SIMULATIONS AND RECONSTRUCTIONS OF PEDESTRIANS AND TWO-WHEEL RIDERS HEAD-TO-CAR IMPACTS.

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1. INTRODUCTION

The impact between the head and the vehicle is the prime cause of death to pedestrians and moped riders (i.e. users of two-wheel vehicles with an engine with a capacity less than 50 cm^3). Accordingly, the accidentological and experimental analysis of these impacts deserves priority attention.

Statistical and accidentological data concerning the impact between the head and the vehicle of users outside the vehicles are summarized. The objectives and methodology of an experimental study of impact between the head and the vehicle are indicated. A number of results of simulations and reconstructions of impact between the head and the vehicle with dummies, with a separate dummy head and with a cadaver are presented.

2. HEAD-TO-VEHICLE IMPACT OF PEDESTRIANS AND MOPED RIDERS

The importance of injuries resulting from head-to-vehicle impacts of the pedestrian has been emphasized frequently (1)(2)(3)(4). In France, where 80% of lethally injured pedestrians are the result of collisions with automobiles (5), head-to-car impact is said to account for 30 to 40% of lethal injuries to the pedestrians.

The accidentological data concerning moped riders are more limited. A recent study of 132 accidents (6) lists 12 injuries with an AIS factor of 4 to 5 resulting from head-to-car injuries as of 24 AIS 4 to 5 injuries that occured in the course of collisions between an automobile and a moped. In France, where about 60% of moped riders are killed in collisions with automobiles, head-to-car impact could cause almost 30% of all lethal injuries.

These results, which show a certain degree of similitude between the main accident data of the pedestrian and those of the moped rider, allow for the estimates firstly of the very serious and lethal injuries to the head by impact against the automobile, compared to impact against the ground (7), and second also for the proportion of very serious and lethal injuries to the head compared to other parts of the body ($>$60% with the pedestrian (8), 70% in a bidisciplinary "moped" rider survey (6)). For instance, the OAIS/AIS ratio for the head from a sample of a hundred pedestrians involved in accidents in the Peugeot-Renault Association survey confirms the incidence of head injuries (Table 1).

With pedestrians, the very serious and lethal injuries to the head (AIS 4-5) mostly stem from impacts of the head against the windscreen frame and the scuttle of European type cars (1)(2)(4). Most of the injuries of medium severity (AIS 2-3) arise from impacts against the surface of the car wings and bonnet. In order to pinpoint the relative importance of the various zones on the vehicle, table 2 gives a classification based on the ΣAIS^3 criterion which combines the frequency and severity data and increases the incidence of the very severe injuries.

OAIS \ Head AIS	0	1	2	3	4	5
6		1			1	22
5						6
4					2	
3	1	4	2	4		
2	7	14	27			
1		9				
0						

Table 1 - Overall Abbreviated Injury Scale Related to Head Abbreviated Injury Scale in 100 Pedestrian Accidents (4)

	Frequency % (n)	ΣAIS^3	$\sqrt[3]{\frac{\Sigma AIS^3}{n}}$	Vm (km/h)
Windscreen frame	24,3 (17)	38	4,2	44,5
Bonnet + wings	25,7 (18)	18,6	2,3	35
Scuttle	12,9 (9)	14,3	3,8	37
Windscreen	18,6 (13)	8,7	2,8	46
Dashboard	4,3 (3)	7,4	4,4	61,5
Roof	2,8 (2)	7,4	5	100
Headlamp area + grill	2,8 (2)	3,9	4	53
Lateral areas	8,6 (6)	1,7	2,1	31,5

Table 2 - Distribution of 70 Pedestrian Head Impacts on the Car (4)

It appears that the windscreen frame (38%) and the scuttle (14.3%) together account according to this criterion for over half the points. One can also observe that the windscreen, its frame and scuttle represent over half the head-to-vehicle impacts. The average severity of the impact in these various areas $\sqrt[3]{\frac{\Sigma AIS^3}{n}}$ reflect the "rigidity" of these regions of the vehicle, in addition to the level of the corresponding collision speeds: for the same mean collision speed, impacts against the windscreen frame have an average severity of 4.2 and impacts against the windscreen an average severity of 2.8.

