INVESTIGATION OF A SERIES OF REPRESENTATIVE EXPERIMENTAL COLLISIONS BETWEEN AUTOMOBILES AND TWO-WHEELED VEHICLES, WITH SPECIFIC ANALYSIS OF SEVERITY OF HEAD IMPACTS.

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ABSTRACT.-

Accidents involving two-wheeled vehicles represent the second most frequent cause of highways fatalities, and this rises the major problem of the protection of drivers of this type of vehicle.

The most representative configurations of automobile-two-wheeled vehicle collisions with regard to the frequency of their occurrence and their gravity have been investigated on the basis of accidentological data gathered on site; certain of these configurations were selected for laboratory simulations. About one score of car-moped crashes were simulated with instrumented dummies, amid conditions that duplicated as accurately as possible those of the real-world accidents, and covering the majority of the most frequently occurring configurations.

The findings overall enabled definition of the kinematics of two-wheeled-vehicle riders in relation with the accelerometric measurements registered during impact; they also enabled pinpointing of the vehicle areas likely to be struck by the head depending on the configuration, and made it possible to draft protective measures with regard both to the riders and to the obstacles encountered. In particular, the typology of the two-wheeled-vehicle riders' head impacts against the front parts of cars emerged as being not basically different from that of the pedestrians' head impacts, and any improvements in this car surface area aiming at pedestrian protection would probably be satisfactory for the protection of two-wheeled-vehicle riders. The solutions should be considered in terms of cost versus effectiveness, but without overlooking the fact that the wearing of a proper helmet constitutes the initial priority, as it is also brought out in the present investigation.

INTRODUCTION.-

To date, the technical progress achieved in the area of highway safety has essentially concerned the protection of individuals who are inside vehicles. Today, the reduction in the numbers of accident victims, all accident causes taken together, points up the relatively large numbers of victims who are exterior to vehicles. In Europe, for example, over 50 % of the highway fatalities involve individuals who are exterior to vehicles (pedestrians, two-wheeled-vehicle riders). In France, for 1979, accidents involving two-wheeled vehicles represented the second most important cause of highway fatalities, with 2,940 killed (i.e. 24 % of the fatal casualties) and 106,000 injured (i.e. 32 % of the total injured)(1)*.The problem rised by the protection of such users is hence very acute. A large number of investigations are necessary for the purpose of improving their protection, because the problems linked to

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(1)* Numbers between parentheses designate references at the end of paper.

their impact kinematics are more complex than for pedestrians. Specifically, the speed of two-wheeled vehicles is often far from negligible as compared with that of cars, and, simultaneously, the impact conditions are extremely varied. In addition, two-wheeled vehicles constitute a heterogeneous array of vehicles: we cannot a priori compare the accidents that involve a fast, heavy motorcycle and a lightweight, relatively slow-moving bicycle. These remarks are also grounds for thinking that the mathematical modelization of this type of crash is no easy matter. These are the reasons for which we performed experimental collisions and, in view of this diversity of situations, we selected collisions corresponding to the problem that seems to be more acute and the most easily solvable at the present time, i.e. accidents involving autocycles and, more specifically, moped-touring car crashes. For the purpose of this investigation, the most representative configurations - at the levels both of frequency of occurrence and of gravity - were selected from the accidentological data. Twenty-two crashes were thus simulated, and have been written up in the present paper.

I - CHARACTERISTICS OF CAR-TWO-WHEELED-VEHICLE CRASHES.-

In France, accidents involving two-wheeled vehicles are the second most important cause of highway fatalities, representing 24 % of the fatal casualties. For the year 1980, it can be estimated that the number of two-wheeled vehicles was around 23 millions, whereas the four-wheeled vehicles represented some 20 millions vehicles (2). These figures underscore the importance of the number of two-wheeled vehicles.

Autocycles are involved in nearly 60 % of the accidents that occur with two-wheeled vehicles, and of all the accidents involving motorized two-wheeled vehicles, 82 % were collisions with passenger cars. Autocycles hence constitute the vehicle category that is by far the most extensively represented in two-wheeled-vehicle accidents.

Analysis of the results of accidentological investigations yields accurate data concerning the circumstances of the accidents. The findings presented are those of the Peugeot S.A./Renault accidentological investigations.

350 accidents occurring between a two-wheeled vehicle and a passenger car were analyzed. In 2 out of 3 collisions, the two-wheeled vehicle came in contact with the front part of the car; this is the most dangerous configuration, since it includes all the fatal casualties in this sample. Collisions involving the rear part of the car were of the least frequent occurrence (about 19 %). Seven main types of configurations were used for classifying the crashes; they are divided into two main groups, as follows:

- collisions without escape: these are cases in which the variation in velocity of the two-wheeled vehicle occurs principally against the car; the risk of head-against-car impact is extremely high in these cases (46 % of the collisions).

- collisions with escape: the victim is thrown off the vehicle without the occurrence of direct head impact; this represents a considerable reduction in risk, since head injuries are by far the most frequent and most serious in this type of riders (26 % of the collisions).

A number of these accidents should be considered separately from the others, in view of the very limited role that the car plays in them: these are side-swipe collisions, which are an extreme case of escape, occurring in the form of the two-wheeled vehicle's sliding against the car, without the occurrence of any major energy exchange, but causing the autocycle's rider to be knocked out to the ground (24 % of the collisions) (Fig. 1). The number of accidents involving two-wheeled vehicle riders being knocked to the ground accounts for 4 % of this type of two-wheeled vehicle car accident.

The diversity of the configurations of the collisions between cars and two-wheeled vehicles and the various kinematics ensuing therefrom justify the experimental simulation of a large number of collisions.

II - THE EXPERIMENTAL COLLISIONS.-

Purpose - Experimental car/two-wheeled-vehicle collisions are a major source of data on the following:

- the possible kinematics of a two-wheeled-vehicle rider during occurrence of collisions;
- the associated levels of acceleration recorded for the sundry body areas.

In addition, they enable the following:

- investigation of the helmet's role and of the level of protection afforded thereby, plus, in liaison with the findings of the biomechanical experimentation, definition of the requirements to be met by a well-designed helmet that would provide satisfactory protection in the majority of the accidents.
- Investigation of protective measures that are either specific or are shared with other user categories, in the light of a data base that enables gauging of the possible influence that could be exerted on the two-wheeled-vehicle rider's kinematics by the introduction of improved safety features onto either the two-wheeled vehicles or the cars.
- Supplying of reference data to accidentologists for evaluating the velocities occurring in accidents in the various configurations.

Testing conditions - In the majority of the simulations performed, the car used was a standard design Renault 5, which is a vehicle widely driven in France. The choice of this single model of car was motivated by concern with precluding a wider scatter of results and with having fairly homogeneous findings for purposes of comparison. However, two tests were performed with a vehicle of a distinctly different profile (tests 1342-1 and 1342-2). At the instant of occurrence of impact, the car began braking with a deceleration of 0.5 to 0.7 g. For a given configuration, several collisions were staged at different speeds, to enable maximum adjustment of the velocity couples listed in the accidentological data. The autocycles used were representative of those most widely found in traffic. In most of the tests, the two-wheeled vehicle was propelled by a sled, thereby recreating the travel preceding the crash; shortly before impact, the two-wheeled vehicle was released from the sled and allowed to roll along the ground.

The two-wheeled vehicle driver was an adult 50th-percentile dummy with a

Hybrid II head. In one case, which was the duplication of a real-world accident, the "driver" was a human subject (MS 77). Test No. 850-1 was also a simulation of this same accident, but performed with a dummy. In certain tests, the two-wheeled-vehicle driver was fitted with a helmet.

The dummy was standardly equipped with accelerometers installed in the head, thorax and pelvis and, depending on the test, in one lower limb just above the knee, on the side of the car's front face.

Several high-speed cameras (300 to 1,000 shots per second) filmed the crash scenes. After the tests, measurements were made of the stopping distances of the vehicles and the dummy, and impact points were recorded, as well as the crush of both vehicles.

