SEVERITY OF HEAD-TO-CAR AND HEAD-TO-GROUND IMPACTS OF PEDESTRIANS

G. Stcherbatcheff, J.P. Boulaire, C. Tarrière, A. Fayon,
Laboratoire de Physiologie et de Biomécanique de l'Association Peugeot-Renault, La Garenne-Colombes (92), France.

C. Got, A. Patel, Institut de Recherches Orthopédiques, Hôpital Raymond Poincaré, Garches (92), France.

1. INTRODUCTION

When a collision occurs between a car and a pedestrian, the victim undergoes multiple impacts against the car before striking the ground. Any study of such collisions must provide a precise answer to the primary question which arises, namely: which of these two types of impact - that against the car, or that against the ground - results in the most severe injuries? Clearly, the effectiveness of any possible modifications to the car in order to protect the pedestrian will depend on the answer to this question.

First, the available accidentological data are examined, after which the experimental data are analysed. The various results are discussed and the difficulties emphasized. The problems set by analysis of injuries to parts of the body other than the head are mentioned. However, the sutdy is mainly concerned with head injuries. Injuries caused by impact with the car are termed "primary" , and those caused by impact with the ground "secondary".

2. ACCIDENTOLOGICAL DATA.

Bidisciplinary analyses of pedestrian accidents have been made by the University of Birmingham (1), the University of Berlin (2), the Peugeot-Renault Association (3), T.R.R.L. (4) and CALSPAN (5).

2.1. Injuries to parts of the body other than the head - Fractures of the tibia, femur and pelvis, knee sprains, bursting of the liver and spleen in the adult and child, together with injury of the thorax and spine of the child, generally correspond to direct, highly-localised impacts against bumpers, the area around the headlamps, the radiator panel and the leading edge of the bonnet. No particular problems arise in analysing the origin of these injuries. A number of results are given below:

- 117 "primary" injuries out of a total of 130 injuries to the lower limbs with a severity of AIS $\geq$ 2 (1),

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- 33 "primary" injuries out of a total of 36 injuries to the lower limbs with a severity of AIS $\geq$ 2 (3)

- 128 "primary" injuries out of a total of 146 injuries to the lower limbs of more than minor severity (4).

- 30 "primary" injuries out of 37 injuries to the pelvis with a severity of AIS $\geq$ 2 (1),

- 46 "primary" injuries out of 54 injuries to the pelvis of more than minor severity (4),

- 3 "primary" injuries out of 3 injuries to the pelvis with a severity of AIS $\geq$ 2 (3),

- 10 "primary" injuries out of 12 injuries to the abdomen of more than minor severity (4),

- 6 "primary" injuries out of 6 injuries to the abdomen with a severity of AIS $\geq$ 2 (3).

The survey conducted by the University of Berlin (2) confirms that most injuries to the lower limbs, pelvis and abdomen are caused by impact against the car, as also are most injuries to the thorax of the child. CALSPAN, however, ascribes relatively greater importance to impacts against the ground, but it would appear that injuries of minor severity were not distinguished from more serious injuries (5).

These various findings show that 80 to 100 % of injuries of a certain severity to the lower limbs, abdomen and pelvis are caused by the car.

Analysis of injuries to the thorax and spine of the adult is a more delicate matter: injuries to the thorax are more extensive, and injuries to the spine may be the outcome of stresses exerted indirectly as a result of the inertia of parts of the body. The few accidentological data available ascribe the origin of these injuries essentially to impact against the car:

- 20 "primary" injuries out of 24 injuries to the thorax of more than minor severity (4)

- 19 "primary" injuries out of 23 injuries to the thorax with a severity of AIS $\geq$ 2 (3),

- the car is the cause of most injuries to the thorax of the adult and the child (2).

Data on injuries to the spine are few and far between: 1 injury to the spine (AIS = 2) and 1 to the neck (AIS = 2) caused by the car (3); 4 out of 5 "thoraco-lumbar" injuries and 7 out of 11 injuries to the neck of more than minor severity are caused by impact against the car (4).

