Development of a Head Impact Test Procedure for Pedestrian Protection

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1 Accident Statistics

About 10,000 or 20% of the traffic fatalities in the countries of the European Community are pedestrians [1]. The EEVC WG 7 Report [2,3] gives a detailed description of the pedestrian accident situation in Europe. For a more recent and more detailed analysis the accident statistics of the Federal Republic of Germany (before Oct. 90) was analyzed.

In the Federal Republic of Germany the number of persons killed in pedestrian accidents dropped from 1970 from about 6,000 to about 1,650 in 1989. The overall fatality rate (the number of fatalities per 100 injured),dropped in the same period from 7,3 to 4,0 (Table 1) while the car population doubled, from 14 to nearly 30 million vehicles [4].

Table 1: Number of pedestrians killed and injured in the Federal Republic of Germany

	1970	1975	1980	1985	1989
fatalities	6,056	3,974	3,095	1,790	1,651
injuries (fatal, major, minor)	83,505	64,006	59,546	45,181	41,448
overall accident severity (fatalities/100 injured)	7.3	6.2	5.2	4.0	4.0

The number of children under 15 years killed in pedestrian accidents dropped sharply and steadily from 1,290 in 1970 to 160 in 1989. Whereas the percentage of children under 15 years involved in all pedestrian fatalities was still 20% in 1970 , it was only 10% in 1989. The proportion of elderly pedestrians killed in the same time period rose from about 40% to 50%, although the absolute number also dropped from 2,509 in 1970 to 826 in 1989. Both age groups are now at a comparable size of 9 Million people.

It can be stated for both age groups, that about twice as many people died as pedestrians than as car occupants. Apart from the general downward trend in the number of killed and injured persons in pedestrian accidents in the

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Federal Republic of Germany, a shift in age distribution - from children to the elderly - in the pedestrians involved in accidents has taken place. In the case of the elderly, however, the risk of being killed in a pedestrian accident is about 6 to 7 times higher than for children due to higher mortality.

If the age distributions for men and women are combined , each with the height distribution of the German population [5,6], a height distribution for fatally injured and injured pedestrians can be obtained. Figure 1 shows the height distribution of injured pedestrians.

50. percentile, n = 43574

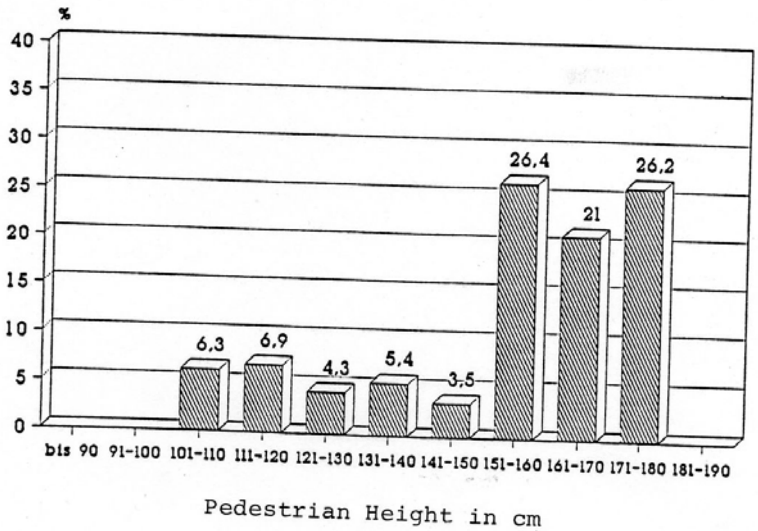

Figure 1: Height distribution in % of injured pedestrians, FRG 1988

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2. Pedestrian Head Injuries

2.1 Description and Distribution Head Injuries

The human head can be divided into different zones - the skin and soft parts, the bony skull and the brain - each with its specific injuries.

In the AIS scale, the boundary between reversible and irreversible damage is between AIS 2 and AIS 3. The border between injuries endangering life and not endangering life can assumed between AIS grades 3 and 4.