For each test, a detailed report was drafted; this report included the following:

- testing conditions,
- summary of the pattern of development of impact and of the principal findings (chronology of the impact),
- detailed layout with measurements of the principal dimensional indications,
- accelerations pertaining to the various body areas,
- trajectories and impact velocities of the head in relation to the vehicle and the ground.

In every case, main emphasis was placed on analysis of the head-impact characteristics as concerned both the kinematics and the impact severity.

The testing conditions are listed in Table 1, by types of configuration. "V1" is the velocity of the car; "V2" is the velocity of the two-wheeled vehicle; "a" is the off-centering between the axis of the car (or of the central pillar, for side impacts) and the direction of the two-wheeled vehicle; and α indicates the angle formed by the directions of the two vehicles (3).

III - THE FINDINGS.-

Investigation of accident severity implies evaluation of the injuries or, in the case of test collisions performed with dummies, evaluation of the injury risk on the basis of the measurements found for the dummy in relation to the kinematics of the impact.

Investigation was carried on by types of configurations, and, since protection of the head is a major problem for accidents involving two-wheeled vehicles, this matter will be dealt with later-on.

For each configuration, we made sure that the impact patterns (braking distances, projection distances, etc...) as well as the vehicle's deformation patterns were comparable to those found in the real-world accidents that had occurred in these same configurations.

Fronto-frontal collisions - Seven simulations were performed for fronto-frontal collisions: for two of them, the trajectories were coaxial, while for the other five, they were oblique, with the two-wheeled vehicle striking the

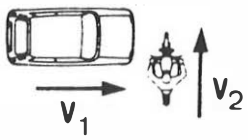
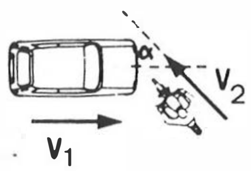
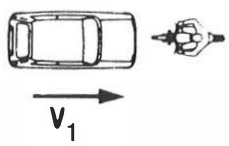
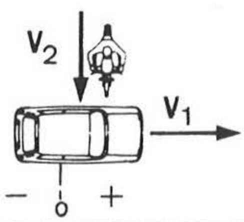
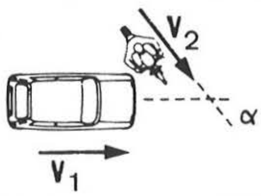
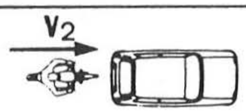
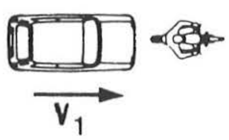
	Test No.	V_1 (km/h) car	V_2 (km/h) moped	a (cm)	α °	Helmet
	752-1	28	0	0	90°	no
	842-1	30	30	0	90°	no
	842-2	30	30	50	90°	no
	850-1	43	21	80	90°	no
	MS 77	42	17	60	90°	no
	1342-1	30	30	40	90°	yes
	1342-2	40	20	60	90°	yes
	1188	32	32	150	90°	yes
	859-1	22	22		30°	no
	859-2	30	14		30°	no
	859-4	22	22		60°	yes
	859-5	30	15		60°	yes
	1187-2	16	32		60°	yes
	842-3	32	0		0°	no
	859-3	50	0		0°	no
	1186-1	33	33	-32	0°	yes
	1186-2	32	32	0	0°	yes
	1186-3	32	32	160	0°	yes
	1190	0	32	0	0°	yes
	1187-1	24	24		60°	yes
	1274	0	35		0°	yes
	1002	48	0		0°	yes

Table 1 - Test conditions for the 22 two-wheeler/car collisions.

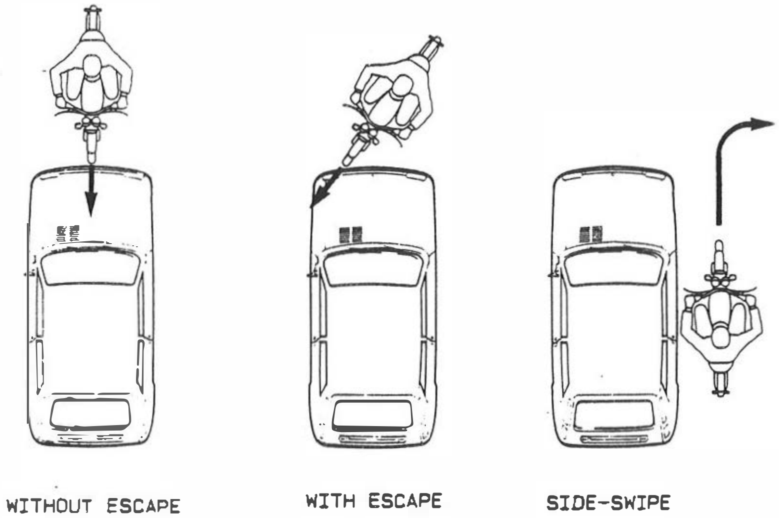


Figure 1 - Classification of the car-two-wheeler collision configurations.