2.2. Injuries to the head - Generally speaking, the origin of head injuries is more difficult to establish than is that of injuries to other parts of

the body. Before presenting and discussing the methodology of this analysis, in relation to experimental data, the available accidentological data are summarized:

University of Birmingham (1):

- out of a total of 40 head injuries with a severity of AIS 4-5-6: 23 "primary", 9 "secondary" and 8 non-classifiable;

- out of a total of 88 head (and facial) injuries with a severity of AIS 2-3: 54 "primary", 26 "secondary" and 8 non-classifiable;

T.R.R.L. (4):

- out of a total of 140 head injuries of more than minor severity: 62 "primary", 41 "secondary" (+ 1 runover);

- out of a total of 35 fatal injuries of all types: 21 "primary" and 14 "secondary". This breakdown gives some indication as to the origin of fatal head injuries, the head being the seat of the majority of all fatal injuries.

University of Berlin (2):

- 52 "primary" and 1 "secondary" injuries with a severity of AIS 4-5 (Cf. figure 22-23, ref. (2)). This result refers only to accidents in which the vehicle was not impacted in the edge area on the vehicle front.

This distribution, which covers all parts of the body, shows that no more than one single highly severe head-to-ground impact occured. According to the criterion used in this survey (Relative Traumatise Degree), head-to-car impacts of the adult and child were the major cause of head injuries.

CALSPAN (5):

36 % of head-to-car impacts result in serious injuries, as against 27 % of head-to-ground impacts with the adult pedestrian. The corresponding figures for the child are 65 % and 13 %.

The Peugeot-Renault Association (APR) (3):

One application of the survey resided in considering two distinct sub-samples: accidents with head-to-car impact (a) and accidents without head-to-car impact (b) (escape via the side of the car, or low collision speed).

(a) Accidents involving a head-to-car impact (n = 69) - Table 1 indicates the severity of injuries to the head ascribable to head-to-car impact in terms of the collision speed. Table 2 indicates the severity of the "secondary" impacts against the ground, together with the non-classifiable cases. As can be seen, no "secondary" impact with a severity of over 2 was detected, all the severe and fatal head injuries falling into the "primary" or "non-classifiable" categories.

Head AIS							Σ	%
5	-	-	2	11	4	6	23	33
4	-	-	1	1	-	-	2	3
3	-	1	-	1	-	-	2	3
2	2	7	8	5	1	-	23	33
1	-	5	6	4	1	-	16	23
0	-	2	1	-	-	-	3	4
	<20	20-30	30-40	40-50	50-60	>60	V km/h	

Table 1 - Severity of "primary" head impacts as a function of the collision speed (N = 69).-

"non-classifiable" Head AIS							Σ	%
	-	1	1	-	2	4	6	
5	-	-	-	-	-	-	0	0
4	-	-	-	-	-	-	0	0
3	-	-	-	-	-	-	0	0
2	2	-	-	1	-	-	3	4
1	-	2	5	5	-	2	14	20
0	-	13	12	15	6	2	48	70
	<20	20-30	30-40	40-50	50-60	>60	V km/h	

Table 2 - Severity of "secondary" and "non-classifiable" head impacts as a function of the collision speed (N = 69).-

(b) Accidents not involving a head-to-car impact - Table 3 indicates the severity of injuries that can only be the consequence of head-to-ground impacts. It can be seen that severe and highly severe injuries start to occur at less than 30 km/h. The severity of these "head-to-ground" injuries compared to the evaluation of the severity of "secondary" head-to-ground injuries (90 % of injuries AIS $\leq$ 1) raises a problem as regards this evaluation. The different kinematics of the pedestrian that are observed in these two types of collision and which probably lead to more severe head-to-ground impacts where there is no previous head-to-car impact (low speed ; escape configurations),

are not sufficient to explain such a large difference between the two head-to-ground impact samples. This difference could possibly be the consequence of underestimating the severity of the "secondary" head-to-ground impacts.

