MOTORCYCLISTS HEAD INJURIES: MECHANISMS IDENTIFIED FROM ACCIDENT RECONSTRUCTION AND HELMET DAMAGE REPLICATION

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ABSTRACT

Motorcycle accident data have been collected in Glasgow, Hannover and Munich as part of a COST action and the data have been used to create a database comprising 218 cases. The purpose of the study was to improve the knowledge of head and neck injury mechanisms. The criteria for inclusion was that a helmet was worn at the time of the accident and that a head impact, although not necessarily a head injury, had occurred. Sixty-seven percent sustained a head injury and 28.2% a neck injury. Also notable were the 53% with a thorax injury and 73% with leg injuries. It is not surprising that when the injuries were subdivided into MAIS that as the MAIS increased so did the proportion with a head injury, from 38% for MAIS 1 to 85% for MAIS 3 and greater. Eighteen cases were replicated with drop tests of a helmeted headform and in 13 cases where the motorcyclist sustained a head injury the rotational acceleration was approximately 9,000 rad/s^2 or greater.

MOTORCYCLE ACCIDENT DATA has been collected in Glasgow (Scotland), Hannover and Munich (Germany) and the resulting data was used to create a COST 327 accident database* comprising 218 cases. The criteria for inclusion in the database was that the casualty (pillion passengers and riders were included) must have been wearing a helmet at the time of the accident and either a head injury of AIS 1 or greater was sustained or it was known that a head impact occurred (mopeds were included but mofas were excluded). Thus, the COST database is a subset of the accident data collected by the organisations. The 218 cases were collected between July 1996 and June 1998 and the results have been analysed to give a better understanding of the injuries sustained, the mechanisms of head and neck injuries and the influence of various parameters, such as age, speed, and impact target on the outcome.

It should be noted that the three organisations responsible for collecting the data were Southern General Hospital, Glasgow, Hannover Medical School, Hannover and The Institut fur Rechstmedecin (forensic medicine), Munich University, Munich. The database was compiled by, and is currently retained by, Hannover Medical School. It should also be noted that the data from Glasgow and Hannover was a subset of a more extensive random study (Hannover) and partly random study (Glasgow) covering a

* Database COST 327, format and software existing at Medical University Hannover, Accident Research Unit

wide range of injury severity. However, the Munich data was drawn from a database of only fatal and seriously injured casualties. COST "actions" are an EC initiative designed to combine research from different countries to initiate European co-operation in a way that benefits all of those who take part. The research funded by the individual countries but the meetings and travel is funded by the EC.

This report describes some of the findings of the analysis together with the results of the replication of the helmet damage by TRL UK. Results and conclusions are based upon analysis of the COST database and of the individual databases so that the differences may be compared.

EFFECT OF AGE

Accident and injury severity are known to be age related and the frequency distribution by age is given in figure 1 below. Overall, as may be expected, there are far more accidents for young than for older riders with 64% of casualties in the 18 to 35 age group. However, it is surprising that the majority are in the 26 to 30 age group and that the 31 to 35 age group, 19%, is only slightly smaller than the 18 to 25 age group, 21%. This contrasts with previous studies for which the 18 to 25 group was by far the largest of all categories.

Trends within each area are similar to each other and to the overall pattern but there are some notable differences. In the under 18 age group the proportion from Glasgow, 2%, was very small compared with 11% from Munich and 5% from Hannover. For the 18 to 25 group, Hannover and Glasgow were similar at 23% and 22% whereas for the 26 to 30 age group Hannover was 27% and Glasgow was 18%. In the 31 to 35 group Glasgow and Munich were similar, 24%, but Hannover was much less at 14%. Variations in other groups can be seen but some of the differences may be exaggerated because of the small number of cases in a particular age group.

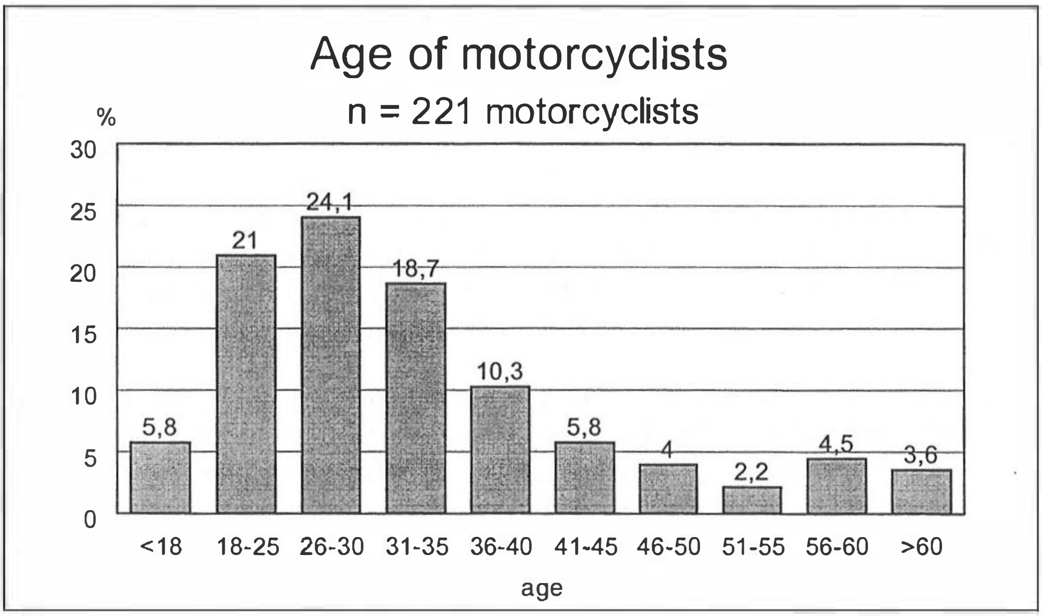


Figure 1 - Motorcycle casualties by age distribution

HELMET MASS DISTRIBUTION AND LOSS.

Table 1 below shows helmets grouped by mass and it is interesting to note that the range of mass, 0.780 kg to 1.650 kg, is more than two to one. However, a large majority, 61%, (unknown excluded) lay in a narrow band of between 1.00 kg and 1.20 kg. Mass may have affected the injury outcome and it was considered important to record this feature.

Table 1 - Distribution of helmet mass

Mass of helmets [g]	N	%	% (known)
780g - 930g	4	1.8	4.7
1000g - 1200g	52	22.9	61.2
1240g - 1425g	17	7.5	20.0
1450g - 1650g	12	5.3	14.1
Unknown	142	62.6	-

Table 2 - Type and loss of helmets

Type of helmets:		
Helmet (not further specified):	n= 3	1.4%
Full face helmet	n=182	87.5%
Open face helmet	n= 22	10.6%
Leather cap	n= 1	0.5%
Loss of helmets:	(unknown n= 19)	
No	n=176	87.6%
Yes (not further specified):	n= 3	3.0%
Yes, before first impact	n= 1	0.5%
Yes, after first impact	n= 14	7.0%
Yes, after second impact	n= 4	2.0%

Table 2 indicates the type and instances of helmet loss. The vast majority, 87.5%, were full faced and this would partly explain the mass grouping noted above, although, type of helmet was recorded for all but three cases whereas mass was not. The distribution by type for each of the regions was also examined. It is notable that 15% of the Hannover sample (excluding the unknown) were open faced, compared with 7.2% for Munich and only 4.7% for Glasgow. Loss of helmet was greatest, 21.4% for Munich which is not what may have been expected given the small number of open faced helmets. However, it is encouraging that the loss of a helmet prior to impact was low at 0.5% but the loss of a helmet during an accident was 12.4%. Thus, there is a substantial need for improvement of retention during an impact.

INJURY DISTRIBUTION

It is important to note that the sample of cases for Munich was restricted to severe and fatal cases only. The Hannover sample was randomly selected whereas Glasgow cases involved an injury or a head impact. COST 327 was based upon a selection from each area that satisfied the criteria that a head impact, although not necessarily a head injury, had occurred. For the COST database, there were 66.5% with a head injury and 28.2% with a neck injury; figure 2 below illustrates this distribution. Also notable were the 53.3% with a thorax injury and 72.7% with leg injuries. It is not surprising that when the injuries were subdivided into MAIS that as the MAIS increased so did the proportion with a head injury, from 38% for MAIS 1 to 85% for MAIS 3 and greater.