The characteristics of the head-to-car impacts of moped drivers are known with less precision. A sample of 50 head-to-car impacts of moped drivers of the Peugeot-Renault Association survey (6) has nonetheless revealed the importance of the windscreen frame, as is already known for the pedestrian (table 3).

	Frequency (n)		ΣAIS^3	$\sqrt[3]{\frac{\Sigma AIS^3}{n}}$
Upper windscreen cross member	14	(7)	30,3	4,2
A-pillars + lower windscreen cross member	10	(5)	23,1	4,3
Lateral areas	20	(10)	23,6	3,4
Windscreen	24	(12)	9,8	2,4
Scuttle	8	(4)	9,2	3,4
Bonnet + wings	12	(6)	3,4	2,1
Back	10	(5)	0,6	1,3
Other	2	(1)	0	0

Table 3 - Distribution of 50 Moped Riders Head Impacts on the Car (6)

The upper cross-member of the windscreen frame would appear to be relatively more dangerous to the head of the moped driver (30% ΣAIS^3) than is the lower cross-member and the scuttle. Kinematics of the head somewhat different from those of the head of the pedestrian (more horizontal trajectories of the head of the moped driver) could possibly explain why the reverse result to that for the pedestrian is obtained (scuttle + lower cross-member of the windscreen frame are more "aggressive" than the upper windscreen frame cross-member). A second peculiarity of moped driver accidents can also be observed, namely that the lateral sections of the vehicle represent also one-quarter of the ΣAIS^3 points.

3. EXPERIMENTAL STUDY OF HEAD-TO-VEHICLE IMPACTS OF PEDESTRIANS AND MOPED DRIVERS: OBJECTIVES AND METHODOLOGY.

Experimental study of the head-to-vehicle impact has a twofold objective:

- to reduce the severity of the head-to-vehicle impacts;
- to discover the tolerance of the human head to impact.

These two objectives can be reached provided a procedure consisting of the following stages be followed:

a - accidentological study of head-to-vehicle impact
b - determination of the relationships between the collision speeds and the head-to-vehicle impact speeds (simulation of accidents with dummies, cadavers and mathematical models)
c - establishment of the correlationship between the severity of the head-to-vehicle impact of real accidents in the various zones and the head impact speed (AIS head/head-to-vehicle impact speed)
d - simulations and reconstructions of head-to-vehicle impacts with a model head, a dummy and with cadavers. Relationships between the injury criteria and the severity of head-to-vehicle impacts observed in real-life accidents (AIS/HIC: contribution to the study of tolerance of the human head to impact)
e - the search for solutions; evaluation of the advantage, in terms of HIC, at a given speed or of the speed for a given severity; estimations of the cost/benefit ratio.

To contribute towards points b, c and d of this study, a few experimental figures are given below.

4. CHARACTERISTICS OF HEAD-TO-VEHICLE IMPACTS: IMPACT VELOCITY; LINK BETWEEN HEAD AND THORAX; SIMULATIONS AND RECONSTRUCTIONS OF HEAD-VEHICLE IMPACTS.

4.1. Head-to-vehicle impact velocity

a) Pedestrians - The relationship between the collision speed and the head-to-vehicle impact velocity was studied in experimental collision with dummies and cadavers and with a mathematical model.

H.B. Pritz (10), in tests with cadavers, distinguishes between a "standard" profile, the "nose" of which is situated 78cm above ground level and a "low" profile ("nose" at a height of 63cm). A linear relationship between the head-to-bonnet impact velocity and the collision speed appears for these two profiles for respective Vi/Vc ratios of 0.7 and 1.1.

In tests with dummies, the TRRL (9) measures head-to-vehicle impact velocities which display a fairly high degree of scatter for collision speeds of from 20 to 30 km/h. In contrast to the figures given by H.B. Pritz, this impact velocity appears relatively higher in collisions with "high" profiles.