Head AIS							Σ	%
5	1	1	-	-	-	2	4	13
4	-	-	1	-	-	-	1	3
3	1	-	1	-	-	-	2	7
2	1	2	2	-	-	1	6	20
1	4	6	1	-	-	1	12	40
0	4	-	1	-	-	-	5	17
	<20	20-30	30-40	40-50	50-60	>60	V km/h	

Table 3. Severity of head-to-ground impacts in accidents not involving a head-to-car impact.

In both samples of head-to-ground impacts, "secondary" and direct head-to-ground impacts, there is few correlation between the severity of the head injury and the collision speed.

An examination of the nature of the head injuries in these two sub-samples ((a) (b)) provides no particular explanation. At a severity index of AIS = 5 three quarters of the injuries resulting from head-to-car impacts and direct head-to-ground impacts consist of a combination of fracture of the skull and highly severe brain trauma (table 4).

Head AIS	E + F	E	F
5	16	5	2
4	-	2	-
3	1	1	-
2	1	21	1

a

Head AIS	E + F	E	F
5	3	1	-
4	1	-	-
3	-	2	-
2	1	4	1

b

E = brain injury
F = skull fracture
E+F at AIS 4-5 level = very severe brain injury + skull fracture

Table 4 - Nature of head injuries in accidents involving (a) and not involving (b) a head-to-car impact.-

If non-classifiable cases are excluded, these various results (1) (3) of accidentological analyse would indicate that at a severity level of AIS 4-5, head-to-car impact is the cause of 72 % to 83 % of head injuries, whilst head-to-car impact gives rise to head injuries of medium severity (AIS 2-3) in 68 % to 70 % of the cases. If non-classifiable cases are taken into account, identified head-to-car impacts would be the cause of 58 % to 76 % of AIS 4-5 head injuries and of 61 % to 67 % of AIS 2-3 head injuries. By contrast, the majority of head injuries with a severity index of AIS = 1 appear to be caused by head-to-ground impact. These data have to be compared to experimental data.

3. EXPERIMENTAL DATA

Experimental collisions performed using adult dummies and comprising measurement of the injury criteria enable the severity of "primary" and "secondary" impacts to be compared.

3.1. Parts of the body other that the head - Experimental data shows that impacts of the lower limbs against the front face of the car are more severe than impacts of the lower limbs (knee and ankle acceleration) against the ground. As regards the pelvis, impact of the thigh against the front face of the car induces a resultant acceleration which is generally greater than that measured on impact with the ground (6) (7) (8). However, an experimental study (9) has given rise to high accelerations when the pelvis strikes the ground. Calculation of an index taking into account the duration of the impact would be a better criterion than the maximum resultant acceleration of the pelvis for comparing impacts of widely differing durations.

Acceleration of the thorax on impact with the ground seldom exceeds 40-50 g. (6) (7) (8) (10). On impact against the car, acceleration of the thorax is moderate at collision speeds of up to 40 km/h ; above this speed, severe thorax-to-car impacts occur (cf. 80 g. in a collision at 43 km/h (7)). However, a study has revealed accelerations of over 50 g. on impact of the thorax against the ground (9).

It should be pointed out that high accelerations of the thorax are sometimes measured during indirect impacts against the elbow or head of the dummy, the shock being transmitted through the arm or neck. Direct impacts near the accelerometer can give rise to stepped-up accelerations.

Although most experimental studies reveal a majority of severe thorax-to-car impacts, one cannot exclude the possibility that impact of the thorax against the ground gives rise to a limited number of injuries of average severity.

As regards the spine and neck of the adult, it is difficult to arrive at any hard-and-fast conclusions. Nonetheless, these injuries are probably associated to severe impacts against the pelvis, thorax and head. The origin of injuries to the spine must be studied in relation to the origin of injuries to the pelvis, thorax and head.

3.2. The head - In order to compare "primary" and "secondary" head impacts, an adequate injury criterion has to be selected. Maximum acceleration is not a good criterion for comparing impacts of widely differing durations. The HIC

criterion, which allows for the duration of the impact, appears better-suited to comparative study. This criterion is used by various authors and their results are presented below.