A special evaluation of the accident material of the Hannover Medical College (Accident Investigation Team) relating to pedestrian head injuries was made at the beginning of the research project and an extract is given here. [7] The vehicle impact speeds recorded in the sample seem to be a bit higher in the selected pedestrian accident cases than in reality.

The material consists of 522 cases of pedestrian accidents with an impact on the front of a passenger car. The age distribution was:

- 41% children < 14 years
- 39% adults > 14 years and < 65 years
- 20% elderly persons > 65 years

The MAIS distribution is shown in Table 2.

	TOTAL	children	adults	elderly
uninjured	1.2	1.9	0.6	-
MAIS 1/2	61.7	75.1	57.0	45.1
MAIS 3/4	25.9	14.7	30.2	36.1
MAIS 5/6	11.3	6.2	12.2	18.9
among them deceased	15.0	3.3	13.9	36.9

Table 2: MAIS - Distribution in %, Pedestrian Accidents, MHH

For these injured pedestrians in the sample the following height distribution is given in Figure 2 with a comparable scaling as in Figure 1.

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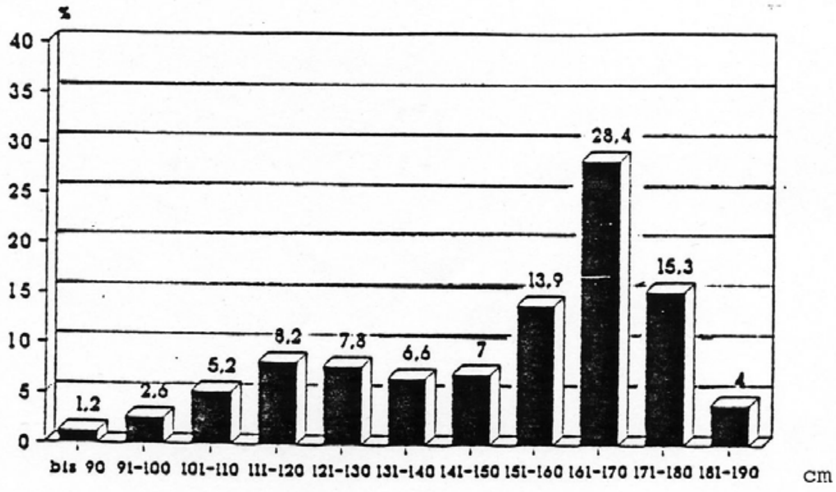
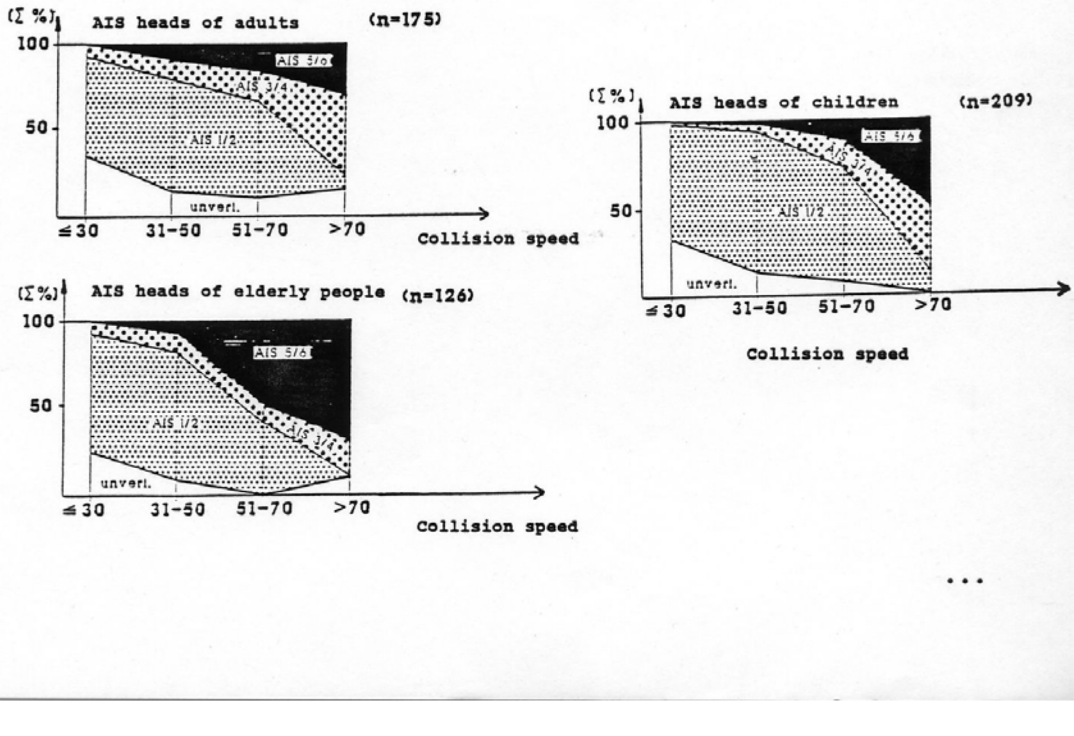