However, the analysis by regions showed that although Glasgow and Munich followed this trend, albeit exaggerated for Munich with only 3 cases of MAIS 2 or less. The pattern for Hannover was that the category with the greatest proportion of head injuries, 81%, was MAIS 2. The reason for this was not certain. One other very inconsistent pattern was the occurrence of abdominal injuries at MAIS 3 and greater. These were very low for Hannover, 7%, compared with 70% for Munich and 48% for Glasgow. It is not surprising that the Munich value was high because of the specialised sample, but this does not explain why Hannover was very low compared with Glasgow. Nevertheless, the overall pattern for the COST 327 database shows that risk of sustaining an abdominal injury increases as MAIS increases, a similar pattern to that for the head.

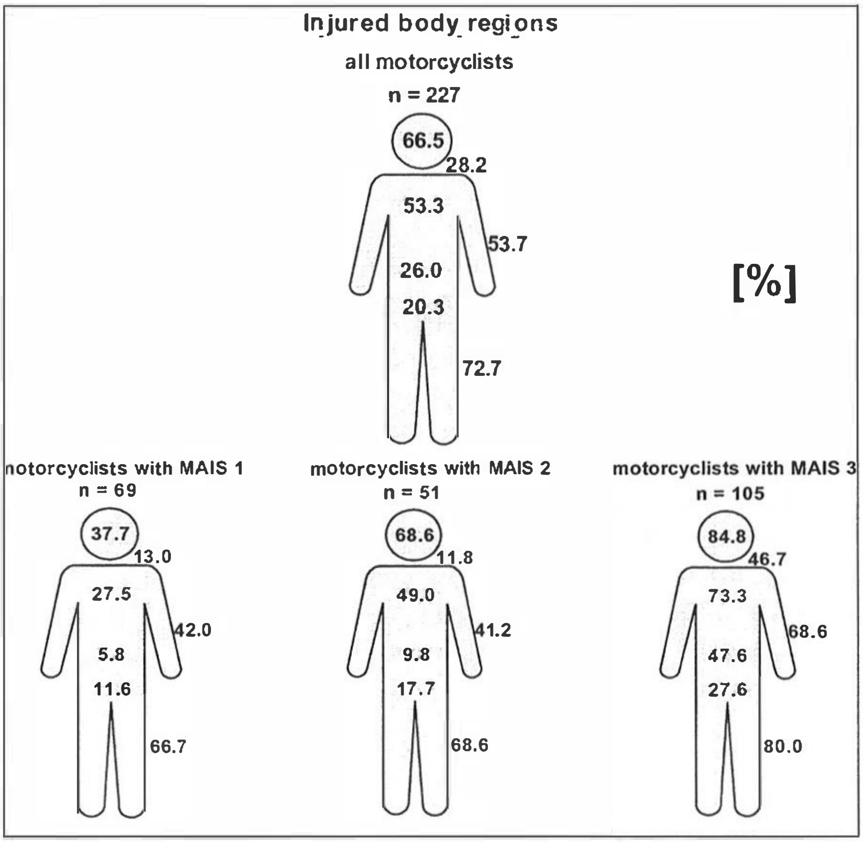


Figure 2 - Motorcyclists' injuries by body region

HEAD INJURY SEVERITY AND RELATED FACTORS.

HELMET DAMAGE AND HEAD INJURIES.

Table 3 gives the location and extent of the damage observed on the accident helmet. For ease of identification, the helmet is divided into 17 areas and each area has a unique two digit number. The first digit indicates the side of the helmet, one for right and two for left as per normal body convention, and three for the crown. The second digit indicates vertical and horizontal position. Frontal, lateral, and rear are used to augment the numbers and further clarify the position.

Location of damage is fairly evenly distributed with 27.3% lateral right, 25.9% lateral left, 24.2% frontal and 21.6% to the rear, slightly fewer than the other regions. Other locations of importance, and frequently damaged, were the chin guard, 9.4% (sections 18 and 28), and the right upper temporal fossa region, 9.6% (sections 13 and 14) and left, 9.0%, (sections 23 and 24), 18.6% total. The lower temporal fossa (sections 15, 16, 25 and 26) was the next most frequently impacted region, 14.9% total for both sides. Only the crown, section 35, received no impacts.

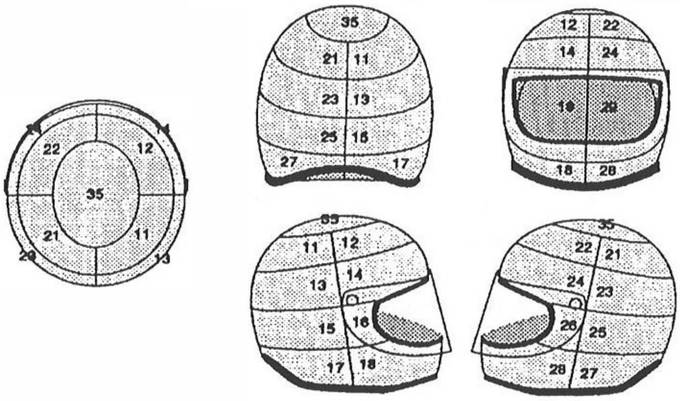
Not surprisingly, laceration (sliding mark) was the most frequent type of damage followed by deformation and then cracks; frequency of occurrence for each type of damage was largely consistent with the overall frequency as discussed above. However, the area most likely to be cracked was the chin guard and the area in the region of the visor attachment. This may indicate that the impacts to these areas were severe or that these parts of the helmets are weaker than other areas. It is likely that the visor area is slightly weaker and that the impacts to the chin guard are particularly severe. Helmet Standards should include tests that reflect these findings particularly in relation to the chin guard and the temporal fossa region, which is known to be particularly vulnerable to injury.

Whether or not injuries occur at the location of impact is often debated particularly in relation to brain injuries, hence the suggestion, although disputed some researchers, that "coup and contra coup" injuries occur. Table 3 indicates the location of damage on the helmet. There is some notable correlation between the damage and head injury region but also some possible exceptions. Both are important in understanding how head injuries occur, how helmet design may affect injuries and, in turn, how the design may be changed to improve protection.

It is clear that injuries to the side of the head (lateral injuries) and injuries to the rear correlate exactly with the damage location. However, injuries to the face, upper and lower, occur not only with frontal impacts as may be expected, but also with lateral impacts. The reason for this is not clear but it is possible that loads to the side of the helmet are transmitted to the face and this should be investigated further. Damage to the upper part of the helmet seems to be evenly distributed around the helmet and probably correlates with the damage location but this should also be investigated further, particularly to examine whether the injury occurs at the impact site or on the side opposite to it.

Table 3 - All defects of the helmet (100%= all defects of each sector)

External helmet defects



	Total		Deformation		Type of defects laceration		crack		other	
Location on helmet	n	%	n	%	n	%	n	%	n	%
Lateral right Sections 11 to 18	199	27.3	39	19.6	142	71.4	16	8.0	2	1.0
Lateral left Sections 19 to 29 (excluding 20)	195	26.8	44	22.6	116	59.5	35	17.9	0	0.0
Frontal Even sections 12 to 28 (excluding 20) plus 19 and 39	177	24.3	29	16.4	116	65.5	30	16.9	2	1.1
Rear Odd sections from 11 to 27 (excluding 17 and 19) plus 16	157	21.6	24	15.3	121	77.1	10	6.4	2	1.3
Total	728	100	136	18.7	495	68.0	91	12.5	6	0.8

HEAD INJURY TYPE AND SEVERITY AND IMPACT SPEED

Within the COST 327 database, 150 of the motorcyclists sustained a head injury and 74 suffered no head injury at all (excluding the unknown). Thirty–three percent of the riders and passengers suffered an impact to the helmet/head but were protected by the helmet and did not sustain a head injury. Of those suffering a head injury, 31.3% sustained only a minor (AIS 1) and 18.7% a moderate (AIS 2) head injury. 16.7% of the motorcyclists sustained a head injury of AIS 6 and almost the same proportion (16.0%) sustained a critical head injury (AIS 5). 10% suffered AIS 3 and 7.3% suffered AIS 4 head injuries.