Volkswagen (9) - The results of 44 tests (on the GOLF model using a percentile-50 adult dummy) show that the severity of the "secondary" head impact did not exceed HIC = 1000 and that the "primary" head impact is of greater severity than the "secondary" head impact above collision speeds of about 35 km/h. A good correlation appears between the severity of the head-to-car impact and the collision speed. In contrast, the severity of the "secondary" impact appears to bear little relation to the collision speed.

University of Berlin (7) - A series of tests performed with an experimental vehicle the profile of which can be adjusted and with a percentile-50 adult dummy shows that the "primary" head impact is more severe than the "secondary" head impact for the various profiles studied. Indices of up to HIC = 2000 at 12 m/s (43 km/h) are observed for head-to-car impact, while the head-to-ground impact does not exceed HIC = 300. FH $\leq$ 500 Hz.

Wayne-State University (11) - The severity of "primary" and "secondary" head impacts was compared in two tests. In both cases, the severity of the head-to-car impact was greater than that of the head-to-soil impact.

Rolls-Royce (12) - The head injury criterion was greater on head-to-ground impact in two cases out of three (collision speed = 24 km/h).

The Peugeot-Renault Association (6) - Head-to-car impacts were specifically studied (13). The injury criterion measured on the head (HIC) can be very high at a collision speed of 32 km/h in the event of the head striking a rigid zone of the car ; against a windscreen, the severity of head impact is generally moderate (HIC $<$ 1000) up to relatively "high" speeds ($\leq$ 45 km/h).

The severity of "secondary" head impacts is essentially a function of the velocity of the head on striking the ground and of the nature of the surface.

The velocities were measured in a few cases (table 5). It appears that head-to-ground impact velocities with a relatively high vertical component can be associated to collisions at low speed. Conversely, high speed collisions can be associated to head-to-ground impact velocities with a relatively low vertical component. This vertical component of the head impact velocity is related, aside from the height through which the head falls and the dummy rotation velocity, to previous ground contacts with other parts of the body, the nature and effect on the kinematics of the head of which cannot be foreseen, since the number of parameters to be considered is too great. This explains the low correlativity between the collision speed and the head-to-ground impact severity.

The horizontal component of the head velocity appears to have less effect on the severity of the "secondary" head impact than does that of the vertical component.

Since the characteristics around the periphery of the head of a dummy are variable, impacts of the same violence which occur at different points of the

Collision speed km/h	$\ddot{y}$ max. g.	HIC	t2-t1 ms. (HIC computation)	Time $\ddot{y} \geq 80g$ ms.	Impacted head area	Head speed at ground contact m/s	Successive body segment ground contacts
21	420	3648	0.9	2.5	Front.	>6	Leg + knee + rotation + head
15	360	2115	1.8	2.5	Occ.	4,3	Leg + pelvis + rotation + head
43	320	1968	2.7	3	Occ.	3 → 8,7	Direct head to ground impact
45	280	1688	2	3	Occ.	4,7 → 10,7	Pelvis + rotation + head
32	310	1477	2.6	3	Occ.	2,3 → 6,7	Direct head-to- ground impact
34	225	952	2.3	3	Front.	2,9 → 5,9	" " " " "
30	145	511	3.7	4	Occ.	3,7 → 5,5	Pelvis + head
45	150	414	3.1	3	Front.	2 → 10,8	Direct head to ground impact
40	62	101	6.1	-	Temp.	1,7 → 5	Pelvis + shoulder + head
32	60	85	5.1	-	Temp.	1,7	Elbow + shoulder + head
33	55	50	7.3	-	Occ.	1,3	Pelvis + head

- 50e perc. Sierra Dummy. -
FH = 1000 Hz

Table 5. Characteristics of Head - to - Ground Impacts -

head may give rise to differing severity indices, particularly in the case of impacts against a rigid surface, which is the case for head-to-ground impacts. This lack of symmetry of the head may explain why impacts of lower violence lead to higher indices (table 5). The rigidity of the neck may also affect the injury criteria measured on the head. in certain configurations (13).