Out of 21 measurements made by the Peugeot-Renault Association in the course of tests on dummies (16 cases), using a mathematical model (3 cases) and on a cadaver (2 cases), the mean head-to-vehicle impact velocity was 1.05 times the collision speed for a standard deviation of σ=0.24 (fig. 1). Less scatter would appear to occur above 40 km/h than at at the lower speeds (m=1.12, σ=0.13 for Vc $\geqslant$40 km/h).

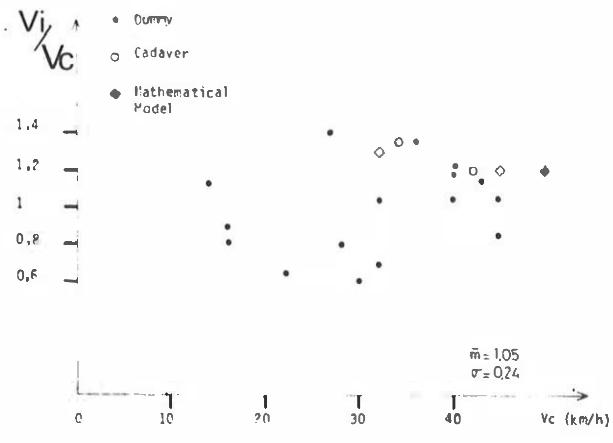


Fig. 1 - Head-Car Impact Speed Versus Collision Speed Ratio in Car-to-Pedestrian Collisions Simulated With Dummies, Cadavers and Mathematical Model.

It is possible to make one definite statement as regards a result which is common to all three of these studies: the head-to-vehicle impact velocity is distributed around the collision speed. However, the direction of variation of the Vi/Vc ratio in terms of the profile of the vehicle gives rise to conflicting results. It would also appear that the collision speed is a somewhat inaccurate estimation of the head-to-vehicle impact velocity. Study of the ratio of the head-to-vehicle impact velocity to the collision speed should be continued, in particular with a cadaver.

b) Moped riders - Analysis of the head-to-vehicle impact velocities of moped riders is more complex. A few analyses of these velocities in fronto-lateral collisions (11) , with the moped driver either halted or moving, showed that the head-car impact speed displays a higher degree of scatter than in pedestrian accidents.

4.2. Direction of the head-velocity on impact for the pedestrian - Simulation of the head-to-vehicle impact with a separated dummy head requires knowledge of the direction of the velocity vector of the head together with the position of the head on impact. A distinction is drawn between head-to-bonnet impact and head-to-windscreen impact in collisions with dummies (16 cases) and cadavers (2 cases) (fig. 2)

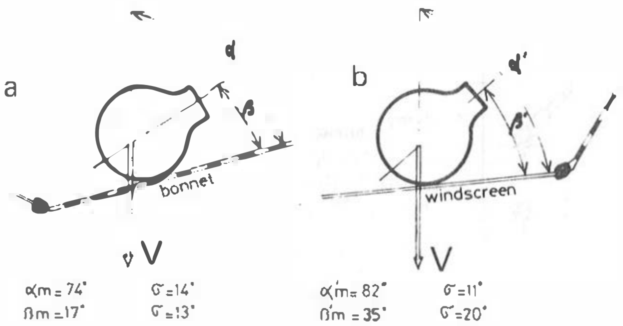


Fig. 2 - Head Average Position and Velocity Inclination at Impact Against the Bonnet (a) and the Windscreen (b).

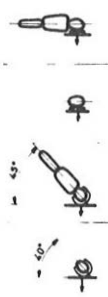
On impact against the bonnet, the average inclination of the head velocity was 74° (σ=14°). On impact against the windscreen, the average inclination to the windscreen of the velocity was 82° (σ=11°).

These figures, which will be used in simulation of head-to-vehicle impact with a separated head, were obtained mainly with the dummy. They should be checked with the cadaver.

4.3. Link between head and thorax - The head-to-vehicle impacts of the dummy are not strictly equivalent to the head-to-vehicle impacts of the separated dummy head: when connected to the dummy, the head is subjected to forces on impact transmitted through the neck. In order to specify the influence of these forces on injury criteria measured on the dummy head, a parallel series of tests was conducted on free-fall onto the head with a dummy equipped with a Hybrid II head and neck and a separated Hybrid II head. The force on impact was measured (see table 4).