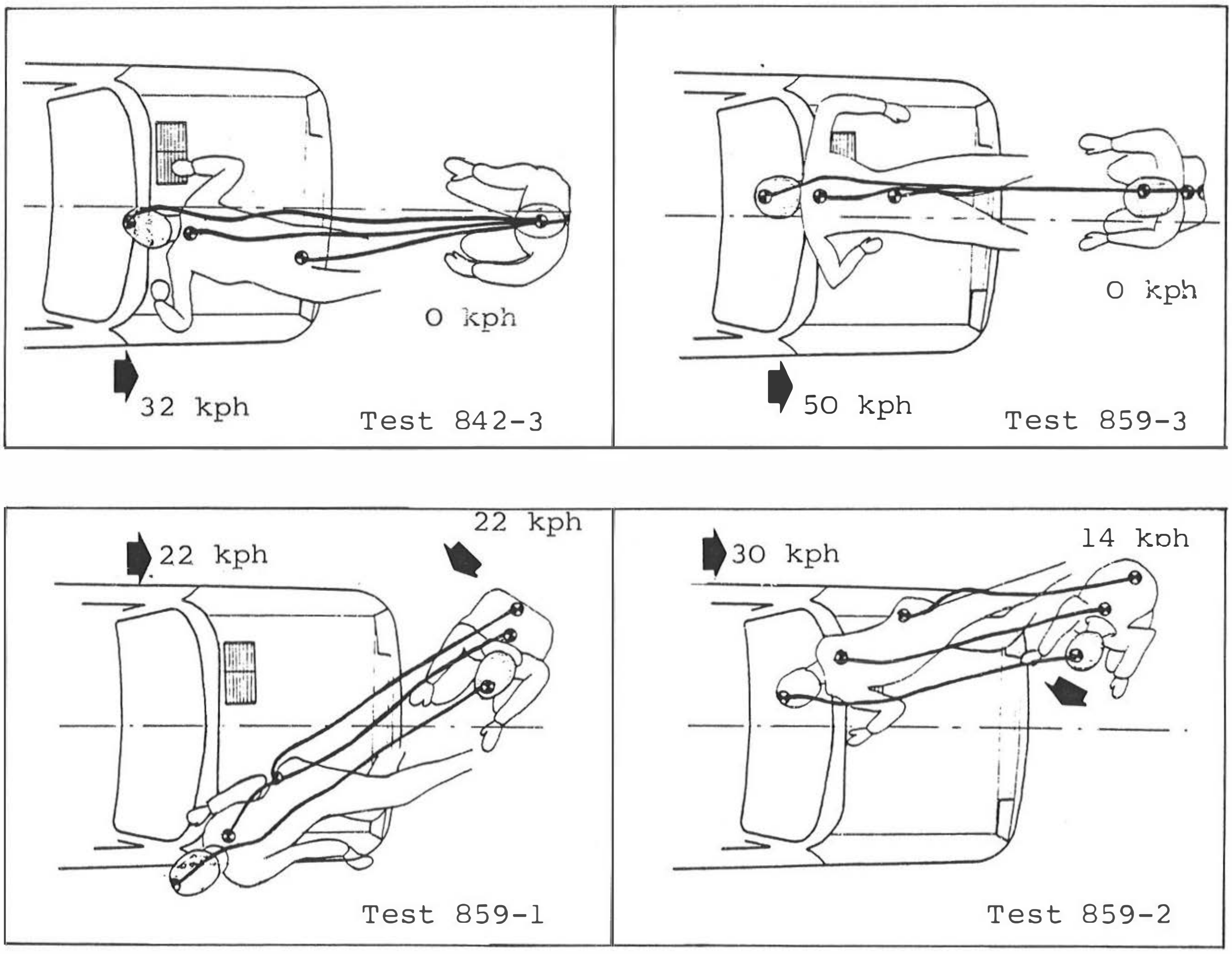


Figure 2

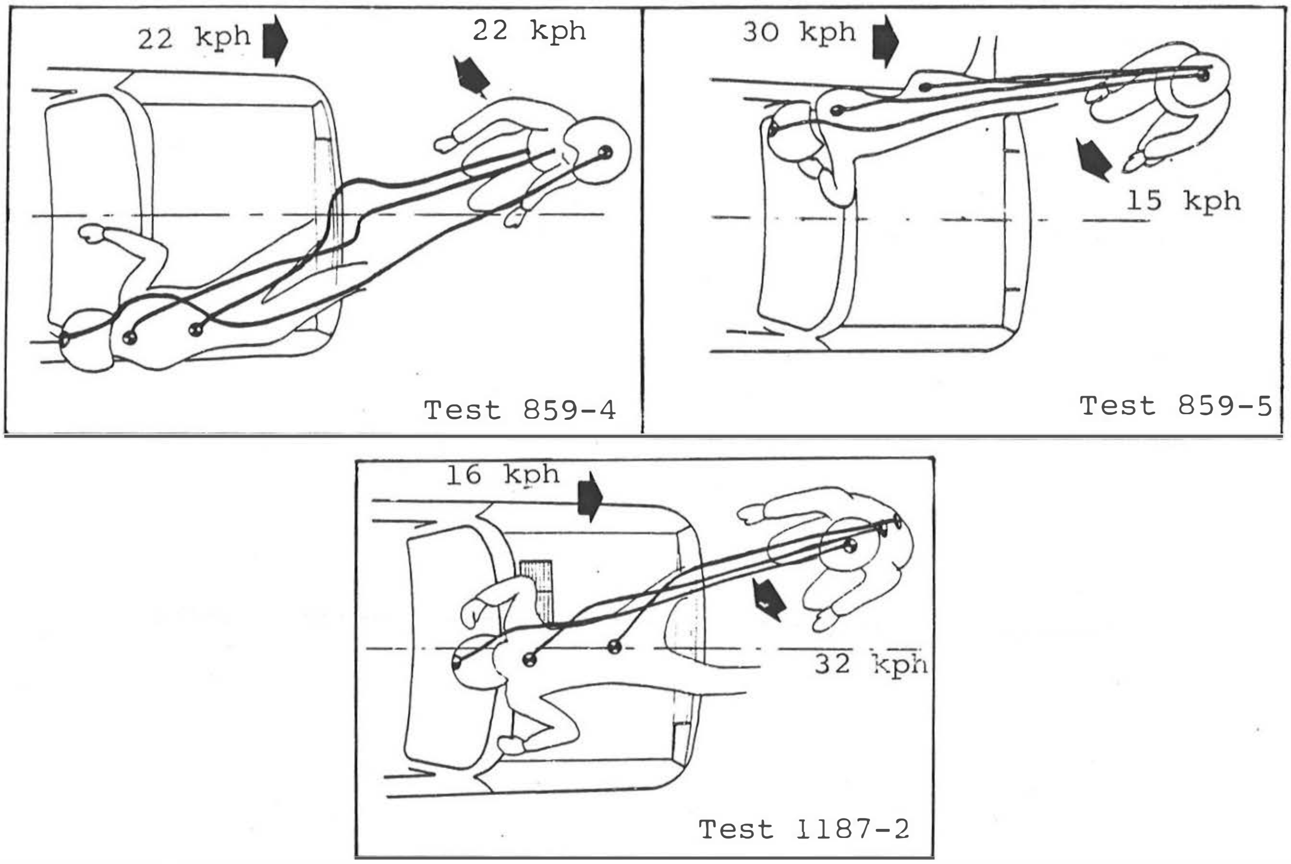
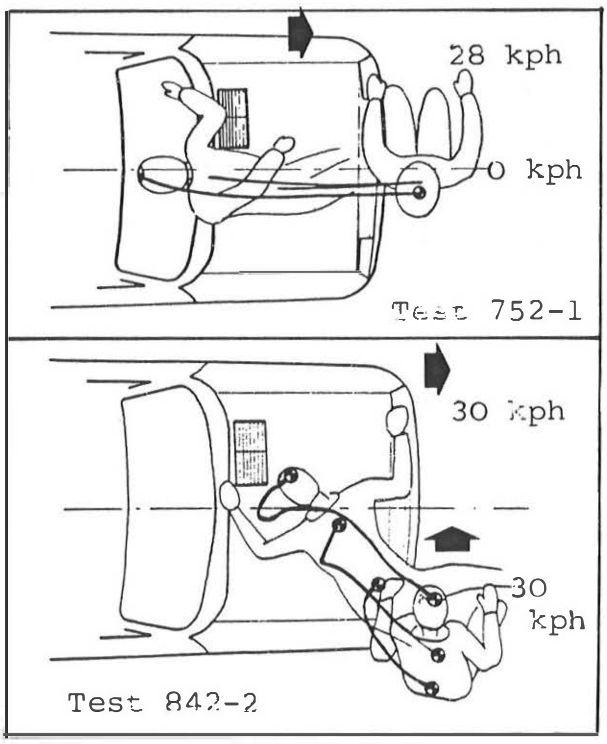


Figure 2 - Kinematics of the dummy in relation with the car for fronto-frontal collisions.



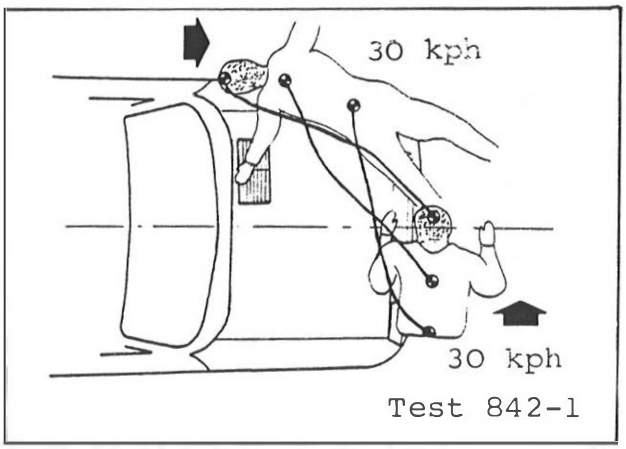


Figure 3

car's front end with a certain incidence angle (30° or 60°). This type of collision accounts for over 35 % of the real-world crashes between cars and two-wheeled vehicles and, in this respect, it is useful to have an experimental reference for this type of crash. If the speed of approach is a parameter sufficient to express the violence of the contact between the car and the two-wheeled vehicle, the dummy's ulterior kinematics depends partly on the velocities of the two mobiles: a collision occurring at 50 km/h x 0 km/h is not strictly the equivalent of a collision occurring at 25 x 25 km/h as concerns projection onto the ground.

The dummy's kinematics were correlated with the physical measurements associated with the impact. These kinematics are listed in Figure 2, and Table 2 summarizes the measurement findings for these seven tests.

Table 2 - Measurement results for impact against the car in fronto-frontal collisions.