Figure 2: Pedestrian height distribution in MHH Sample n=503

Elderly pedestrians more frequently sustained more serious injuries than children, and the mortality rate is much higher.

AIS 5/6 head injuries occur at over 30 km/h and are very frequent at over 50 km/h especially among elderly persons. The AIS head injury distribution for people in different age groups are shown in Figure 3.

Figure 3: Cumulative frequency of AIS - head injuries in relation to collision speed for different age groups



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In the speed range of relevance for the test procedure, viz. 30 - 50km/h, a distinction is made between injuries to head bones and brain, Table 3.

	Total	Car Velocity			
		below 30	31 - 50	51 - 70	over 70
Total persons (n)	528	147	246	100	35
incl. head injuries					
none	61.9%	84.4%	64.6%	31.0%	37.1%
isol. facial frac	1.5%	4.3%	-	1.4%	4.5%
isol. skull frac.	4.0%	-	2.3%	5.8%	9.1%
isol. brain trauma	70.1%	87.0%	80.5%	63.8%	31.8%
face + skull	1.0%	-	-	1.4%	4.5%
face + brain	9.0%	-	6.9%	8.7%	27.3%
skull + brain	6.5%	8.7%	6.9%	2.9%	13.6%
face + skull + brain	8.0%	-	3.4%	15.9%	9.1%
children total (n)	213	63	102	39	9
incl. head injuries					
none	66.7%	88.9%	67.6%	33.3%	44.4%
isol. facial frac	-	-	-	-	-
isol. skull frac	2.8%	-	3.0%	3.8%	-
isol. brain trauma	81.7%	85.7%	88.0%	80.8%	40.0%
face + skull	-	-	-	-	-
face + brain	7.0%	-	3.0%	7.7%	40.0%
skull + brain	2.8%	14.3%	3.0%	-	-
face + skull + brain	5.6%	-	3.0%	7.7%	20.0%
Adults total (n)	308	83	140	60	25
incl. head injuries					
none	58.1%	80.7%	61.4%	30.0%	32.0%
isol. facial frac	2.3%	6.3%	-	2.4%	5.9%
isol. skull frac	3.9%	-	1.9%	4.8%	11.8%
isol. brain trauma	64.3%	87.4%	75.9%	54.8%	29.4%
face + skull	1.6%	-	-	2.4%	5.9%#+
face + brain	10.1%	-	9.3%	9.5%	23.5%
skull + brain	8.5%	6.3%	9.3%	4.8%	17.6%
face + skull + brain	9.3%	-	3.7%	21.4%	5.9%

Table 3: Breakdown of head injuries by isolated fractures and isolated brain traumas and by combined injuries - for children and adults

The high share of isolated brain traumas seemed to justify a measurement of the resulting acceleration and a calculation of the HIC for a test procedure, although higher levels of severity often involve a combination of fracture and brain trauma.