In the first configuration, with the dummy horizontal, a maximum acceleration 20% higher is observed with the separated head, with proportional increases in the SI and HIC. The maximum force measured on impact is comparable, but the impulse, associated to a longer duration impact, is higher with the complete dummy.

In the second configuration, with the dummy at an angle of 45°, the neck would appear to be of greater influence, the maximum acceleration is 30% higher with the separated head, but since the impact is shorter, the SI and HIC injury criteria are comparable. The higher maximum force with the complete dummy, combined with a longer duration impact, means that the head receives twice the impulse than in the "separated head" configuration. The ratios of $\frac{F_{max}}{\gamma_{max}}$ or $\frac{\int F dt}{\Delta V}$ have the physical dimension of a mass and are greater with the complete dummy in both configurations compared to the corresponding figures with the separated head.



impact speed m/s	test conditions	damping material	γ max (g)	S.I	H.I.C	$t_2 - t_1$ ms (HIC)	F max (daN)	F max / γ max	$\int F dt / \Delta V$
7.1	dummy	6 cm polystyren foam	146	1217	1029	7	840	5.75	5.96
7.1	separated head	6 cm polystyren foam	175	1415	1241	6	860	4.90	5.06
7,1	dummy	helmet 2,5 cm polystyren foam	114	1172	944	12	930	8.15	7.20
7,1	separated head	helmet 2,5 cm polystyren foam	150	1098	977	7.5	800	5.33	5.43

Fig. 4 - Comparison Between the Characteristics of Head Impacts with a Separated Head and a Complete Dummy in Two Configurations.

These results would indicate that with the dummy, the SI and HIC injury criteria should be of the same order of magnitude or below these same criteria measured on a separated head in impacts at the same speed and with all other factors equal. A more comprehensive study based on a greater number of tests could lead to the choice of an experimental head with a mass which is higher and variable with the conditions of impact in tests attempting to discover the equivalents between the dummy head impacts and impacts of a head which is separated from the dummy.

In an initial stage, the tests presented below were carried out with a Hybrid II head of given mass (4.3 kg).

4.4. Simulation of head-to-vehicle impacts - The severity indices of head impacts in the various zones of standard production vehicles during collisions simulated with a Sierra dummy equipped with a Hybrid II or Sierra neck and head and with a separated Hybrid II head are presented below. The corresponding accidentological data yielded by the Peugeot-Renault Association Accident Survey (4) are also presented.

4.4.1. Head-to-bonnet + wings impacts -

a) Experimental collisions (fig. 3) - With overall simulations performed on various model vehicles in zones situated away from the line of the joint between the bonnet and the wings and the bonnet and the scuttle, the head-to-bonnet impact HIC value did not exceed 1000 up to collision speeds of 40 km/h (see fig. 3).

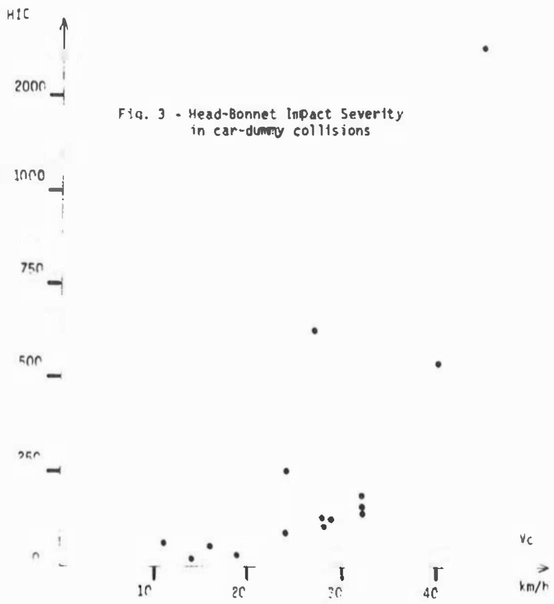


Fig. 3 - Head-Bonnet Impact Severity in car-dummy collisions

b) Separated dummy head (table 5) - Conducted under the testing conditions of figure 2a, impacts of separated heads against a series bonnet were somewhat more severe than with the dummy, although an HIC figure of 1000 was not exceeded up to impact velocities of 40 km/h in the center of the bonnet.