Test No.	Resultant velocity (km/h)	Head impact velocity (km/h)	VI/VR	γ max. head (g)	γ max. thorax (g)	γ max. pelvis (g)
842-3		18		75	22	35
859-3	50	26	0.52	58	29	87
859-1		no head impact				
859-2	44	20	0.41	50	19	38
859-4	42	18	0.43	-	15	43
859-5	39	18	0.51	50	24	5
1187-2	32	24	0.75	40	48	70

Since the ground impacts in these simulations induced the occurrence only of head impacts, without the occurrence of pelvic or thoracic impacts, ground impact will be analyzed in relation with the role of helmet.

One collision caused direct impact of the thorax and pelvis onto the car hood, and involved relatively low levels of acceleration (γ thorax = 22 g and γ pelvis = 35 g). The accidentological findings confirm this point. The pelvis and thorax seem to emerge as body areas that are not especially exposed to danger in car/two-wheeled-vehicle collisions of this type. The situation is quite different as concerns the head. In one single case, the head escaped, but head impacts were observed in the other six collisions, most frequently against the windshield. Table 2 shows the correlation between the head's impact velocity and the relative closing speed of the two vehicles, depending on the autocycle's direction, in relation to the axis of the vehicle*.

The head's impact velocity was about one-half the approach speed of the two vehicles. This reduced head velocity can probably be accounted for by the dummy's being thrust into speed by the car. Assuming that the behavior of a

(*) For oblique collisions the relative closing speed is calculated as the sum of the norms of the projections of speed vectors for the car and the two-wheeled vehicle.

human body was accurately simulated by the dummy, two remarks are in order, as follows:

- in this configuration, even an accident occurring at high speed could produce an only moderately violent head impact.
- However, analysis of the real-world accidents showed that this type of accident is generally serious; this can be accounted for by the diversity of shapes of cars and of struck areas, according to this diversity.

Fronto-lateral collisions - In fronto-lateral collisions, the car's front strikes the side of the two-wheeled vehicle; the impacts are off-centered to varying extents in relation to the car's median axis, with the impact kinematics, of course, being influenced thereby. In this series, we included an oblique rear collision (test 1187-1), involving a two-wheeled vehicle and a car moving in the same direction; the dummy's kinematics closely resembled those found in sheerly fronto-lateral impacts. The dummy's kinematics varied widely depending on the test, even when the initial conditions were closely similar. The factors that influenced the kinematics were quite numerous, including the speeds of the two vehicles, pattern of off-centering of the impact, and, in the simulations, the not inconsiderable effect of the interposition of the dummy's arm, an effect which is difficult to assess in real-world accidents and which surely does not have the same consequences.

Figure 3 and Table 3 show the relation between the dummy's kinematics and the physical measurements found for the impacts of the various body areas against the vehicle.

Table 3 - Measurement results for impact against the car in fronto-lateral collisions.

Test No.	Resultant velocity (km/h)	Head impact velocity (km/h)	VI/VR	γmax. head (g)	γmax. thorax (g)	γmax. pelvis (g)
752-1	28	27	~1	155	28	40
842-1	30	no direct impact		43	32	40
842-2	30	interposition of the elbow		140	60	70
850-1	43	30	0.7	90	45	115
1342-1	30	29	~1	65	21	-
1342-2	40	21	0.52	82	26	80
1188	32	50	1.6	117	44	84
MS 77	42	42	1	255*	55	68
1187-1	24	no impact				

* occipital transducer only

Out of the nine tests performed, only three induced chest impacts against the vehicle and only one of these can be qualified as rather violent: γ maximum = 55 g. Analysis of the real-world accidents confirms the low frequency of occurrence of this type of impact in fronto-lateral collisions - only two cases out of thirty-one. As concerns the pelvis, high but short-duration

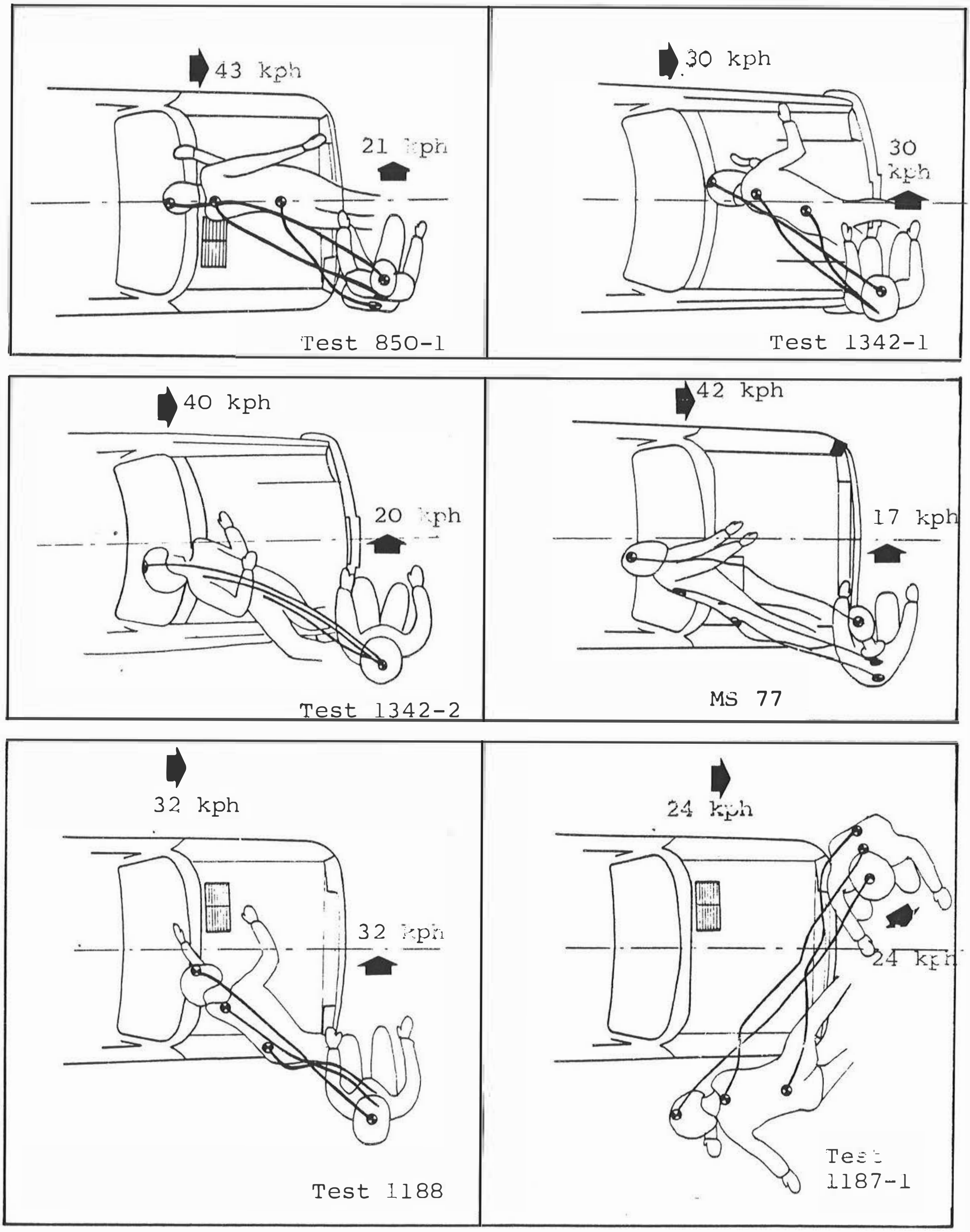


Figure 3 - Kinematics of the dummy in relation with the car for fronto-lateral collisions.

accelerations were found in four cases, but the γ 3 ms did not exceed 50 g; it should be noted that a threshold of tolerance proposed for the pelvis, in terms of acceleration, is 90/100 g during 3 ms (4).

The values obtained are hence compatible with the non-occurrence of pelvic injury. In the real-world of accidents, there occurred no pelvic fracture as the result of the pelvis striking the car for this type of configuration.

The acceleration values for the lower limbs were high whenever there was occurrence of direct impact of the bumper against the leg (from 130 to 170 g at thigh level). Since these values are not clearly related to the risk of occurrence of injury to the lower limbs of accident victims in this type of experiment, these values can nevertheless serve as indicators of violence. However, there is reason to believe that at these impact speeds, fractures of the lower limbs could have occurred, as is observed in real-world accidents, and as were observed in tests at velocities on and after 17 and 24 km/h (5).