To some extent, the distribution of head injury severity was found to be consistent with that of accident severity reported. However, it was found that accidents with no injury and minor head injuries (AIS 0 and AIS 1) were more frequent (54%) than accidents with moderate head injuries (33.3%). Fatal accidents were more frequent than serious and fatal head injury (AIS 5 and AIS 6, 21.9%). These differences can be explained by the fact that fatal accidents include not only fatal head injury but also fatal injury to other body regions and severe accidents may be associated with minor injury.

However, of particular interest was the relation between head impact speed and head injury. Not surprisingly the majority of low speed impacts were associated with minor head injury (< 10 km/h and AIS 0 = 72.7%) and the higher the impact speed, the more likely it became that the head injury was critical or fatal. For example, between 61 and 70 km/h, 36.3% were AIS 6 and between 71 and 80 km/h, 63.6% were AIS 5. However, even at very high speed, head impacts were not always associated with severe head injury. This is evident from Table 4 where, in four cases, an impact with the road surface occurred at a speed exceeding 80 km/h without head injury. In addition, two cases with impact speeds exceeding 100km/h resulted in head injury of only AIS 3.

Table 4 - AIS Head in relation to head impact speed (100%=all motorcyclists of each speed range, 74 unknown AIS-Head or unknown head impact speed)

AIS Head	**Total**		**AIS 0**		**AIS 1**		**AIS 2**		**AIS 3**		**AIS 4**		**AIS 5**		**AIS 6**	
Head impact speed	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
< 10	11	7.2	8	72.7	2	18.2	-	-	-	-	-	-	1	9.1	-	-
11 - 20	15	9.8	2	13.3	10	66.7	3	20.0	-	-	-	-	-	-	-	-
21 - 30	31	20.2	14	45.1	9	29.0	3	9.7	-	-	-	-	2	6.5	3	9.7
31 - 40	14	9.2	3	21.4	4	28.7	3	21.4	-	-	1	7.1	2	14.3	1	7.1
41 - 50	24	15.7	8	33.3	4	16.7	5	20.8	1	4.2	-	-	2	8.3	4	16.7
51 - 60	22	14.4	5	22.7	2	9.1	5	22.7	-	-	4	18.2	1	4.6	5	22.7
61 - 70	11	7.2	2	18.2	3	27.3	1	9.1	-	-	-	-	1	9.1	4	36.3
71 - 80	11	7.2	-	-	-	-	1	9.1	-	-	1	9.1	7	63.6	2	18.2
81 - 90	4	2.6	1	25.0	-	-	-	-	-	-	1	25.0	1	25.0	1	25.0
91 - 100	6	3.9	3	50.0	-	-	-	-	-	-	-	-	1	16.7	2	33.3
> 100	4	2.6	1	25.0	-	-	-	-	2	50,0	1	25.0	-	-	-	-
total	**153**	**100**	**47**	**30.7**	**34**	**22.2**	**21**	**13.7**	**3**	**2.0**	**8**	**5.2**	**18**	**11.8**	**22**	**14.4**

Figure 3 illustrates the cumulative frequency of estimated head impact speed for all 157 cases where the speed was known. The 50% cumulative frequency occurs at approximately 43 km/h, which appears surprisingly high when compared with the typical 20km/h impact speed for drop tests in helmet Standards at which speed accelerations are measured that are life threatening. Therefore, the test speed should be raised to that of the 50% cumulated frequency. However, such exceptions as shown in Table 4 may explain the high median of the head impact speed.

The cumulative frequency of the estimated head impact speed was determined for different regions of the head. Figure 4 shows the analysis for the forehead, face, and side and top of the head. It is evident that impacts to the side and the top of the head occurred at higher speeds (50%, median = 58 km/h) compared with those to the face and forehead (50%, median = 48 km/h).

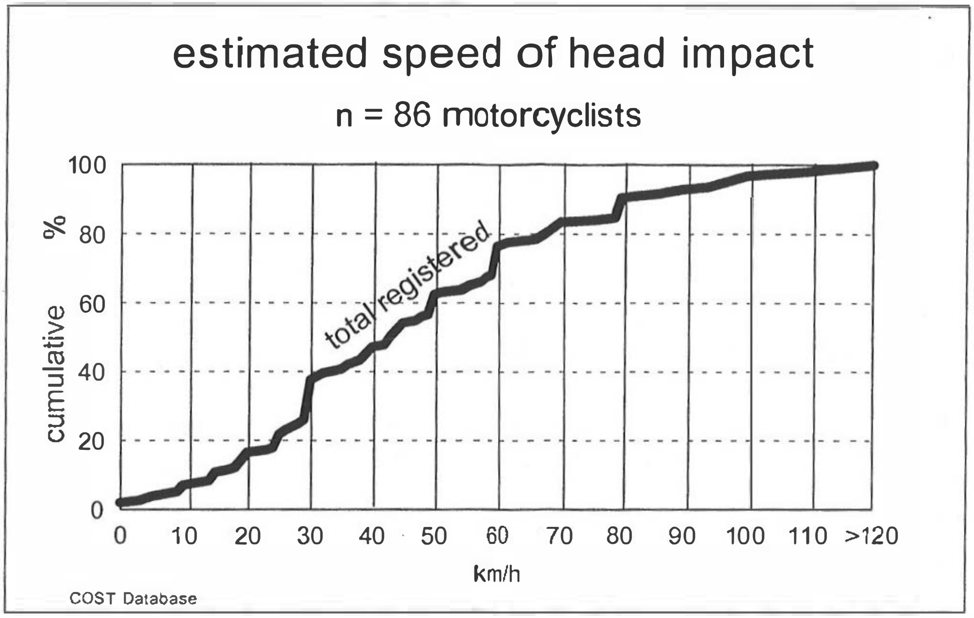


Figure 3 - Estimated speed of head impact (100%=all motorcyclists), n=71 unknown

This result is somewhat surprising when the biomechanical injury tolerance of different head regions is considered. For example, the frontal bone is much stronger than the temporal bone and therefore, it may have been expected that the median impact speed would have been greater for the forehead than the side of the head. However, for this particular relationship the helmet protection may have been the decisive factor whereby less protection is provided in the facial region. This is particularly true for full-faced helmets and applies to the open faced type.

In accordance with biomechanical principles, figure 5 illustrates that low severity soft tissue injury and moderate concussion occurred at a head impact speed of 40 - 45 km/h (50% median). This is significantly lower than that for fractures and other more severe head injuries for which the 50% median was 60 km/h as is also illustrated in figure 5. This demonstrates that helmets can protect against skull fracture and severe brain injuries.

It should be noted that speed was estimated according to the evidence available. For many cases this was based upon a computer calculation, using the accident data and physical principles as the basis for the calculations. This included tyre skid marks, scrape marks on the road from vehicle body components and indications on the vehicles, such as clothing or skin contact of casualty body contact. Head impact speed was based upon the calculated motorcycle impact speed and the analysis of body kinematics. Relative speeds between the motorcycle and the vehicle were the result of vector summation.