In the zone around the line of joint between the wings and the bonnet and against the wings, the impacts turned out to be much more severe, and HIC of 4485 being reached at 32 km/h impact velocity. These zones do not allow sufficient dynamic distortion or are too rigid.

Impact Localization	V m/s	V km/h	HIC	γ max (g)	Δv m/s	Dynamic Deformation (car structure + headskin) (mm)
Center of bonnet	6,7	24	95	71	9,1	50
	8,9	32	398	175	11,5	81
	11,1	40	553	204	14,1	98
Bonnet - scuttle - wings Junction Point	6,7	24	948	145	8,5	20
	8,9	32	4485	500	9,4	35
Wing	6,7	24	[illegible]	146	7,0	25
	8,9	32	2354	280	9,1	[illegible]

Table 5 - Hybrid II Separated Head Against Bonnet **and Wing Impact Severity**

c) Accidentological data (table 6) - As an example, the head-to-bonnet and wing impacts of the Peugeot-Renault Association Survey are shown below. Most of these impacts occured in relatively low aggressivity zones of the bonnet, away from the joint line between wings and bonnet or bonnet and scuttle.

AIS rate	<20	20-30	30-40	40-50	50-60	>60 km/h
5				3	1	
4			1			
3						
2		3	5			
1		2	1			
0		1	1			

Table 6 - Head Bonnet and Wing Impact Severity in Actual Accidents (4).

4.4.2. Head-to-Windscreen frame and head-to-scuttle impacts -

a) Experimental collisions (fig. 4) - Limited in number at collision speeds of less than 40 km/h, head-to-windscreen frame impacts resulted at 40 km/h in high and very high severity indices.

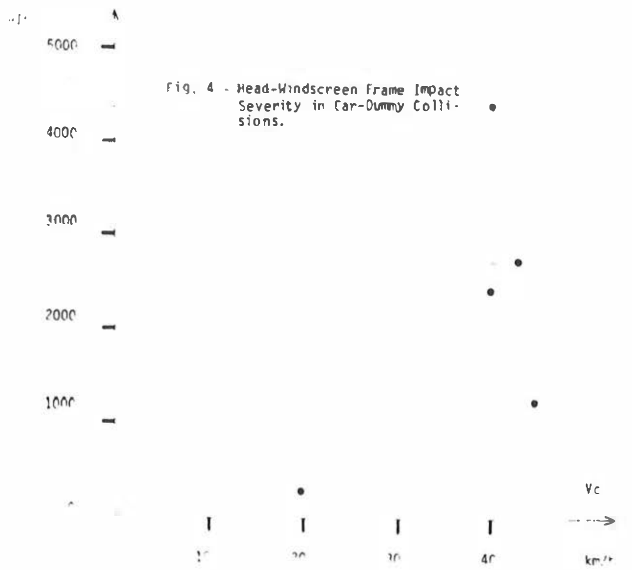


Fig. 4 - Head-Windscreen Frame Impact Severity in Car-Dummy Collisions.

b) Separated dummy head (table 7) - These tests were performed with the configuration shown in figure 2b on a series car. An HIC severity index of 1500 was exceeded in every case except one at impact speeds of 32 km/h or more.

Note the low dynamic deformation which accompanies these impacts (car structure + head skin).

Impact Localization	Vi (m/s)	Vi (km/h)	HIC	γ (g) max	ΔV (m/s)	Dynamic deformation (car structure + head skin) (mm)
. Scuttle	6,7	24	624	100		
"	8,9	32	1211	160	10,0	40
. Windscreen frame	6,7	24	781	165	8,7	37
"	8,9	32	2224	250	10,0	32
"	11,1	40	3297	256	13,1	36
"	11,1	40	1671	106	13,4	24

Table 7 Hybrid II Separated Head Against Windscreen Frame and Scuttle Impact Severity.

c) Accidentological data (table 8) - The accidentological data of head-to-windscreen frame impacts or head-to-scuttle impacts confirm their severity above collision speeds of 30 to 40 km/h.