Examination of Table 3 shows that, unlike the situation with fronto-frontal collisions, there seems not to be any simple relation between the closing speed of the two vehicles and the impact velocity of the head. The car's speed is not the only parameter to be taken into consideration, since the two-wheeled vehicle velocity has a direct incidence on the occurrence of head impact. A single collision resulted in an escape. In all the other cases, there was the occurrence either of a head impact, either of an interposition of the arm, thereby artificially preventing such an impact. For the two collisions reproduced with the other vehicle, there was no fundamental difference in kinematics except in the occurrence of flatter head trajectories, since this vehicle had a lower, more plunging profile than the Renault 5. Two salient points are noteworthy as regards kinematics:

- the influence of the difference in impact velocities seems to be but slight; when the car is moving at 40 km/h, the head's trajectory is only slightly flatter than at 30 km/h.

- the influence of the initial off-centering on the head's ulterior kinematics seems to be preponderant.

As concerns the influence of the off-centering, it would be useful to establish a comparison with the accidentological observations in order to evaluate whether this parameter has the same importance in the real-world accidents.

Latero-frontal collisions - Four latero-frontal collisions were performed, in which the autocycle impacted the side of the car; in three cases, the two-wheeled vehicle and the car were actuated, with the two-wheeled vehicle impacting the car on more-or-less the latter's front part.

The diagrams of the kinematics are shown in Figure 4, and the measurement findings are listed in Table 4.

In these four simulations, we observed no violent impact of the thorax in terms of acceleration; this fact was due to the off-centering of the impacts in relation to the B-pillar of the car, since in the real-world accidents, we had noted several cases of AIS $>$ 2.

Table 4 - Measurement results for impacts against the car in latero-frontal collisions.

Test No.	Resultant velocity (km/h)	Head impact velocity (km/h)	VI/VR	γmax. head (g)	γmax. thorax (g)	γmax. pelvis (g)
1186-1	33	no	impact	-	-	-
1186-2	32.5	no	impact	-	42	92
1186-3	32.5	30	0.9	190	31	62
1190	32	18	0.56	85	18	30

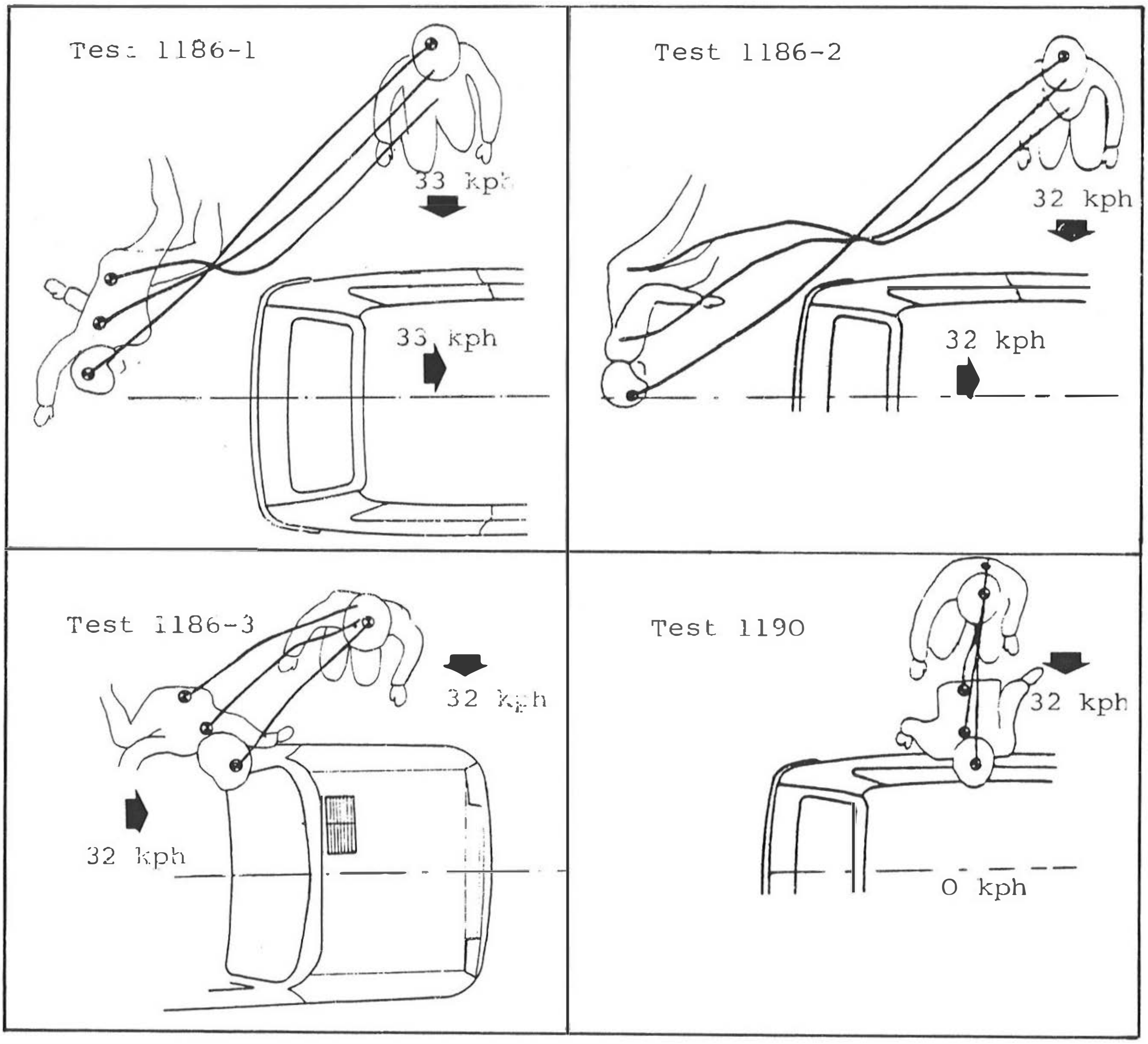
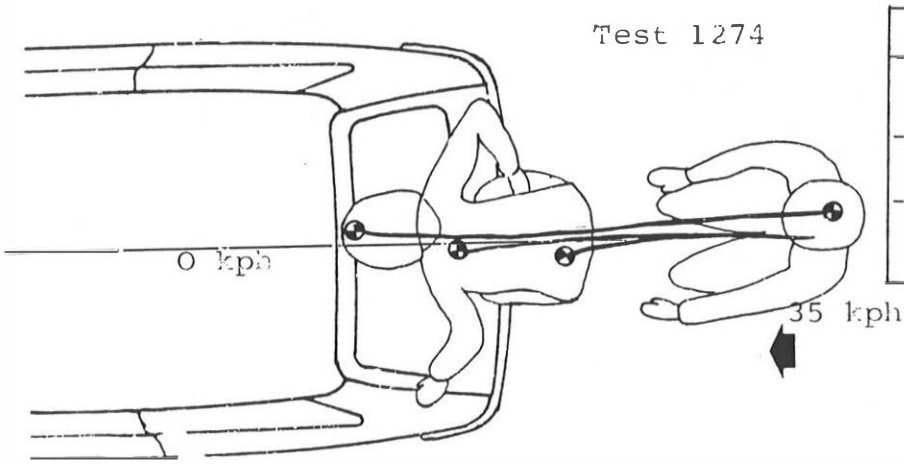


Figure 4 - Kinematics of the dummy in relation with the car for latero-frontal collisions.

There was no occurrence of pelvic impact against the car, and this is in good agreement with the accidentological investigation.