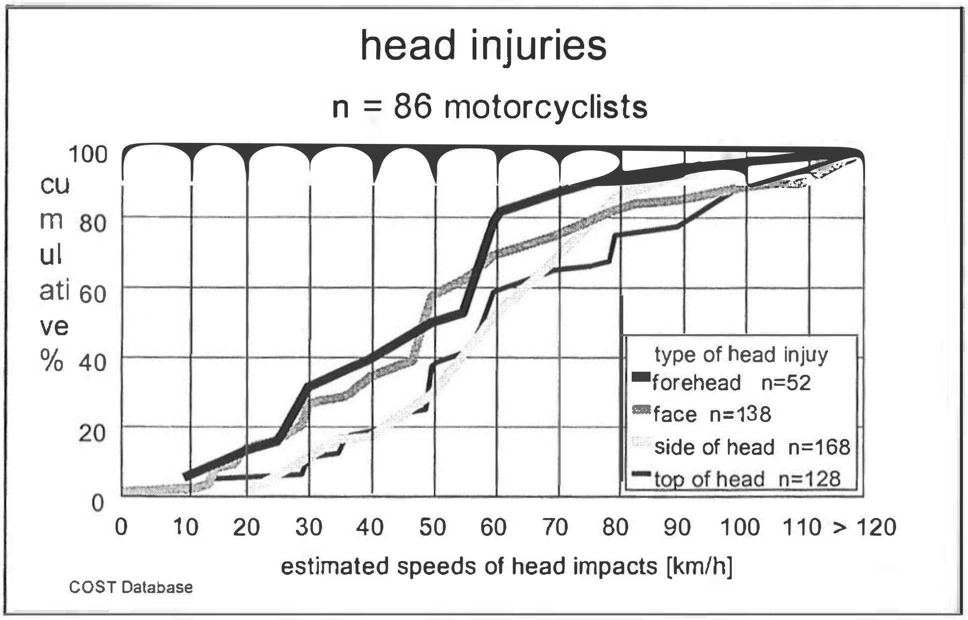


Figure 4 - Estimated speed of head impact for each head region (100%=each head region), n=71 unknown

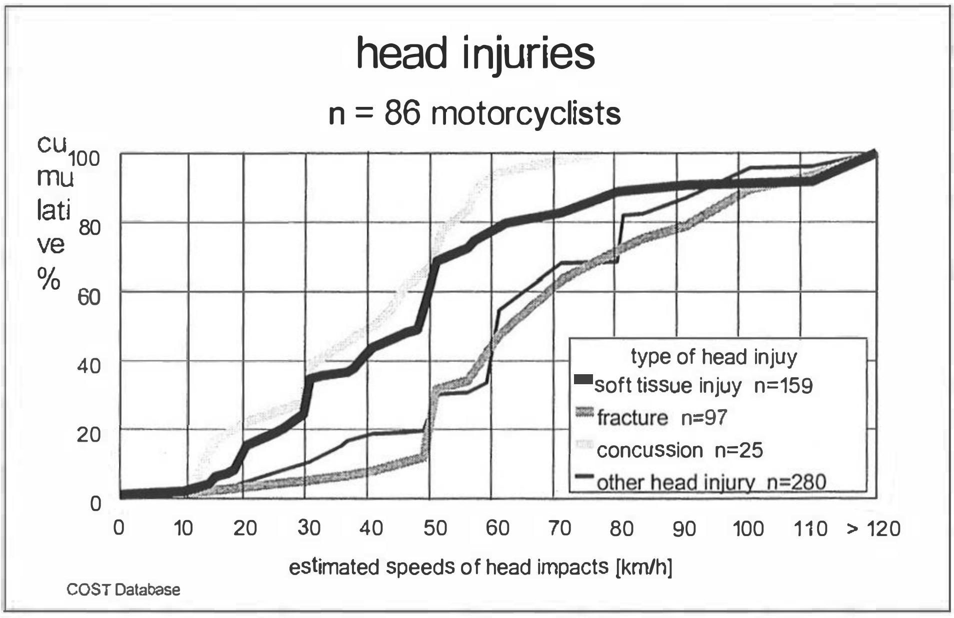


Figure 5 - Estimated speed of head impact for each type of head injury (100%=all motorcyclists of each type), n=71 unknown

Figures 6 to 10 show the relation between impact speed and four types of injury, soft tissue, skull fracture, fracture, concussion and brain injury, for five different locations of impact on the helmet. Of particular interest is the median speed at which brain injury occurs, which may be assumed to be indicative of the sensitivity of the brain to a given impact severity at different locations. For the face and upper head, the median speed is approximately 60 km/h whereas for the head lateral and head rear, the median speed is approximately 50 km/h. This is consistent with what may be expected for the lateral location but the rear may be expected to be less susceptible than the lateral position. However, the median speed for concussion is always lower than that for brain injury, which is entirely consistent with what may be expected. Further investigation of these parameters is recommended.

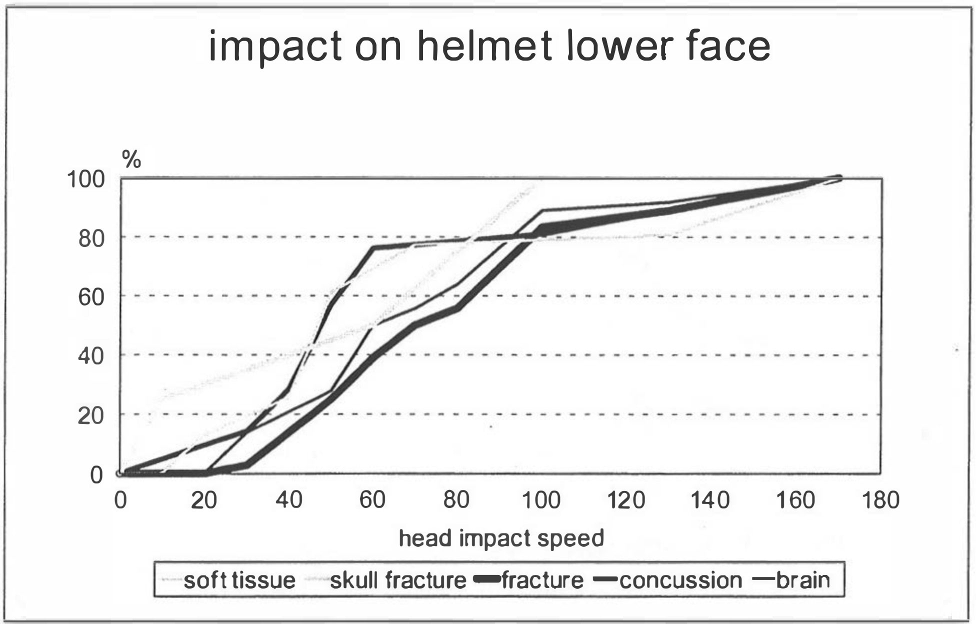


Figure 6 - Cumulative speed of head impact for each type of head injury, impact on lower face area of helmet, (100%=all motorcyclists of each type)

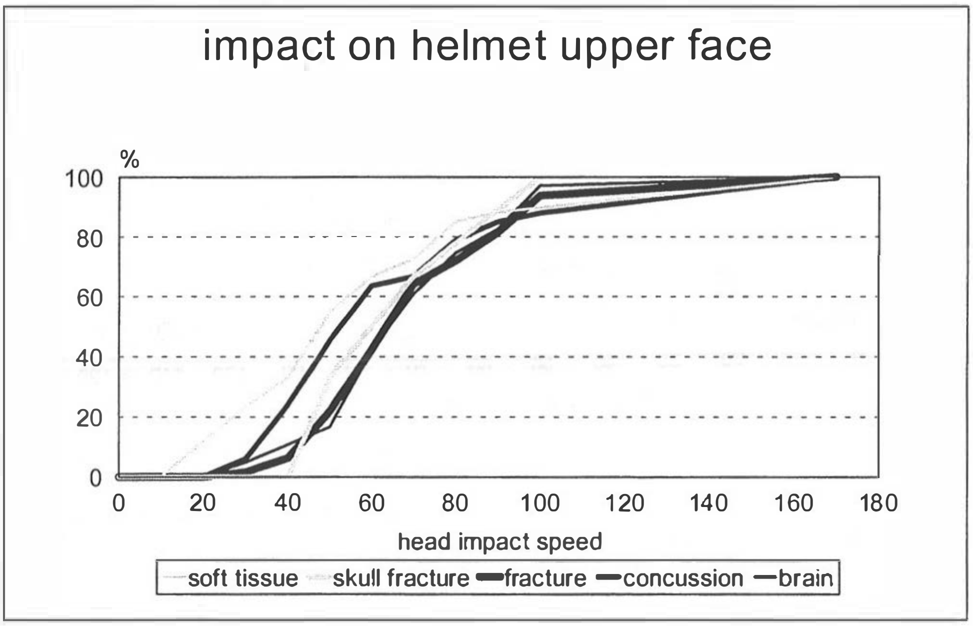


Figure 7 - Cumulative speed of head impact for each type of head injury, impact on upper face area of helmet, (100%=all motorcyclists of each type)

