. In contrast the 121 drivers who were knocked out sustained 96 (57%) contacts with the hub and 46 (28%) with the rim. In addition there were only 8 (3%) contacts with the rim/spoke join amongst conscious drivers but 25 (15%) amongst unconscious drivers. No unconscious drivers were reported to have struck the spoke while 11 (4%) of conscious drivers did so.

Table 7 shows that 101 (84%) of the 120 drivers with a brain injury were unconscious for less than 15 minutes. The contact points associated with these relatively minor brain injuries provide a pointer for the parts of the wheel that may cause more severe brain injury. The steering wheel hub and rim/spoke join appear, therefore, to be the stiffer areas and are more frequently associated with these injuries.

TORSO CONTACTS ON THE STEERING WHEEL

The steering wheel rim was the part of the wheel most frequently associated with minor and moderate torso injuries. The rim/spoke join, usually the part of the wheel with the smallest surface area, was the most common cause of severe torso injury along with the hub. The spoke alone was never found to have caused torso injury. Table 12 shows the distribution of contacts for 3 groups of injury severity.

Table 12. Steering wheel contacts of drivers with torso injury

Contact point	Torso injury severity		
	AIS 1	AIS 2-3	AIS 4-6
rim	112 (69%)	18 (75%)	3 (13%)
rim/spoke join	24 (15%)	6 (25%)	11 (48%)
hub	26 (16%)	0 (0%)	9 (39%)
n/k part of wheel	37	6 -	7 -
Total contacts	199	30	30
Total drivers	191	29	13

Contacts with the rim accounted for 112 (69%) of the identified torso contacts causing AIS 1 injuries and 18 (75%) of those causing AIS 2 or AIS 3 injuries. The rim only caused 3 (13%) of the torso injuries of AIS 4 and above. The incidence of contact with the rim/spoke join increased steadily from 15% amongst those with AIS 1 injuries to 48% amongst those with AIS 4+ injuries. The incidence of hub contact also increased from 16% to 39%. The steering wheel rim, generally the least stiff part of the wheel, is the part closest to the torso and is therefore the most likely to be struck. The portions of the rim that are supported by the spoke are stiffer and therefore more likely to be associated with more severe injury. The hub of most wheel designs only creates high torso loads once the rim has bent down leaving the hub proud.

IMPLICATIONS FOR STEERING SYSTEM DESIGN

The steering system of European cars have, for many years, been subject to legislative requirements that limit rearwards intrusion and peak torso loads under standard test conditions. These requirements were designed to provide maximum benefit to unrestrained drivers. More recently, in recognition of higher rates of restraint use, amendments have permitted optional performance tests that limit peak head impact loads. These head impact loads relate to severe head injury and recent proposals have suggested further modifications to include requirements relating to facial bone fractures. In addition it has been suggested that, with high restraint use, the requirements relating to torso protection are no longer necessary.

This analysis has shown that contact between a restrained driver and the steering system is a frequent event and the majority of drivers strike the wheel with their head at a delta-v above 50 km/h. Torso contacts are less frequent than head contacts but the resulting injuries tend to be more severe. The use of Harm to weight these injuries shows that, on an economic scale, torso injuries from steering wheels are of a slightly greater importance. The design of steering columns for a population of restrained drivers should however limit the forces that cause both head and torso injury.

Apart from minor surface injuries, the most common head injuries are unconsciousness for less than 15 minutes or facial bone fractures. Although very severe head injuries do occur they are rare and benefits would be greater if the performance requirements of steering wheels were to reflect the tolerance levels of the less severe group and be carried out at the typical speeds at which they occur. These head injuries have an AIS value of 2 and generally occur under the conditions of a 45 km/h delta-v impact to the vehicle. The analysis suggests that a consequence of such a requirement would be a reduction in the loads generated by the hubs of steering wheels.

The same reasoning suggests that the performance requirements to reduce torso injuries should limit the torso loads below those that cause an AIS 3 injury, typically a bruised lung with AIS 2 rib fractures or a contused liver. The test should reflect the conditions at a vehicle delta-v of 64 km/h. Such requirements are likely to result in improvements in the performance of the rim/spoke join and also the wheel hub.

Measures that reduce the probability of steering wheel contact might also be expected to reduce injuries. The limiting of forward motion by improved restraint performance and designs of steering system layout that maximise occupant survival space should both be addressed.

CONCLUSIONS

- The steering wheel is a frequent source of head injuries, particularly at a delta-v above 50 km/h.
- Torso injuries are less frequent but are much more severe accounting for slightly more Harm than head injuries.
- Steering wheels account for 16% of the harm of all head injuries and 25% of the Harm of all torso injuries.
- The minimum vehicle delta-v at which head and torso contacts occur are 17 km/h and 16 km/h respectively.
- Head injuries above AIS 1 occur at a slightly higher vehicle delta-v than a torso injury of the same AIS.
- Most head injuries from the steering wheel are a result of a face contact rather than cranium contact. They are most commonly sustained by the face but AIS 2 unconsciousness is also frequent.
- The most common non-minor head injury caused by a steering wheel contact is AIS 2 unconsciousness. Facial bone fractures are also common and more severe brain injuries do occur.
- The injury source allocation within the data has successfully discriminated between torso injuries sustained from the wheel and the seat belt.
- Most torso injuries are to the chest but when abdomen injuries do occur they are severe.
- Abdomen injuries are usually not a result of rib fracture but are caused by wheel contact with the abdomen.
- Steering wheel performance requirements need to include limits for both head and torso injuries.
- Steering wheels should limit head loads below those that cause AIS 2 unconsciousness or facial bone fracture in an impact corresponding to a vehicle delta-v of 45 km/h.
- Steering wheels should limit torso loads below those causing a bruised lung with AIS 2 rib fractures or a contused liver at an impact to the vehicle of 64 km/h.

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