AIS	<20	20-30	30-40	40-50	50-60	>60
5			2	8	2	1
4				1		
3		1				
2	1	1	2	2		
1		2	3			
0						

Vc km/h

Table 8 - Head-Windscreen Frame and Scuttle Impact Severity in Actual Accidents (4).

4.4.3. Head-to-windscreen impacts -

a) Complete dummy (fig. 5) - In collisions using a dummy, head-to-windscreen impacts are of moderate severity up to 40 km/h.

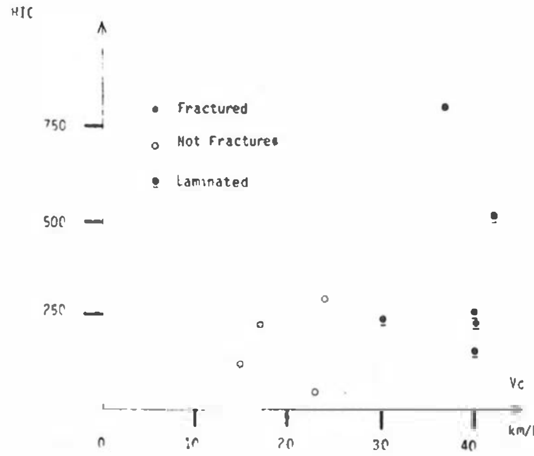


Fig. 5 - Head-Windscreen Impact Severity in Car-Dummy Collisions.

b) Separated dummy head (table 9) - Impacts with a separated dummy head were induced at the centre of a laminated and tempered windscreen under the conditions shown in figure 2b. The corresponding injury criteria are somewhat more severe than during experimental collisions (influence of the link between head and thorax?) but did not exceed an HIC of 1000 up to 45 km/h. Note that as opposed to collision data, the severest impacts occured on the laminated windscreen. Impacts were induced in the upper corners and near the lower edge of laminated and tempered windscreens. No appreciable increase in the severity was observed in these zones, particularly if allowance be made for the secondary impact against the windscreen frame which occured in these tests.

Impact Localization	Vi (m/s)	(km/h)	HIC	γ max. (g)	Fractured
Laminated windscreen, close to lower edge	6,7	24	914	175	yes
" " "	6,7	24	580	170	
Center of laminated windscreen	9,4	34	942	265	"
Center of tempered windscreen	9,4	34	508	185	"
Center of laminated windscreen	12,2	44	942	327	"
Center of tempered windscreen	11,1	40	755	207	"
Corner of laminated windscreen+frame	9,4	34	432	207	"
Corner of tempered windscreen+frame	9,4	34	612	228	"
Corner of laminated windscreen+frame	12,2	44	756	210	"
Corner of tempered windscreen+frame	12,2	44	730	216	"

Table 9 - Hybrid II Separated Head Against Windscreen Impact Severity

c) Accidentological data (table 10) - The accidentological data corresponding to head-to-windscreen impacts confirm the moderate severity of head-to-windscreen impact up to collision speeds of 40 km/h. A lethal head-to-windscreen impact (fracture of the base of the skull) was obtained against a tempered windscreen in a collision occuring at 40-50 km/h. The second lethal head-to-windscreen impact corresponds to a collision at over 100 km/h.

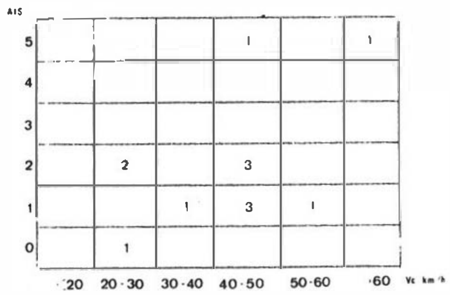


Table 10 - Head Windscreen Impact Severity in Actual Accidents (4)

In view of these results and accidentological data for moped riders (6) the windscreen would appear as the most favourable region of the vehicle as regards head impact.