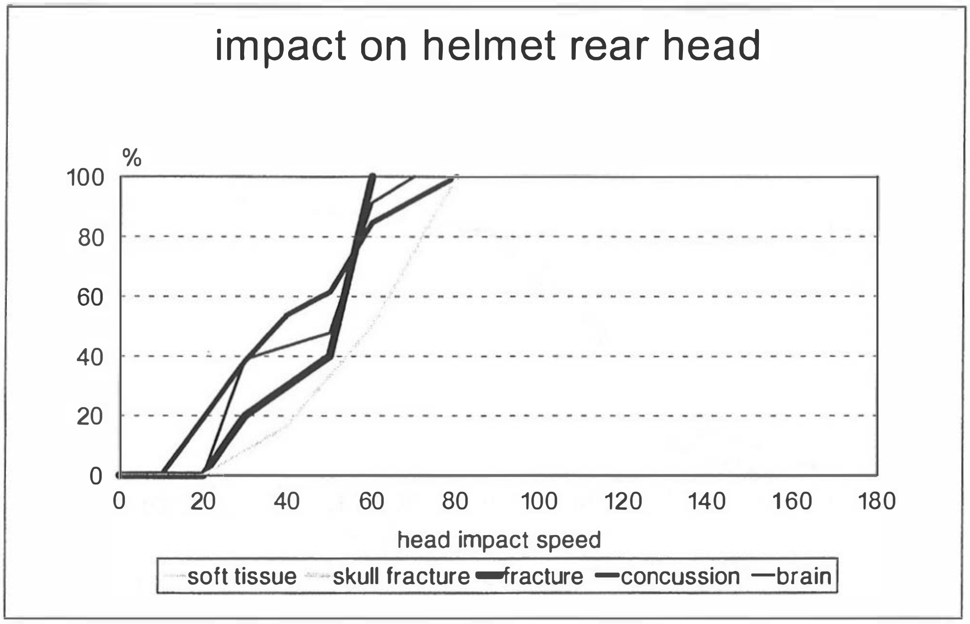


Figure 8 - Cumulative speed of head impact for each type of head injury, impact on rear head area of helmet, (100%=all motorcyclists of each type)

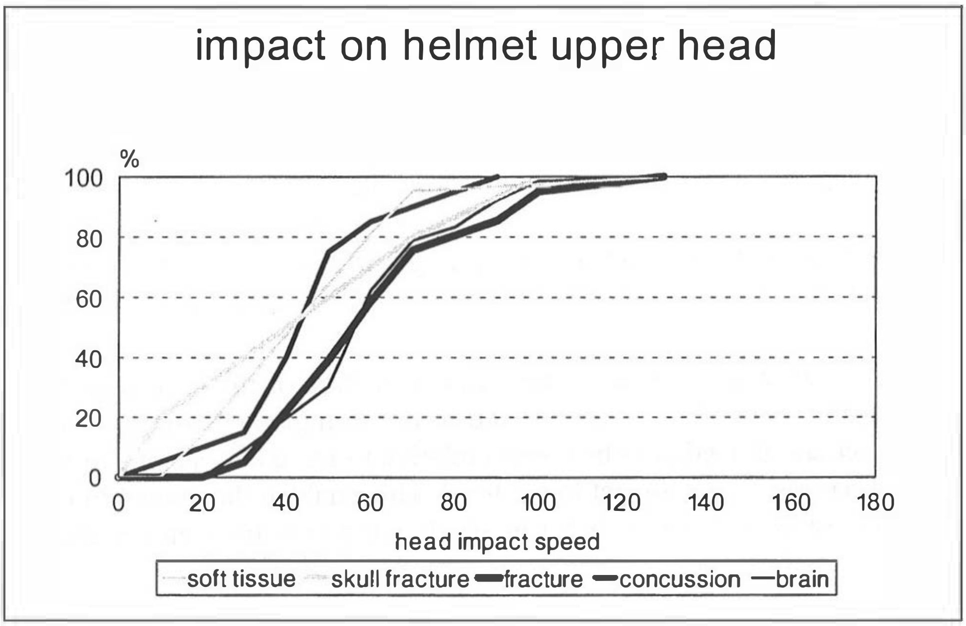


Figure 9 - Cumulative speed of head impact for each type of head injury, impact on upper head area of helmet, (100%=all motorcyclists of each type)

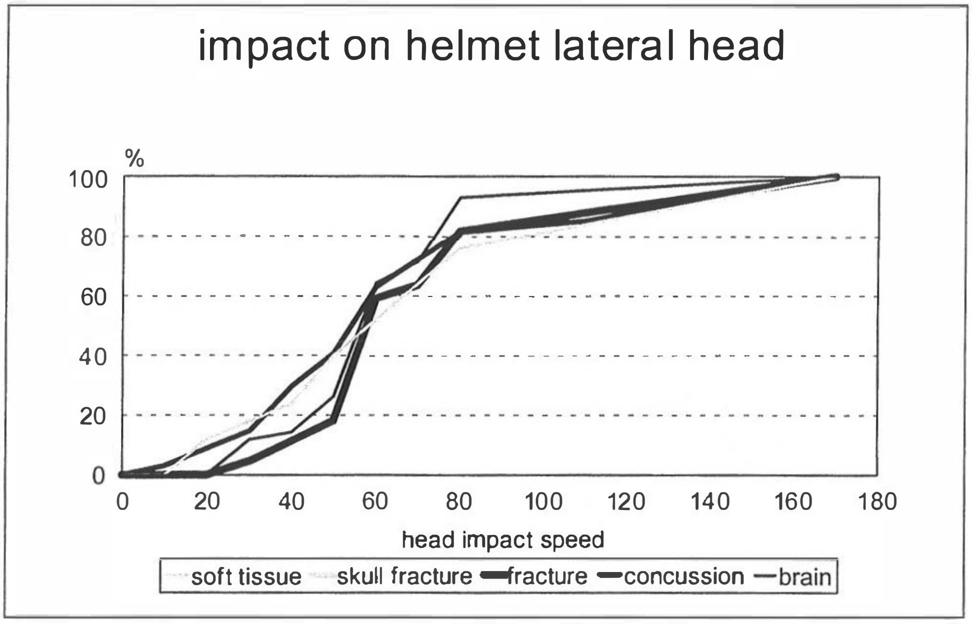


Figure 10 - Cumulative speed of head impact for each type of head injury, impact on lateral head area of helmet, (100%=all motorcyclists of each type)

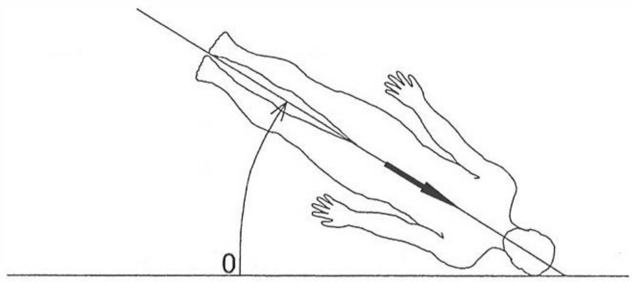
HEAD INJURY TYPE AND HEAD IMPACT ANGLE.

Determining the impact angle of the body and the head was an important part of the reconstruction of the accident. The body impact angle was determined for every head impact and it was found that 60% of the motorcyclists impacted with a shallow body angle of less than 15 degrees, nearly parallel to the opponent, such as road surface, vehicle etc. A further 16.6% collided at an angle of the body of between 16 and 30 degrees and only about 20% impacted with a body impact angle above 30 degrees.

However, the body angle is not necessarily indicative of the head impact angle and this was analysed separately according to the convention given below in Tables 5 and 6. The head impact angle needed to be known relative to three dimensions to establish the location and direction of the impact to the head. This enabled the impact to be identified as direct and likely to induce largely linear acceleration or oblique and likely to induce a substantial rotational component.