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Car/pedestrian accidents at high collision speeds often result in pedestrian head impacts on windscreens. The likelihood of head impacts on windscreens has also become more widespread in recent years due to the installation of the engine in a position across to the direction of driving and the shorter length of the bonnet of European cars.
The max. possible wrap-around length up to the windscreen for the 20 vehicles most often encountered among new registrations in Germany was measured (~ 60% of the total) [17]. The mean value was 1.8m and the min. and max. values approx. 1.6m and 2.0m resp. These values can differ if account is taken of the braking diving of the vehicle and the sole and heel height of the pedestrian's shoes.

When account is taken of the height distribution for pedestrians above and the ratio of body height to wrap-around distances, it becomes clear that impact on the windscreen is possible or probable for an adult pedestrian upward of 1.7m in height for a speed range of 30 - 50km/h, (Fig. 4).

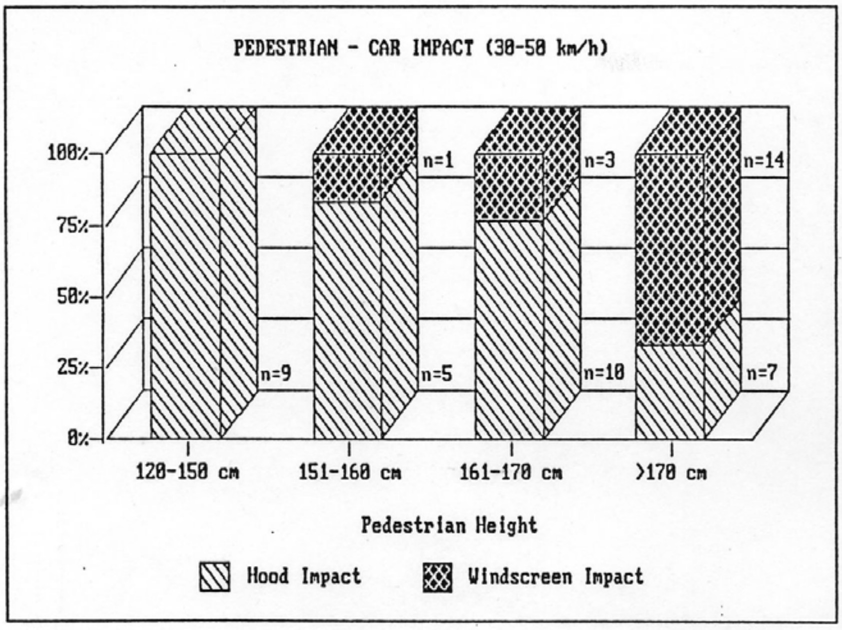

Fig. 4: Head-Bonnet and Windscreen Impacts vs. Pedestrian Height Speed Range from 30 - 50 km/h (Figures from [7]

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A special analysis was carried out for pedestrian accidents with head-to-windscreen contact, showing that cuts (incl. eye injuries) occur almost entirely in the case of tempered safety glass, while obtuse traumas tend to occur more in the case of laminated glass. [9]

Some tests were carried out with leather-lined dummy heads being dashed at 30 km/h against tempered safety glass and laminated glass windscreens for one and the same vehicle which showed the same results. [10]

2.2 Literature on Pedestrian Cadaver Head Impacts

To obtain a frame of reference for pedestrian head impact test conditions, it is necessary to know the impact points, impact speeds and impact angles for the pedestrian heads. To this end, all the above data were taken, wherever possible, from different literature and plotted in graphs.

Plotting the wrap-around length L and the pedestrian height H reveals an accumulation of L/H values between 1.1 and 1.2, as shown in Fig. 5. This is in agreement with the not differentiated cadaver test data in [16].