The incidence of the profile of the véhicle on the violence of the "secondary" head impact has already been studied (6) (7). If one considers the tests performed by the APR with different vehicle profiles, it can be seen that at collision speeds of 30 to 45 km/h, head-to-vehicle impact was of the greatest severity 13 times out of 23, and a severity of HIC = 1500 was exceeded 4 times for head-to-car impact, as against 5 times for head-to-ground impact (table 6). At collision speed under 30 km/h, the severity of head-to-ground impact was highest 9 times out of 17, while a severity of HIC = 1500 was exceeded three times for head-to-ground impact. It should be noted that the configurations for these tests (percentile-50 dummy 1.75 m tall and impact against the central area of the front face of the cars) increase the frequency of head-to-windscreen impacts and reduce the risk of highly severe head-to-car impacts against the windscreen frame.

Synthesis - The tests performed by Volkswagen (9), the University of Berlin (7) and the Wayne-State University (11) reveal the greater severity of "primary" head impacts as based on the HIC criterion, since no index exceeded HIC = 1000 for "secondary" head impacts. The tests performed by The Peugeot-Renault Association (6) reveal a risk of severe "secondary" head impacts at collision speeds from 15 to 45 km/h. We have no simple interpretation allowing these results to be explained (HIC < 1000 on head-to-ground impact in more than 50 tests at low and high collision speeds (7) (9) (11) ; HIC > 1500 on head-to-ground impact eight times in fourty tests (T.6)). The presented experimental results give no information as regards the head-to-ground impact severity in accidents without any head-to-car impact and on the head impact severity of the child. These configurations would increase the relative incidence of head-to-ground impacts.

For further study, systematic measurement of the head velocity on striking the ground should enable the scatter caused by the asymmetry of the characteristics of the dummy head and the use of different models of dummy head to be eliminated. By projecting a standard head against the ground at measured speeds during overall tests, it should then prove possible to make measurements of a better-established injury criterion.

4. DISCUSSION

4.1. Accidentological analysis - Accidentological data would indicate that head-to-car impact causes the great majority of highly-serious injuries and of serious injuries to the head. However, the difficulty of this analysis makes any estimation of the precision of this result hazardous. The following are a number of factors enabling a hypothesis to be put forward :

- the appearance of external injuries ;

- the location of the injury or injuries on the head ;

	Collision Speed < 30 km/h.			Collision Speed ⩾ 30 km/h.		
	Collision speed km/h	"primary" HIC	"Secondary" HIC	Collision speed km/h	"primary" HIC	"Secondary" HIC
Head-to-Car Impact is the most severe	24	250	13	40	4460	490
	17	220	54	43	2670	2000
	28	133	26	41	2384	102
	28	105	0	45	2140	1560
	24	86	11	37	810	0
	11	58	0	32	570	43
	16	48	8	40	543	101
	14	20	0	42	511	0
				32	327	187
				40	238	0
				30	242	7
				32	156	50
				32	18	0
Head-to-ground Impact is the most severe	21	34	3648	42	969	3972
	15	112	2115	44	847	1920
	21	305	1800	45	1243	1688
	27	635	851	32	148	1477
	24	13	724	40	249	963
	24	289	712	34	32	952
	19	28	564	40	149	699
	15	22	88	30	113	511
	16	4	55	32	56	155
				37	22	47

- 50e perc. Sierra Dumy -

Table 6 - Head - to - car and head - to - ground impact severity -

- the nature of the injury or injuries ;

- the deformation of the car ascribable to impact of the head ;

- the presumptive circumstances of the fall, allowing for the deceleration of the car, the collision speed, the profile of the car, the height of the pedestrian, etc... ;

- the traces on the ground, if any.

The external appearance of the head in certain cases reveals the probable origin of an impact observed. If, in addition, an injury that can be pinpointed (fracture, subdural hematoma) corresponds to the point of impact concerned on the head, the origin of this injury can be established.

Location of the impact on the head also enables a hypothesis to be formulated as regards its origin, allowing for the way in which the pedestrian is struck (from the left, from the right, head-on, or from behind), together with the additional hypothesis of limited rotation of the head between the moment of initial contact and that when the head strikes the car. Here again, if this trace of impact is associated to a well-located injury (fracture, subdural hematoma), its origin can be established.