The analysis showed, Table 5, that 45% were at 0° and thus perpendicular to a line vertically through the body. Thirty-four percent were between 1° and at 45° to this vertical and toward the top of the head whereas 14% were in this range toward the base of the skull. However, Table 6 gives the analysis in the horizontal plane. This shows that most of the recorded head impacts were at an impact angle XY between minus 45° and plus 45° and lead to a dorsal flexion of the cervical spine 67.0% and rapid rotational motion. Only 7.8% occurred at the rear of the helmet within the range of 135° and 180°. About 20% were side impacts.

An oblique impact from the top often leads to a compression of the cervical spine when the head is in an upright position in relation to the body. Otherwise the impact results in dorsal, ventral or lateral flexion of the neck and the cervical spine in combination with a compression. 28.7% of all head impacts were frontal impacts with 0 degree, 6.1% were rear impacts with ±180 degrees

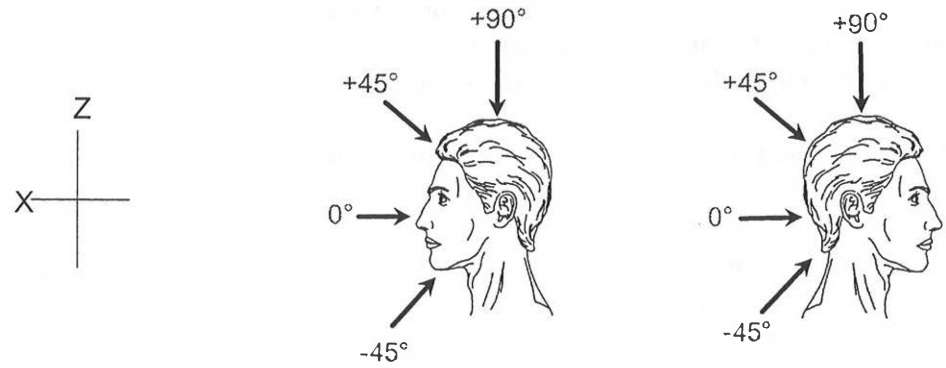


Body Impact Angle	**n**	**%**
< 15°	69	60.0
16 – 30°	19	16.6
31 – 45°	10	8.7
46 – 60°	5	4.3
> 60°	9	7.8
Unknown	3	2.6
Total	**115**	**100.0**

Figure 11. Body impact angles for head injuries in degrees [°]
(100% = 115 angles - all head injuries

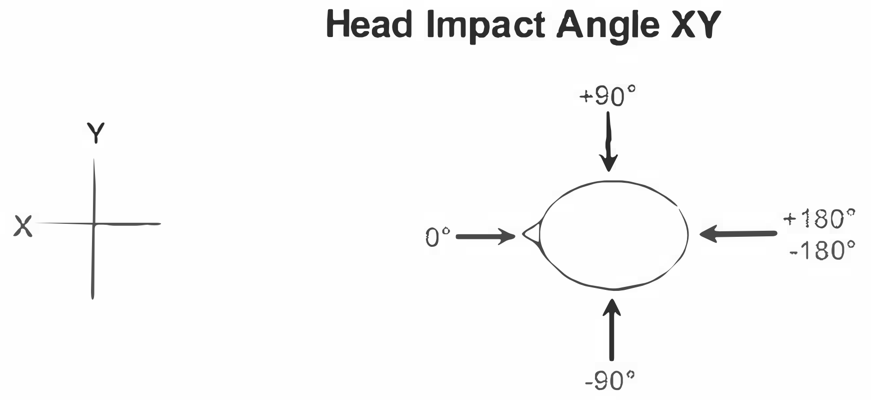
Table 5 - Head impact angles ZX and XY in degrees [°] (100% = all head injuries)

Head Impact Angle ZX



Head Impact Angle ZX	0	1 - 45	46 - 89	90	(-45) - (-1)	unknown	total
N	52	40	1	0	16	6	115
%	45.2	34.3	0.9	0	13.9	5.2	100

Table 6 - Head impact angle XY in degrees [°] (100% = all head injuries)



Head Impact Angle XY	0	1 - 45	46 - 90	91 - 135	136 - 179	±180	(-179) - (-136)	(-135) - (-91)	(-90) - (- 46)	(- 45) - (-1)	Un-known	Total
N	33	20	13	-	1	7	1	1	8	25	6	115
%	28.7	17.4	11.3	-	0.9	6.0	0.9	0.9	7.0	21.7	5.2	100

REPLICATION OF HELMET DAMAGE AND STATISTICAL ANALYSIS OF THE RESULTS

The aim of this work was to replicate head impacts sustained during real motorcycle accidents while measuring the dynamics of the head. In this way it was possible to correlate the documented head injuries with the associated instrumentation data.

Essentially, there are four phases to this work:

1. Compile a database to include; accident profiles, casualty injuries and helmet damage
2. Select accident cases that are appropriate for replication
3. Replicate helmet damage in the laboratory
4. Process and analyse the instrumentation data

TRL UK replicated the helmet damage using a purpose-built helmet drop test facility. The method allowed impact parameters, including impact speeds, angles and targets, to be controlled and quantified. By inspection of the helmet it was possible to modify the impact parameters until the desired damage was produced. Instrumentation was used to measure the dynamics of the impact and ultimately enable the accelerations, likely to have been experienced by the casualty, to be estimated.

Analysis of the damage to the shell and liner was used to identify the kinematics of the impact. Surface scratches, scuffs and paint chips often relate to the impact speed, angle and target shape. The accuracy of the replication was judged by comparing the replicated damage with the accident damage. The test helmet was an identical make and model to the accident helmet to ensure similar performance during the impact. When this was not possible, a similar helmet was used.

The following outputs based upon calculations from the replication test data were compared with the injury severity and analysed statistically.

Resultant (peak) linear acceleration,
Resultant (peak) rotational acceleration,
Head Injury Criterion (HIC)
Head impact velocity
GAMBIT

Figures 12 to 17 show these parameters plotted against head injury severity in AIS (currently 18 data points). The linear regression coefficient was calculated for all impact parameters and was found to vary from r=0.6 for HIC to r=0.75 for GAMBIT.

The probability of injury, AIS, was predicted from the values of rotational and linear acceleration measured in the replication tests and compared with the medical assessment of the injury. For the cases with head impact but no injury, AIS 0, the measured peak linear and peak rotational acceleration varied from 88g to 190g and from 3022 to 9446rad/s^2. The probability function accurately predicted a low risk of less than 50% for AIS 1. The cases, with a known AIS of 2, were predicted to have a probability of AIS 2 of 50% or less. More severe cases, known AIS 3-5, were predicted to have a probability of injury of greater than 50% for AIS 3 or greater. It should be noted that in 13 cases where the motorcyclist sustained a head injury the rotational acceleration was approximately 9,000 rad/s^2 or greater. In only two cases of head in jury was the rotational acceleration somewhat lower than this value.

HIC, as may be expected, correlated to injury similarly to peak linear acceleration. For all but one non-injury case, HIC values below 1000 (HIC 248 - 578) were measured and even the majority of AIS 2 cases did not exceed HIC 1000. Over 75% of cases involving severe head injuries with AIS 3 to 5, gave values of HIC greater than 1000.

Head injury is likely to increase with increasing velocity but the relationship will be dependent upon the helmet performance and the stiffness of the surface struck. Inspection of figure 16 shows that with current helmets injury is unlikely below about 6m/s. At 10m/s and above, injury is very likely and the severity increases rapidly with increasing velocity. Between 6m/s and 10 m/s the outcome is less predictable. However, it seems likely that a head injury will be sustained and it is possible that the severity could be as high as AIS 4 even at approximately 7m/s. This information is particularly relevant to the velocity at which Standards require helmets to be tested and the criteria that are applied.

It is clear that rotational as well as linear acceleration is a factor in the type and severity of head injury severity that is sustained. Currently GAMBIT is the only criterion to include both parameters. Figure 17 indicates that injury is unlikely below a value of 1 but above this injury is highly probable and for values of just below 2 and greater there is a substantial risk of severe injury, AIS 3-5. These results confirm that GAMBIT is a useful indicator of injury but the severity for a given value does not agree with published information. This should be investigated further.