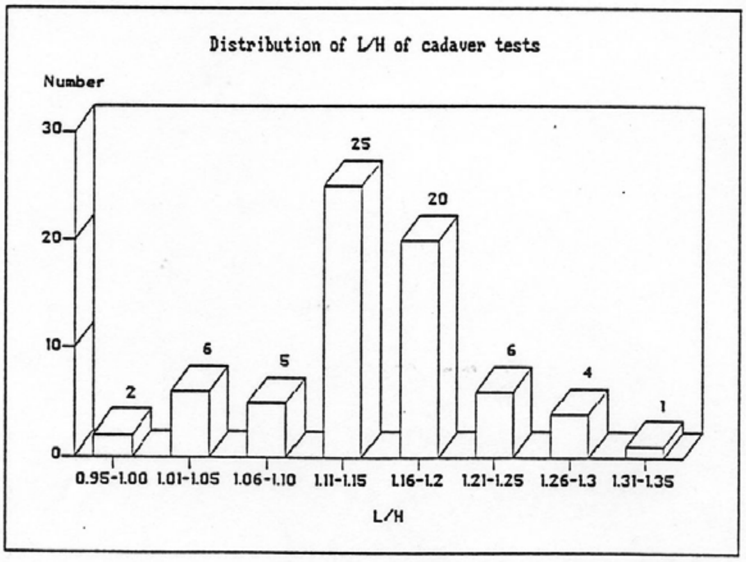

Figure 5: Distribution of L/H of Cadaver Tests and Real Accident Cases from Different Literature Sources [n = 69]

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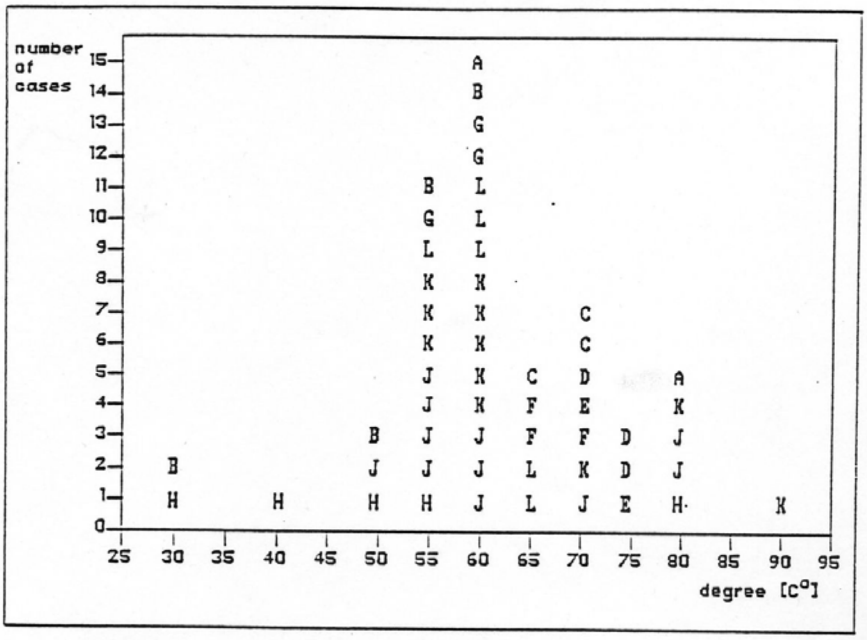
The head impact angle can only be obtained from films of cadaver tests. Fig. 6 shows the angle of impact taken from the literature. This shows an accumulation of cases for a head impact angles of 50° to 80° in the case of adults.

The impact angle for children's heads can only be obtained from mathematical simulation, e.g. [17] or from dummy tests because of the lack of child pedestrian tests.