4.5. Reconstructions of head-vehicle impacts - Study of head-to-vehicle impact by the experimental method raises many problems, the foremost being that of choosing a representative accident with head-to-vehicle impact of a certain violence or severity and for which the accidentological data are complete. One must also ensure that the deformation observed is essentially caused by impact of the head and has not been accentuated by impact of the thorax or any other part of the body. The remaining problems are methodological in nature.

a) Impacts with an experimental separated head - Choice of an experimental head raises the problem of its mass. The results presented in section 4.2. showed that in tests with a dummy, the influence of the neck cannot be neglected. However, the neck of a human subject is not so stiff as that of a dummy and the link between head and thorax could have less importance with respect to impact of the head. The choice of a mass close to that of the head of the pedestrian involved in the accident may represent an initial approximation. However, the question then arises of the signification of injury criteria on a non-standardized head. Furthermore, search for the impact velocity of the head according to the criterion of the deformation observed on the vehicle resides on a good correlation between the deformation of the zone struck and the energy absorbed.

b) Reconstructions with dummies - The reconstruction of a head-to-vehicle impact in a collision between a car and a dummy reouires a number of tests before arriving at an acceptable result. In addition, the stiffness of the neck of the dummy and that of its shoulder in tests where the shoulder touches the vehicle at the same time as the head modify the characteristics of the impact of the head compared with that of a human subject.

c) Collisions using a cadaver - Reconstruction of a collision between a car and a pedestrian using a cadaver calls for a subject the dimensions of which are comparable to that of the pedestrian involved in the accident. A certain number of tests with a dummy and an experimental head will be required to prepare the test with the cadaver. These various questions have not all been answered and tentative reconstructions are necessary in order to clarify problems. It is in such an attitude that a number of the results of reconstructions are given below.

4.5.1. Collision between car and pedestrian - The reconstruction of a collision between a car and a pedestrian involving impact of the head against the bonnet have already been given (8). Microscopical analysis of the brain of the cadaver prepared in accordance with the method of injection used by the Peugeot-Renault Association (12) was not at the time available and are now presented below, together with a brief reminder of the data obtained on a dummy head (table 11).

	γ max. (n)	HIC	t_2-t_1(HIC) (ms)	Bonnet deformation (mm)	Head-Bonnet impact speed (km/h)
Dummy	260	2136	10	52	45
Separated head	160	840	18	53	45
Cadaver	260	4751	10	46	49
Accident				52	

Table i. - Head-Bonnet Impact Reconstruction (8)

The injury on the head of the pedestrian involved in the accident attributed to head-to-bonnet impact consists of a fatal subdural hematoma. The head of the cadaver did not display vascular ruptures in the section examined under a microscope. However, very considerable displacement of the first vertebra could have resulted in fatal injury by respiratory arrest. The higher HIC criteria on the head of the cadaver and that for the dummy matches what is generally observed in equivalent impacts (γ_R measured on the perimeter of the skull, angular acceleration). On the other hand, the lower injury criterion corresponding to longer impact on the separated dummy head is in contradiction to the data of 4.1. and is not amenable to simple interpretation.

The absence of any detectable brain injury coupled to fatal injury to the neck can be related to the corresponding injury criterion on the head of the cadaver: HIC = 4751.

In contrast, one cannot conclude in terms of injury criteria on the dummy head.

4.5.2. Collision between car and moped - A fronto-lateral collision between a Renault 5 type car and a moped involving head-to-windscreen impact was reconstructed with a dummy. From the accidentological data, the speed of the car can be estimated as 40 to 50 km/h, and that of the moped at 10 to 25 km/h. Impact between the head and the fractured tempered windscreen resulted in a head injury of AIS = 2. (non helmeted head)

In the test with the dummy, the car, advancing at a speed of 45 km/h struck the moped which was advancing at 22 km/h. The traces and deformations on the front of the car were comparable to that of the real-life accidents. An impact between the head and the fractured windscreen (HIC = 884) occurred (head-to-vehicle impact velocity: 32 km/h). An impact between the head and the tempered windscreen carried out with a separated head at a speed of 34 km/h displayed a severity of HIC : 508.