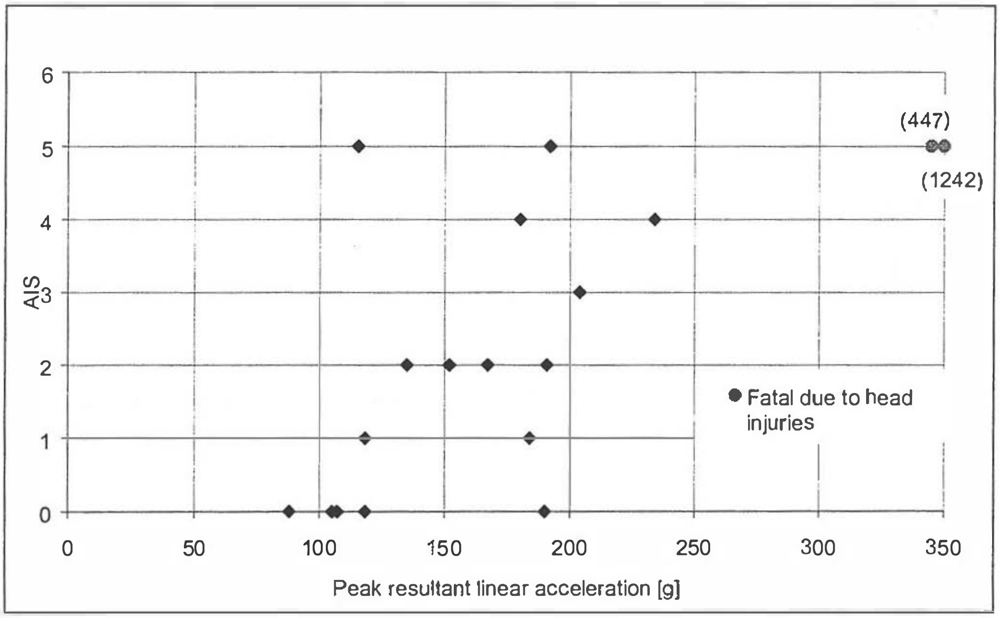


Figure 12: Head injury AIS for peak linear acceleration measured by impact replication

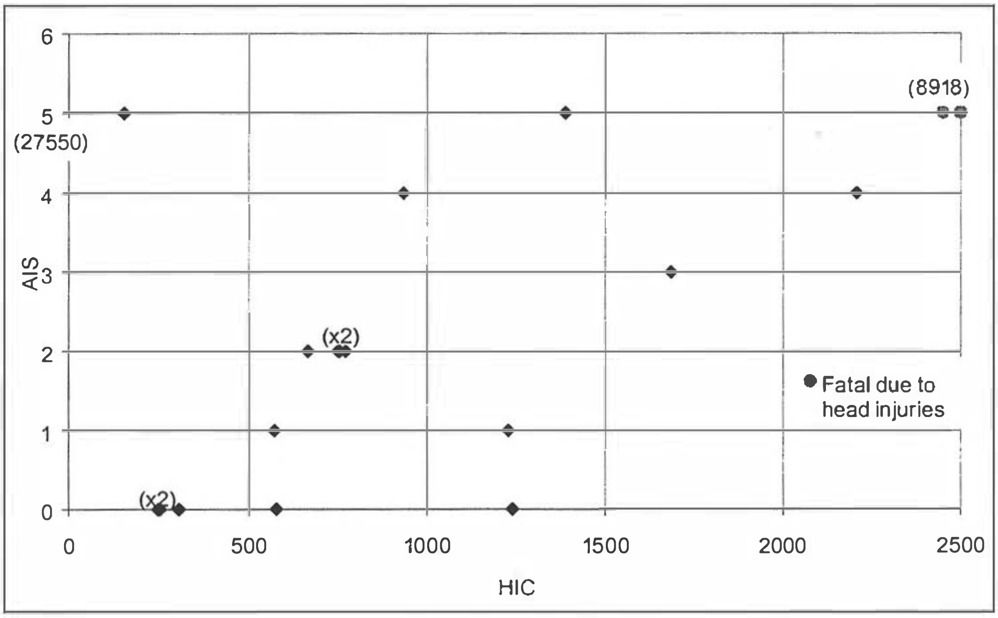


Figure 13: Head injury AIS for HIC based on impact replication data

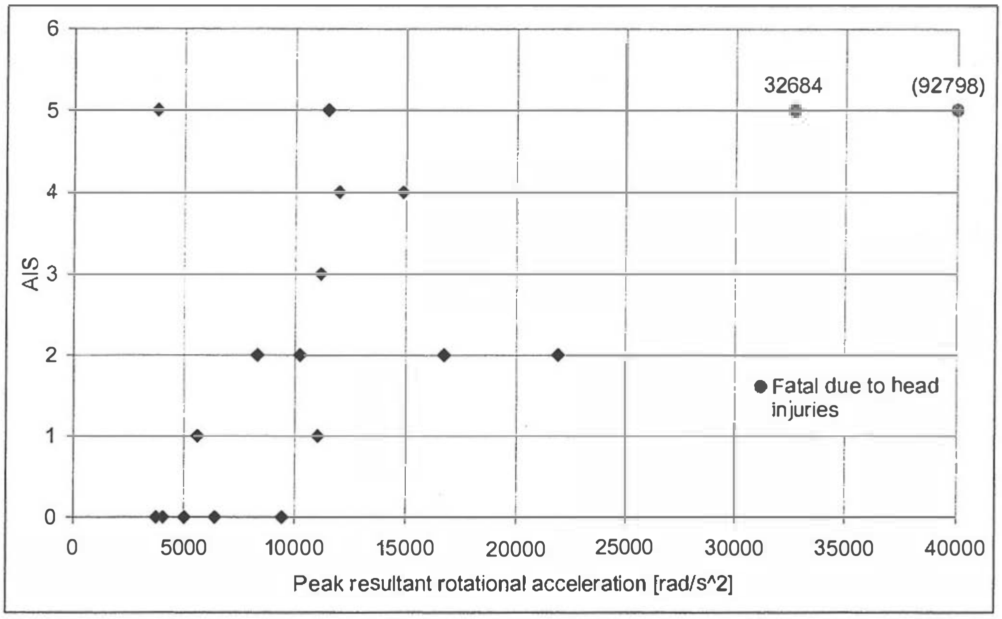


Figure 14: Head injury AIS for peak rotational acceleration measured using impact replication