The presumptive circumstances of the fall onto the ground, allowing for the overall kinematics, can in certain cases enable the risk of highly severe impact of the head against the ground to be estimated. For instance, if the pedestrian has slid along the bonnet during moderate braking of the car, and falls to the ground with the feet forward, when the vehicle is at rest, the probability of highly severe head-to-ground impact is low.

Traces of impact of the head against the car enable the violence of this impact to be compared with reference to experimental data. However, the detection of an apparently severe head-to-car impact and the coupling of this impact to the injury observed involves the risk of ignoring the possibility of a "secondary" head-to-ground impact which may be severe and have aggravated the injury resulting from the primary impact. This very probably leads to overestimating the severity of head-to-car impacts and underestimating that of head-to-ground impacts. What is in fact in certain cases ascribed to a single impact is often the outcome of two successive impacts. Should albeit the first impact have truly occured at a level of AIS = 5, it would not be superfluous to detect a "secondary" head-to-ground impact severity of AIS = 3 or 4 with a view to appraising the effectiveness of any eventual modifications made to the car.

However, the essential difficulty resides yet more in detecting the origin of head injuries of average severity that are the result of traumas of the brain and loss of consciousness of varying duration. What was the decisive impact causing the injury ? Did the injury result from two successive impacts of comparable severity ? The traces on the head do not generally justify any conclusion, since average severity impacts may leave no traces on the scalp. Here again, there is the danger of overestimating the severity of head-to-car impact and ignoring a "secondary" impact of comparable severity.

4.2. Comparison of accidentological and experimental data - Experimental data yield no decive elements to the study of any given accident, since several reconstitutions of the accident with a dummy can give rise to widely differing severity indices for the head-to-ground impact. The reconstitutions enable the severity of a head-to-car impact to be appraised and not that of a head-to-ground impact for a given accident. Synthesis of the results of a considerable number of experimental simulations nonetheless makes it possible to estimate the risk of a severe head-to-ground impact for a given configuration, from the statistical standpoint.

If one examines, from the statistical standpoint, the risk of highly severe head-to-ground impact, the accident simulations with a dummy show different results. The simulation results presented by Volkswagen can be compared to the Peugeot-Renault accident investigation (no highly severe "secondary" head impact) (3) (9). Conversely, the dummy tests results from APR (6) can be compared to the accidentological data presented by the University of Birmingham (1) (highly severe "secondary" head impacts at the different collision speeds). However, the possibility of observing the location of a fracture and traces of impact on the head and on the car for most head injuries with a level of AIS 4-5 justify the assumption that the detection of the major cause of these injuries must be correct, the danger being that of ignoring a secondary head-to-ground impact of lesser severity and of surestimating the severity of the "primary" head impact. The accidentological data stating that 58 % to 76 % of AIS = 4-5 injuries are mainly due to impact against the car should be a good estimate.

As regards injuries with a severity of AIS = 2-3 resulting essentially in loss of consciousness, the experimental works showed that head-to-ground impacts corresponding to such a severity level are rather frequent. The difficulty or impossibility of accurately detecting the origin of these injuries has been emphazised. For these injuries, the creation of a third category would be justified, namely injuries caused be the vehicle plus the ground, or of indeterminate origin.

To clarify matters, Table 7 proposes a matrix enabling a distinction to be drawn between the various accident configurations from the standpoint of the probability of a severe or moderate head-to-car or head-to-ground impact. These data must be used with caution, since each accident represents a case sui generis, concerning which any conclusions must be preceded by painstaking analysis, in particular of the traces of impact and injuries.

In the future, it would be useful to study the relative severity of "primary" and "secondary" head impacts at collision speeds where modifying the car would permit to reduce the severity of the "primary" head impact. In the speed range from 30 to 50 km/h, the published results show that the major cause of head injuries would be the "primary" impact in more than 50 % of cases (6) (7) (9) (1) (2) (3) and that the majority of highly severe head impacts correspond to head-to-car impacts (7) (9) (1) (2) (3). Tests with a child dummy should also be conducted in the future.