Cadaver Standing Position	Car
A = facing sideways B = facing sideways	Audi 100 Citroen GS
C = facing sideways D = ? E = ? F = ? G = facing backwards	Citroen GS Audi 100 Renault R4 Peugeot VW Golf
H = facing backwards	MB
I = frontal K = facing sideways	Div. Div.
L = facing sideways	Audi 100

Figure 6: Head impact angles from cadaver tests in literature

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The literature [16] shows that the head impact speed v_H - related to the collision speed v_O - has a considerable scatter and values v_H/v_O of 0.5 - 1.5 and even more are possible. An evaluation of other literature, too, shows that a v_H/v_O value of 0.8 - 1.4 can be expected. [15,21,22,23] This scatter is due in part to the arm support on the bonnet in cadaver tests. Without arm supports we could assume an v_H/v_O value of approx. 1.2 [15] in the case of pontoon-shaped vehicles and even higher values in the case of wedge-shaped vehicles, are possible. Here again, the head impact speed for children can only be obtained from mathematical simulation or dummy tests but these seem more to be in the range of the cars impacting speed. The above remarks apply to the impact speed range of 30 - 50km/h under consideration here.

3. Test Method Development

3.1 Head Impactor Propelling System

The impactor test rig of the BASt was developed to conduct component tests, e.g., to simulate head impact in pedestrian accidents. The system is process-controlled and performs a linear acceleration via an impact piston on which the test specimen is fastened by a holding system. The pressure required for the preset target velocity is generated by a pump in a piston accumulator, which accelerates the piston to the required speed. The hydraulic system can be run in two different test modes. In the "guided flight mode", the specimen is fastened to a carrier frame and the frame onto the obstacle. In the "free flight mode", specimens can be detached from the holding system and allowed to strike the obstacle freely.

The max. speeds and dimensions are:

v_{max} = 50 km/h m_{min} = 4 kg m_{max} = 40 kg

In the free flight tests, e.g. the head impact tests, the specimen is held by an electromagnet and released at the time of chosen velocity. With the test rig, the direction of catapulting can be arrested in a range between vertical and horizontal position. An electric drive permits vertical adjustment of the system to the outer dimensions of various vehicles, Fig. 7.

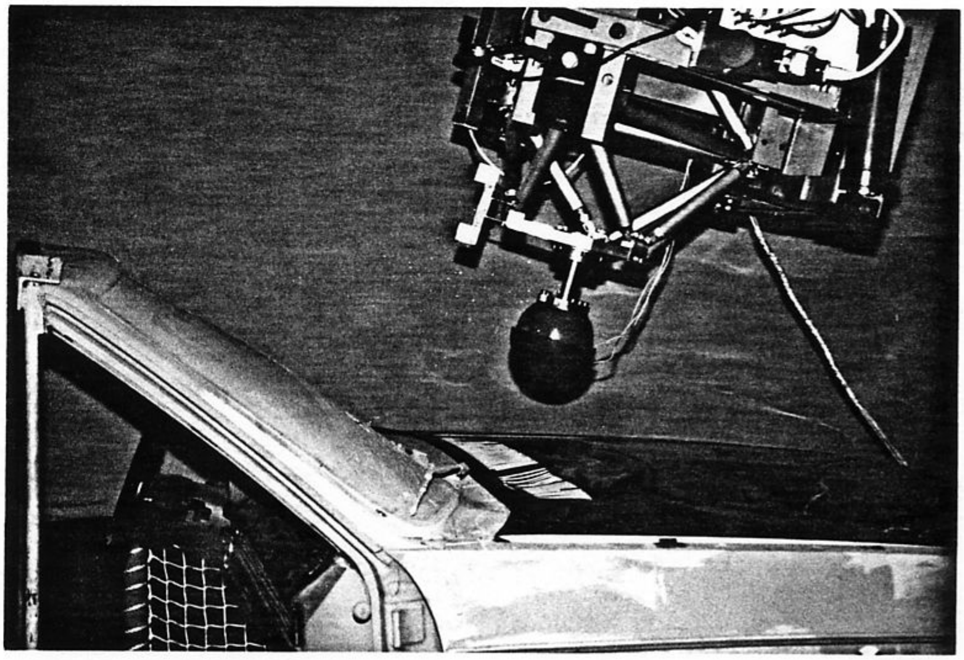

Fig. 7: Impactor Propelling Rig

The test parameters for the process control of the system are entered via the control panel. The following variables - mode of impact (free flight or guided), impact speed, specimen weight, impact angle must be set prior to testing.