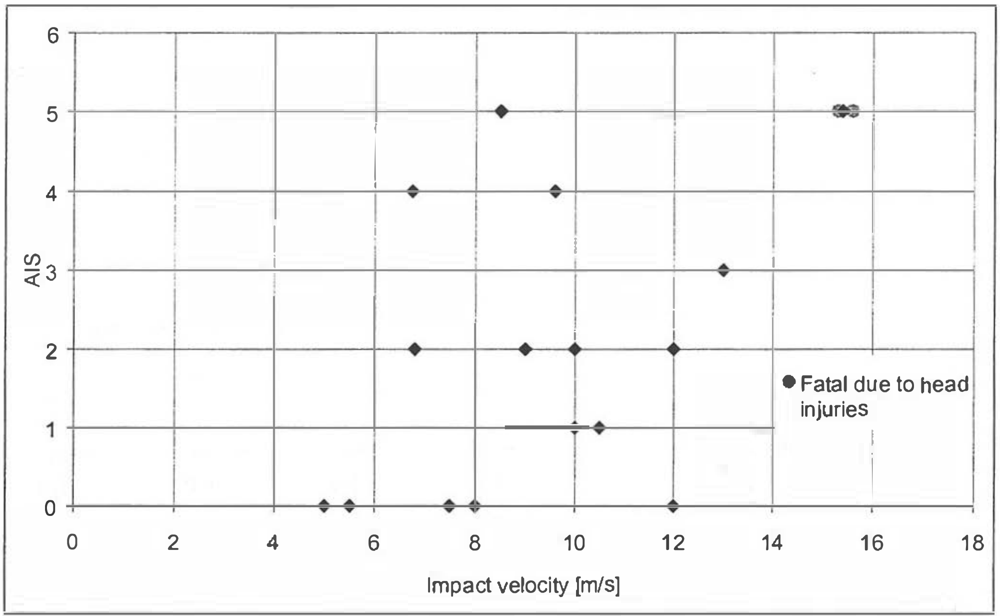


Figure 15: Head injury AIS for replication impact velocity

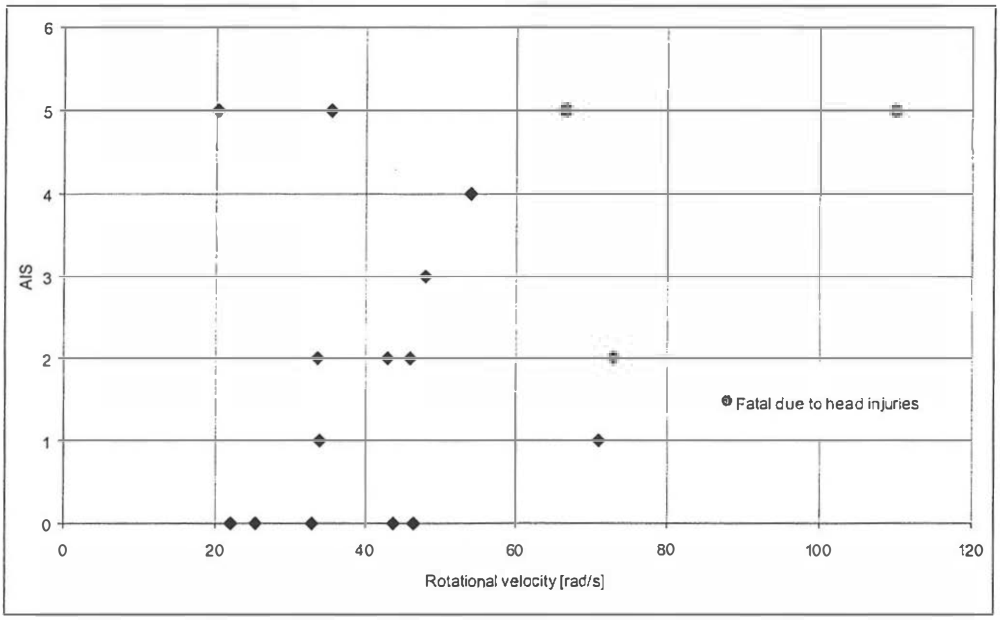


Figure 16: Head injury AIS for rotational velocity measured using impact replication

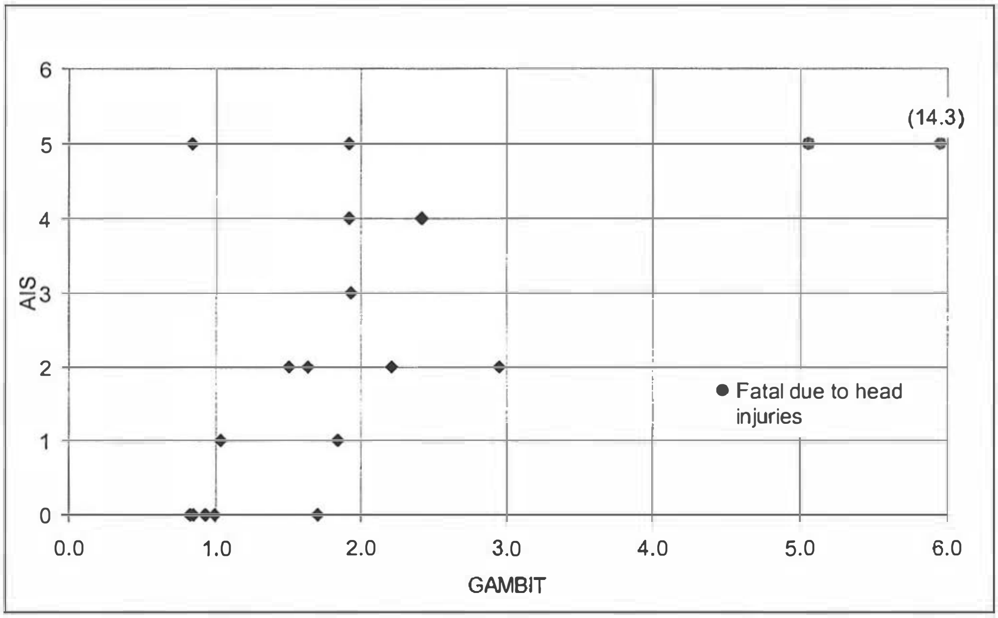


Figure 17: Head injury AIS for GAMBIT calculated using impact replication data

CONCLUSIONS

1 It was surprising that in this study the majority of casualties were in the 26 to 30 age group and that the 31 to 35 age group, 19%, was only slightly smaller than the 18 to 25 age group, 21%. This contrasts with previous studies for which the 18 to 25 group was by far the largest of all categories.

2 Helmet mass was recorded and the range, which varied between 0.780 kg and 1.650 kg, was more than two to one. However, a large majority, 61%, (unknown excluded) lay

in a narrow band of between 1.00 kg and 1.20 kg. The vast majority, 87.5%, were full faced and this would partly explain the mass grouping noted above, although, type of helmet was recorded for all but three cases whereas mass was not. Loss of helmet prior to impact was low at 0.5% but, the loss of a helmet during an accident was 12.4%. Thus, there is substantial need for improvement of retention during an impact.

3 For the COST database there were 66.5% with a head injury and 28.2% with a neck injury. Also notable was the 53.3% with a thorax injury and 72.7% with leg injuries. When the injuries were subdivided into MAIS as the MAIS increased so did the proportion with a head injury, from 38% for MAIS 1 to 85% for MAIS 3 and greater. However, the overall pattern for the COST 327 database showed that risk of sustaining an abdominal injury increases as MAIS increases, a similar pattern to that for the head.

4 Location of helmet damage was distributed fairly evenly with 27.3% lateral right, 25.9% lateral left, 24.2% frontal and 21.6% to the rear, slightly fewer than the other regions. Other locations of importance, and frequently damaged, were the chin guard, 9.4% and the right upper temporal fossa region, 9.6%and left, 9.0%, 18.6% total. The lower temporal fossa was the next most frequently impacted region, 14.9% total for both sides.

5 The cumulative frequency of the estimated head impact speed was determined for different regions of the head. The analysis was divided into the forehead, face, and side and top of the head. It is evident that impacts to the side and the top of the head occurred at higher speeds (50%, median = 58 km/h) compared with those to the face and forehead (50%, median = 48 km/h). Of particular interest is the median speed at which brain injury occurred, which may be assumed to be indicative of the sensitivity of the brain to a given impact severity at different locations. For the face and upper head the median speed was approximately 60 km/h whereas for the head lateral and head rear, the median speed was approximately 50 km/h. This is consistent with what may be expected for the lateral location but the rear may be expected to be less susceptible than the lateral position. However, the median speed for concussion was always lower than that for brain injury, which is entirely consistent with what may be expected. Further investigation of these parameters is recommended.

6 The probability of injury, AIS, was predicted from the values of rotational and linear acceleration measured in the replication tests and compared with the medical assessment of the injury. For the cases with head impact but no injury, AIS 0, the measured peak linear and peak rotational acceleration varied from 88g to g and from 3022 to rad/s^2. The probability function accurately predicted a low risk of less than 50% for an AIS of 1. The cases with a known AIS of 2 were predicted to have a probability of AIS 2 of 50% or less. The more severe cases, known AIS 3-5, were predicted to have a probability of injury of greater than 50% for AIS 3 or greater. It should be noted that in 13 cases where the motorcyclist sustained a head injury the rotational acceleration was approximately 9,000 rad/s^2 or greater. In only two cases of head injury was the rotational acceleration somewhat below this value. It is clear that rotational as well as linear acceleration is a factor in the type and severity of head injury severity that is sustained and this should be recognised in the test requirements for Standards.