The gravity of the head's impact against the car depends on the kinematics; in two cases, an escape was observed. In a third case (test 1190) with the car stopped, we found the occurrence of a helmeted head's impact against the side drip-rail at a speed of 18 km/h, resulting in a low HIC (230); the helmet, whose frontal part was subjected to impact loading, did its job properly. In test 1186-3, in which the impact was skewed in a forward direction, it was no longer the head that struck the car; rather, the windshield-frame corner of the car, with the latter moving at 8.3 m/s, hit the dummy's temple below the area protected by the helmet, inflicting a high HIC: 1821. In this latter case, impact violence was due to the velocity of the striking car, whereas in the previous case it was due only to the speed of the two-wheeled vehicle prior to impact. This remark leads us to break down the latero-frontal collisions in which head impacts occur into two distincs groups, since the gravity of the injuries sustained in these two groups is different in terms of the type of head impact that they cause.

Other types of collisions - Two additional simulations were performed with a view to ascertaining the kinematics of two-wheeled-vehicle drivers in more configurations. In the frontal collision involving the crash of a two-wheeled vehicle against the rear of a car (test 1274), only the head struck the vehicle at high speed - 29 km/h - the same range of speed as the approach speed. The impact of the helmeted head occurred against the upper rear cross-member and, despite the apparent rigidity of the area struck, the resulting acceleration and HIC were low; this was due to the combined effect of three factors, i.e. the helmet's action in the frontal area, the crushing of the car area struck, and the thrusting into speed by the car, which induced a speed variation of less than 29 km/h for the dummy's head. The kinematics and the measurement findings are given in Figure 5.

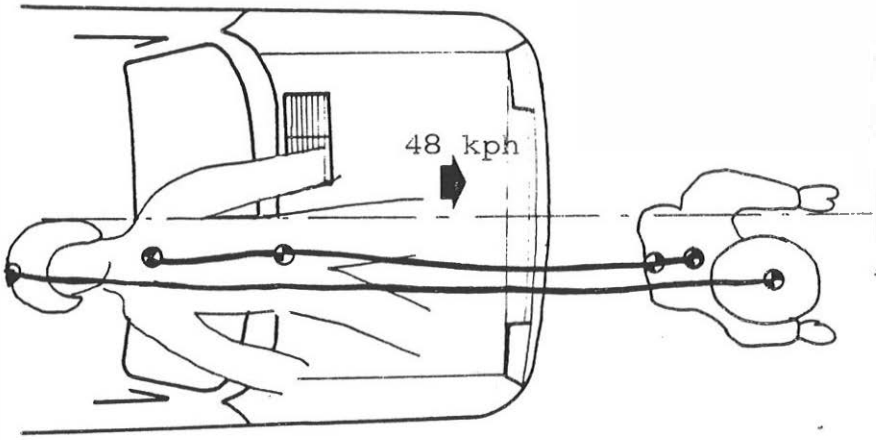


	V kph	γ max	HIC
Head	29	80	156
Thorax		38	
Pelvis		30	

Figure 5 - Kinematics of the dummy in relation with the car for rear-frontal collisions.

A crash involving an autocycle that had been struck in the rear by the front part of a car was also duplicated (test 1002). The kinematics of the impact is shown in Figure 6. The helmeted head struck the car against the upper joint of the windshield. The head's impact velocity was extremely high (50 km/h), but its acceleration was low, because there was actually no direct impact of the head against the roof; the extensive crush of the roof and of the laminated windshield were due to the thrust of the body via the intermediary of the shoulders. The lack of measurements related with the protection of the neck does not enable prejudging of possible injuries at this level; nevertheless such an impact speed is likely to produce severe injuries, which cannot be detected with the neck of the dummy used.

Test 1002



	V kph	γ_{max}	HIC
Head	53	43	70
Thorax		44	
Pelvis		28	

Figure 6 - Kinematics of the dummy in relation with the car for frontal-rear collisions.

IV - ANALYSIS OF HEAD IMPACTS.-

In view of the nature of the tests, for a more detailed analysis of head impact severity, it is necessary to distinguish between impacts against the car and impacts against the ground. In fact, if the ground constitutes in these experimentations a homogeneous obstacle, similar to a noncrushable plane, the same is not true of the car, considering the diversity of the stiffnesses and shapes of the areas struck.

The findings for these impacts are listed in Table 5.

Impacts against the ground - Investigation of head-against-the-ground impacts is delicate, in particular for the evaluation of velocities. In fact, before the performing of a test, it was not always possible to accurately anticipate the localization of the head's impact against the ground; consequently, in certain cases, the impacts occurred in a dimly-lit space and often at the limit of the camera scope. As a result, measurement of head-against-the-ground impact velocities could be fraught with error and should be considered in a critical way. More, the lateral stiffnesses of both thorax and shoulder of the dummy makes that lateral falls of a human being cannot be properly simulated.

Figure 7 represents the HIC values in terms of the velocity of the

Test No.	Head Impact Against the Car: Type	HIC	Velocity (kph)	Impacted area	Head Impact Against the Ground: Type	HIC	Velocity (kph)	Normal velocity (kph)
752-1	parietal	206	27	windscreen	occipital	9	6.1	5.8
842-1	escape	428	-	no impact	interposition of the arm	170	39.6	15.8
842-2	no contact	743	-	interposition of elbow	arm under the head	89	-	-
850-1	top of the head	884	29.5	tempered windscreen	face	1130	28.8	18
MS 77	parietal	1370	41.8	upper cross-member	-	899	-	-
1342-1	parietal	341	29	scuttle	top of the helmet	23	25	16
1342-2	parietal	155	21	windscreen	parietal	317	29	25
1188		639	50	bonnet - interposition of the arm	parietal	1650	25	22
859-1	no direct impact				occipital	99	-	-
859-2	top of the skull	170	20	windscreen	parietal	57	32.4	9
859-4	front	14	18	bonnet	top of the skull	21	12.6	9.4
859-5	front	105	18	windscreen	parietal	203	18	17.2
1187-2	front	113	24	windscreen	-	52	-	-
1186-1	no impact				occipital	484	31	18
1186-2	" "				occipital	798	27	22
1186-3	right temple	1821	30	upper joint of windscreen frame	no impact			
1190	front	230	18	side-drop-rail	no impact			
842-3	frontal	129	18	lower cross-member	facial	427	19	12.6
859-3	frontal	230	26	laminated windscreen	parietal	134	25	14
1187-1		(5) no head impact				(13)	no head impact	
1274	frontal	156	29	upper cross-member of back window	the dummy fallson his back	202	23.5	20
1002	occipital	70	53	upper joint of windscreen frame	occipital	33	-	-

Table 5 - Conditions of head impacts and corresponding measurement results for head impacts against the car and against the ground.

head's impact against the ground, for both helmeted and non-helmeted dummies. On the abscissa, there is also indicated the equivalent falling height that induces the same impact velocities, on the one hand in order to gauge the vertical speed thrust induced by the impact against the vehicle and, on the other hand, in order to compare with the fall heights of the fake helmeted heads provided for by the existing norms (1.83 m and 2.4 m). This figure permits the observation of two facts, as follows:

- in the sample considered, and within the limits of the accuracy of the

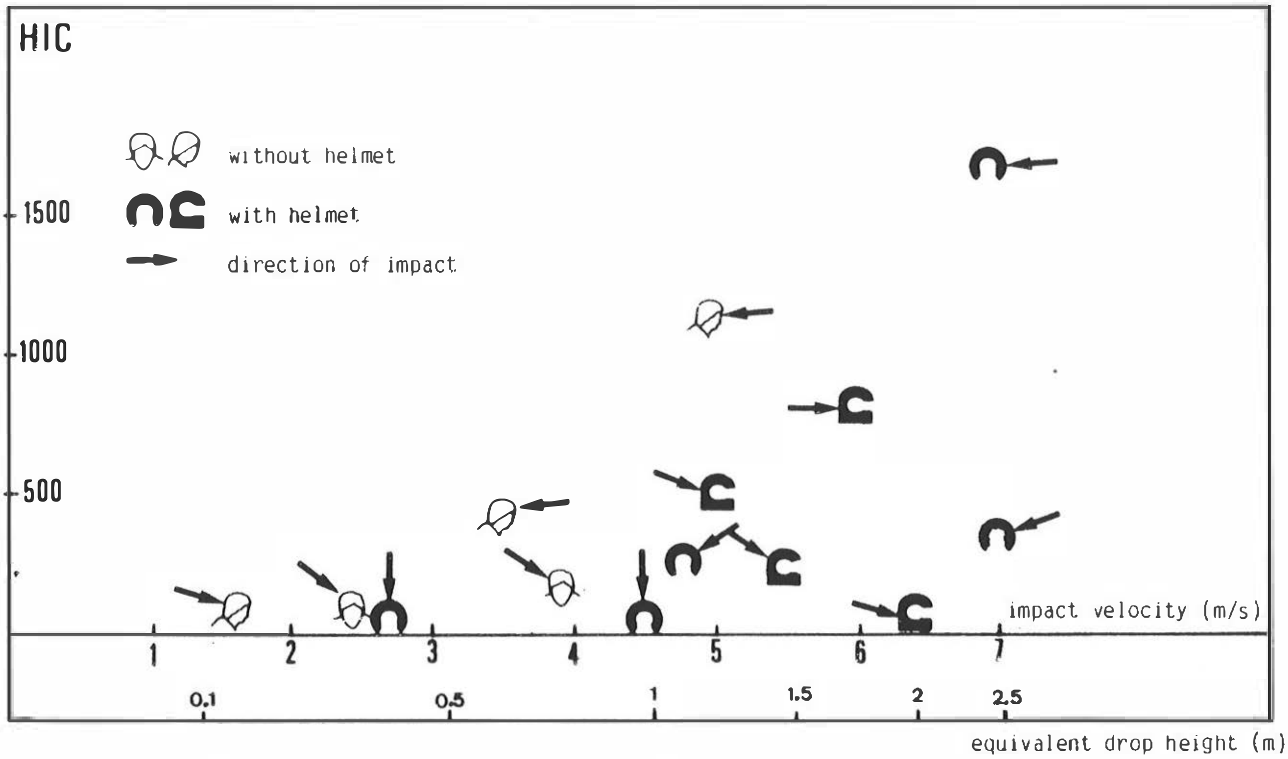


Figure 7 - HIC versus head impact velocity at impact against the ground.

measurements, there emerges a positive effect of the helmet.

- Once again, we find the influence exerted on the measured HIC values by the impacts occurring against the edges of the helmet. For a stated impact velocity, we note an increased HIC when we move away from the top of the skull, the most vulnerable areas being those located on the borderline of the shock-absorbent material in the temporal area. This confirms the fact that a reliable helmet should have a high impact mitigating capacity in the temporal area. Laboratory tests performed with dummies had yielded the same conclusions: the "edge effects" must be reduced.

More generally, and unlike the most severe car/pedestrian collisions, the head-against-the-ground impacts were more severe in terms of HIC than the head-against-the-car impacts, despite the moderate vertical velocities. This may possibly have been due to the detrimental effect of the velocity at which the dummy slid across the ground surface.

It is significant to note that although head-to-helmet relative movements were frequently observed, the helmet fastening system never failed.

Impacts against the car - Interpretation of the findings of the head-against-car impacts had to take into account the diversity of the areas struck.

Figure 8 synthetizes the findings recorded for head-against-car impacts. The areas impacted are indicated and correlated with the impact conditions (velocity of the head) and the consequences thereof (HIC).

Because of the difficulty of evaluating the stiffness of the areas

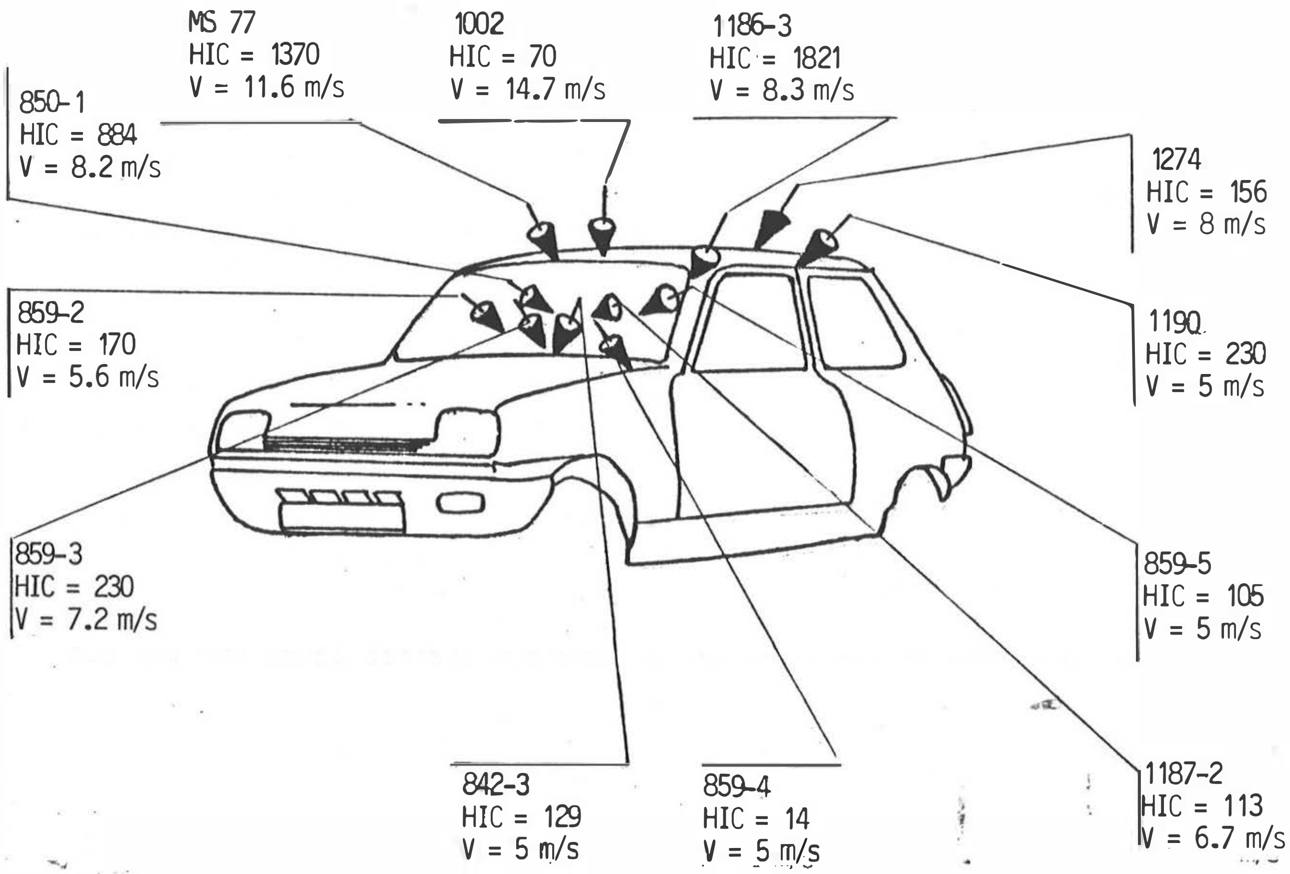


Figure 8 - Relation between impacted areas, head impact velocity and severity (in terms of HIC).

struck, no clear correlation emerges between these three parameters. However, it can be noted that the windshield emerges as the least dangerous area for the head (even at the relatively high impact speed of 7.7 m/s). Impacts against the hood also yielded low HIC values; the highest HIC values resulted from the two impacts against the windshield frame. The effect of the helmet cannot be appreciated on the basis of this sample, since the areas impacted are not identical for the tests performed with and without helmets.

In the current state of progress, the data assembled are primarily of obvious value for determination of the velocities of head-against-car impacts; in the tests performed, these velocities were consistently under 50 km/h, and in most cases were 35 km/h, for both types of vehicles.