5. CONCLUSIONS

1.Impact against the front face of the car accounts for 80 to 100 % of

COLLISION SPEED km/h:		0	10	20	30	40	50	+50	not available
VERY SEVERE AND FATAL HEAD INJURIES	No head-to-car impact.	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
	Head impact in a "rigid" area of the car.	⊗ + ▱?	⊗ + ▱?	▱ ⊗ ?	▱ + ⊗?	▱ + ⊗?	▱ + ⊗?	▱ ⊗ ?	
	Head impact in a "soft" area of the car.	⊗	⊗	⊗ + ▱?	⊗ + ▱?	▱ + ⊗?	▱ + ⊗?	▱ ⊗ ?	
	Head-to-fractured windscreen impact and penetration into the car.	///	///	▱	▱	▱	▱	▱	
	Head-to-fractured windscreen impact + fall to the ground.	///	///	⊗ + ▱?	⊗ + ▱?	⊗ + ▱?	⊗ ▱ ?	⊗ ▱ ?	
	Head against not fractured windscreen impact.	⊗	⊗ + ▱?	⊗ + ▱?	///	///	///	⊗ + ▱?	
HEAD INJURIES OF MODERATE SEVERITY	No head-to-car impact.	⊗	⊗	⊗	⊗	⊗	⊗	⊗	
	Head impact in a "rigid" area of the car.	▱ ⊗ ?	▱ + ⊗?	▱ + ⊗?	▱ + ⊗?	///	///	▱ ⊗ ?	
	Head impact in a "soft" area of the car.	⊗ + ▱?	⊗ ▱ ?	▱ + ⊗?	▱ + ⊗?	▱ + ⊗?	///	▱ ⊗ ?	
	Head-to-fractured windscreen impact + penetration into the car	///	///	▱	▱	▱	▱	▱	
	Head-to-fractured windscreen impact + fall to the ground	///	///	▱ + ⊗?	▱ + ⊗?	▱ + ⊗?	▱ + ⊗?	▱ + ⊗?	
	Head against not fractured windscreen impact	▱ ⊗ ?	▱ + ⊗?	▱ + ⊗?	///	///	///	▱ ⊗ ?	

LEGEND: Probable cause of head injury { ▱ Car; ⊗ Ground } | ▱ + ⊗? Car + possible aggravation on the ground | ⊗ + ▱? Ground + possible aggravation on the car | ▱ ⊗ ? Non classifiable without Complementary data

Table 7 - Cause of pedestrian head injuries -

injuries with a severity of AIS $\geq$ 2 on the lower limbs, pelvis and abdomen of the pedestrian.

2. The origin of the injuries to the thorax and spine of the pedestrian is probably impact against the car in the great majority of cases.

3. The major cause of head injuries with a severity of AIS = 4-5 is head-to-car impact in 58 to 76 % of the cases. Head-to-ground impacts with a severity of AIS = 2-3-4 following highly severe head-to-vehicle impacts are difficult to detect by accidentological analyse and are probably underestimated.

4. The major cause of head injuries with a severity of AIS = 2-3 is difficult or impossible to determine by accidentological analysis. In certain cases, the aggregrate effect of two successive impacts could cause the injury observed (mainly loss of consciousness). Accidentological data, which indicate that the car is the major cause of these injuries in 61 to 67 % of the cases, probably overestimate the importance of the head-to-car impacts.

5. The ground is the major cause of head injuries with a severity of AIS = 1.

In the future, studying the relative severity of "primary" and "secondary" head impacts at collision speeds from 30 to 50 km/h would allow to estimate the efficiency of arranging the car so that to reduce the "primary" head impact severity. At present stage, it appears that the "primary" head impact is, in collisions from 30 to 50 km/h, the most severe impact in the majority of cases and the cause of the majority of highly severe head injuries. This result should be controlled by further experimental tests with adult and child dummies. The speed of the head on ground impact should be measured and a standardized head should be used so that to make measurement of a better established injury criterion, the characteristics of the head (thickness and rigidity of the skin) determining the level of the injury criterion.

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