An attempt was made to reconstitute this accident with a cadaver. However, the impact of the moped was too off-centre from the axis of the vehicle at the front and the pelvis did not strike the front face, resulting in a more horizontal trajectory of the head and impacts against the upper cross-member of the windscreen (head impact velocity: 40 km/h, HIC = 1370 and γm = 250 g). The injury to the head of the cadaver resulting from this impact corresponds to a fatal injury: fracture of the skull, with very considerable vascular ruptures.

4.5.3. Collision between car and moped - Head-to-bonnet impact occurred in a fronto-lateral collision between car and moped. The speed of the car could be estimated as 40 to 45 km/h from the accidentological data. The injury to the non-helmeted head corresponded to loss of consciousness at an AIS level of 2. The head struck the corner of the bonnet alongside the windscreen about 5 cm from the lines of joint between the wing and bonnet and the wing and scuttle near the shock absorber rod beneath the bonnet, perforating the sheet metal on impact.

An initial test at 32 km/h with the Hybrid II head led to insufficient deformation of the bonnet. Three tests at 40 km/h resulted in deformations comparable to that observed in the real-life accident (40 mm). The corresponding injury criteria are high (see table 12). The stiff sections located a few centimeters from the centre of impact make reconstruction a particularly delicate task. Accordingly, this reconstruction cannot be considered satisfactory, without knowing to what extent the shock absorber rod or lines of joint between the wing, the bonnet and the scuttle were involved in the impact (cf. the scatter of the injury criteria for impacts at the same speed). However, one can conclude that the impact was probably of a severity higher than HIC=1000.

Impact speed (km/h)	γmax. (g)	HIC
32	145	660
40	300	2964
40	220	1920
40	257	3459

Table 12 - Head-Bonnet Impact Reconstruction With a Separated Hybrid II Head.

These few results of a tentative reconstruction emphasize the difficulty of experimental study of head-to-vehicle impact and the need to carry out a considerable number of tests in areas with a complex structures to enable the severity of a head-to-vehicle impact to be assessed in terms of the injury criterion on a dummy head.

5. CONCLUSIONS.

1. Head-to-car impact is said to cause 30 to 40 % of fatal injuries of all pedestrians and almost 30 % of fatal injuries of all moped riders in France.

2. Impact between the head and the lower cross-member of the windscreen frame and scuttle with the pedestrian and impact between the head and the upper cross-member of the windscreen frame with the moped are the main causes of highly serious and fatal injuries with these traffic users.

3. Experimental study of head-to-vehicle impact should enable progress to be achieved in defining the tolerance of the human head to impact and also in defining a specification for the protection of the head.

4. The head-to-vehicle impact velocity is distributed around the collision speed with a certain degree of scatter ($m = 1.02$; $\sigma = 0.24$ in 16 tests with a dummy, 2 tests with a cadaver and 3 tests with a mathematical model).

5. The velocity vector of the head on impact was inclined at an angle of 74° ($\sigma = 14°$) on the surface of the bonnet and 82° ($\sigma = 11°$) on the windscreen in tests with a dummy (16 cases) and a cadaver (2 cases).

6. The injury criteria measured on the dummy head on impact (γmax., HIC) are related to the characteristics of the neck of the dummy. These injury criteria were lower or of the same order of magnitude on the dummy than on the separated dummy head in impact at the same speed.

7. Experimental head-to-vehicle impact data indicate a severity for impact between the head and the tempered or laminated windscreen of less than HIC = 1000 up to an impact or collision speed of 44 km/h, whether this impact can be in the centre or corner of the windscreen. Impacts of the head in stiff zones (windscreen frame, line of joint between wings, bonnet and scuttle) are severe or highly severe above 32 km/h. The severity of head-to-bonnet impact in zones capable of a certain amount of deformation was below HIC = 1000 up to 40 km/h.

8. Study of the head-to-vehicle impact observed in real-life accidents by the experimental reconstruction method in order to show the relationship between injury criteria and head injuries raises questions which have to be answered: the choice of an experimental head and the importance of the link between the head and the thorax. The initial results would show that a considerable number of tests is required to achieve meaningful results in studying any specific impact.

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