When the car's front part was involved (fronto-frontal and fronto-lateral collisions), the head's impact velocity was not always linked to the approach speed. Besides, both the kinematics and the velocities of the head in the vehicle's longitudinal plane may be compared to those yielded by the simulations of pedestrian-against-car impacts. There is hence reason to believe that the findings for head-against-vehicle impacts yielded in collisions involving pedestrians are transferable to car-against-two wheeled-vehicle collisions as concerns the more or less aggressive character of the areas most frequently struck (6)(7).

As concerns the other areas of the car, the problem is different: in most cases, impact violence is solely a matter of the velocity of the two-wheeled vehicle prior to impact, with the speed of the car influencing the occurrence or nonoccurrence of this impact.

In conclusion, one of the foremost findings of this investigation of head-against-car impacts is that, in many cases, for the purpose of processing their data, the types and velocities of these impacts can be combined with those observed in the simulations of car-against-pedestrian crashes.

V - PROTECTIVE MEASURES.-

At the conclusion of such an investigation, it is important to anticipate the measures that might be devised for the protection of two-wheeled-vehicle riders.

Although it is not the purpose of this paper to deal with accident prevention measures, it still allows us to note - without taking cost into account - the undeniable fact that the benefit which may be expected from improved passive safety is a priori more limited than the benefit to be gained from such measures as the creation of separate traffic lanes for the two-wheeled-vehicle traffic.

As regards secondary safety only, in terms of cost/effectiveness, two kinds of measures can be distinguished, i.e. those aimed at improving the safety of two-wheeled-vehicle riders and those that may also be beneficial to pedestrians.

Equipment of two-wheeled-vehicle riders - At present writing, the only compulsory passive safety equipment for two-wheeled-vehicle riders, is the helmet. It should be borne in mind that the head is the body area most exposed to damage, and that the wearing of a helmet is an essential condition governing the safety of two-wheeled-vehicle riders. To this end, the findings yielded by the present investigation and, in particular, knowledge concerning head impact velocities, can serve as reference data for drafting helmet specifications for these users. Since these velocities were in most cases moderate - and were in all cases under 35 km/h - there is reason to believe that with identical performances, a helmet for autocycle rider could be as a whole more efficient than a helmet for a motorcyclist, for whom impact velocities can be extremely high.

With regard to other equipment, specifically as concerns the lower limbs, few investigations have been carried out. Protection by means of shock-absorbent materials might be expedient, bearing in mind, however, that prevention of fractures can involve the use of a considerable volume of materials, scarcely compatible with the kind of use afforded by light two-wheeled-vehicles.

Equipment of two-wheeled vehicles - No reference data are available concerning the effects of safety equipment for two-wheeled vehicles. The TRRL has carried on investigation of equipment for motorcycles, designed to provide protection in the event of the occurrence of frontal impacts (8).

As concerns autocycles, to the best of our knowledge nothing is available, and it is fairly a delicate matter to consider improvements designed for such light-structured-vehicles.

Analysis of the experimental collisions reported on in this paper shows that autocycles play a minor role in the dummy's kinematics after the initial impact. In frontal impacts, the coupling between the rider and his autocycle could bring about dangerous interferences between the two-wheeled vehicle and the rider's abdomen: such occurrences were observed in certain tests in which the autocycle's trajectories were closely parallel, but the absence of measurements in relation with an abdominal protection criterion (penetration, force) prevents us from assessing the risk of injury at this level in these tests; however, it does seem likely that an accident victim who was involved in conditions similar to those of certain tests would have sustained abdominal injuries.

In conclusion, the equipment for two-wheeled vehicles of whatever nature will have to be tested so as to prove, on the one hand, that the anticipated benefit actually exists and, on the other hand, that the risk of injury has not been transferred from one body area to another, with no overall benefit to the accident victim.

Improvements to passenger cars - When the front face of passenger cars is involved in the impacts (fronto-frontal or fronto-lateral configurations), as it was in over 65 % of the car-against-two-wheeled collisions, it is reasonable to feel that any improvement to this part of the car designed for the protection of pedestrians cannot fail to be of benefit to autocycle riders, with the action of the helmet enhancing the protective effect here. On the other hand, the possible improvements to other areas (rear, side) could be achieved for the benefit of two-wheeled-vehicle riders only. The problem is more general and does not concern the vehicle alone; rather it concerns all the obstacles that are likely to be struck on the public highways.

This latter motive clearly shows that the protection of two-wheeled-vehicle riders involves primarily the wearing of an efficient helmet, for it seems unrealistic to reduce the aggressivity of all the obstacles on the public highways, of whatever nature (passenger cars, commercial vehicles, features of the highway environment, etc.)

The protection of the other body areas seems more problematical and delicate. Thus, any item of equipment designed either to couple the rider and the two-wheeled-vehicle together or to reduce the violence of impacts against the lower limbs will have to be subjected to specific, real-world scale investigations that will test its harmlessness and efficacity.

CONCLUSIONS.-

22 experimental collisions between cars and autocycles were performed under conditions that were of maximum similarity to those of real-world accidents and were representative of the latter to a maximum extent. The array of findings yielded by this investigation enabled improved definition of the user's kinematics in relation to the accelerometric measurements recorded during occurrence of impact.

- If these collisions are compared with car-against-pedestrian collisions, we find that additional degrees of liberty are introduced, thereby resulting in an extremely wide variety both of the two-wheeled-vehicle driver's kinematics and of the areas struck by this driver; virtually all areas of the car are likely to be struck.

- It was difficult to interpret the head-against-car impacts because of the variety both of the areas struck and of the impact velocities; the latter are essential data for optimizing protection of the head in the occurrence of collisions between cars and autocycles. The main findings are as follows:

. In the event of a centered or oblique fronto-frontal collision, the head's impact velocity is about one-half the vehicle's closing speed, but there is a high risk of head-against-car impact for this type of collision, and it occurs against car areas that are also involved in pedestrians' head impacts.

. In fronto-lateral collisions, the head's impact velocity varies between 0.5 and 1.5 times the vehicles' closing speed.

. For collisions against the rear or the side of the car, when the head strikes the car, the head's relative velocity is about that of the autocycle prior to impact.

- The factors favorable to the autccycle rider's undergoing travel without head impact were identified as follows:

. When the autccycle is struck on its side, the velocity of the autocycle and its off-centering in relation to the car's axis during occurrence of collision reduce the risk of head impact.

. When the autocycle strikes the side of the car, only those impacts that are considerably offset toward the front of the car, at speeds that are similar for both the two-wheeled vehicle and the car, result in head impacts.

-All the head-against-ground impacts occurred at velocities whose vertical components were lower than or equal to 20 km/h. The onset of velocity of the autocycle driver because of the speed of the two-wheeled vehicle is revealed more by the existence of a strong horizontal component of the head's velocity at the moment of impact against the ground (up to 20 km/h). This is the reason for believing that a properly designed helmet affords effectual protection against the skull fractures and brain concussions that can ensue from falls against the ground in the cases of the collisions reported on here.

-In general, the thorax and the pelvis seemed to be relatively unendangered, a fact that was confirmed by the low frequency of occurrence of injuries to these body areas of the autocycle riders in the real-world accidents.

-The protective measures that can be envisaged for autocycle riders may be classed in two categories, as follows:

. effective utilization of an efficient helmet for head protection,
. improvement of the car surface areas that are the most frequently struck, noting that the typology of the head impacts occurring against the front part of the car is not fundamentally different from that of the head impacts of pedestrians.

-The analysis of vehicle crush and of impact diagrams yielded by these test collisions can serve as reference data for the accidentologists.

At present writing, this investigation constitutes an experimental approach that yields a fairly comprehensive survey of car-against-autocycle collisions; however, additional investigation will be necessary if we are to better perceive the realities of accidents involving two-wheeled vehicles.

- Certain highly particular configurations could be analyzed and the range of impact violence could be extended.

- Virtually, all the tests were performed with the same car; testing with other cars would enable us to control and complete the findings.

Unlike the car-against-pedestrian collisions, the approach to this type of collision by means of a mathematical model seems not appealing, in view of the diversity of the configurations, and especially in view of the need for tridimensional analysis.

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