The system has an ultrasonic speed sensor for measuring the test speed. For the component head impact test procedure, described below only the free impact form was selected, since it takes account of the real situation where the angle of inclination and angle of deflection of the head are not necessarily identical.

3.2 Adult Head Impactor Development

Two main parameters must be laid down for a head impactor in its development: outer diameter and mass. Different ECE regulations (17, 21, 25) specify a diameter of 165mm for an (adult) head impactor, as does [13], and there are no reasons for not adopting this value. Impactor mass in these regulations is 6.8 kg, which appears to be too high relative to real head weights.

In a prior BASt study [8], the idea of shooting a dummy head alone against the bonnet was examined but rejected because of considerable scatter in the measured values.

Table 4 presents an overview of cadaver head weights and impactor weights from the literature.

Head (Impactor)	Weight	Literature
Cadaver head	3.7 - 5.0 kg	Beier 1980
Cadaver head	3.5 - 3.9 kg	Hodgson 1975
Cadaver head (with neck)	3.6 - 5.3 kg	Hodgson 1975
Cadaver head (neck?)	4.3 - 4.9 kg	Harless 1857
Impactor ECE 21	6.8 kg	ECE-Regulation
Dummy head	4.5 kg	Tennant 1974
Dummy head with neck	5.2 kg	own measurements
Specimen for head test pedestrians		
Steel hemisphere	7.1 kg	Kramer 1979
Hybrid II dummy head on pendulum	4.4 - 5.2 kg	Grösch 89/Kaeser 83
Wooden sphere	5.2 kg	Huß 1982
Dummy face and mould	4.5 kg	Pareira 83/Pritz/Hoyt 88
Sphere	6.8 kg	ECE/GRCS 1985
Dummy head Hybrid II	4.8 kg	Ferrero 1990
Dummy head Hybrid II + ballast 1 kg	4.6 - 5.6 kg	Brun-Cassan 1982
Head mass for pedestrian in computation models	5.0 kg	Janssen 1990
	6.0 kg	Glöckner 1977

Table 4: Literature Review of Head Impactors

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The spheres used so far have been made of metal or hardwood, and some had a skin cover.
For the pedestrian head impactors, Leukorit was chosen as material. This is an impact-resistant pure phenolic resin. It is fitted with a steel insert for 3 centrally located uniaxial accelerometers.
Impactor weight was defined at 4.8 kg in the first iteration of the later comparative tests with pedestrian cadavers. This is slightly above the impactor weight proposed in [11, 12, 14] as test weight in the American proposal for a pedestrian head impact test. Weight is adjusted by fitting steel rings.

For impacts on (what can be) extremely hard exterior car elements a skin cover seemed to be necessary for the pedestrian head impactor. Figure 8 shows the final design. Comparative tests in a BASt preliminary study [8] also showed that a certain damping effect can be achieved even in the case of hard elements located under the bonnet, whereas the skin cover plays only a subordinate role in the case of bonnet sections with large-area deformations. Another consideration in the choice of a skin was the calibration capacity of the impactor. The silicon skins produced met the existing calibration requirement for the heads of Hybrid III dummies. A hardness of 50 shore required a skin thickness of 7.5 mm. The absolute external diameter of 165mm is retained. To meet the above dummy head calibration requirements, the same test weight (4,6 kg) must exist. Fig. 9 shows the design drawing of the impactor and its elements. A calibrating weight of 500 g, which is employed for calibration instead of the additional weight of 700 g used for test (impactor weight 4,8 kg) purposes is needed.

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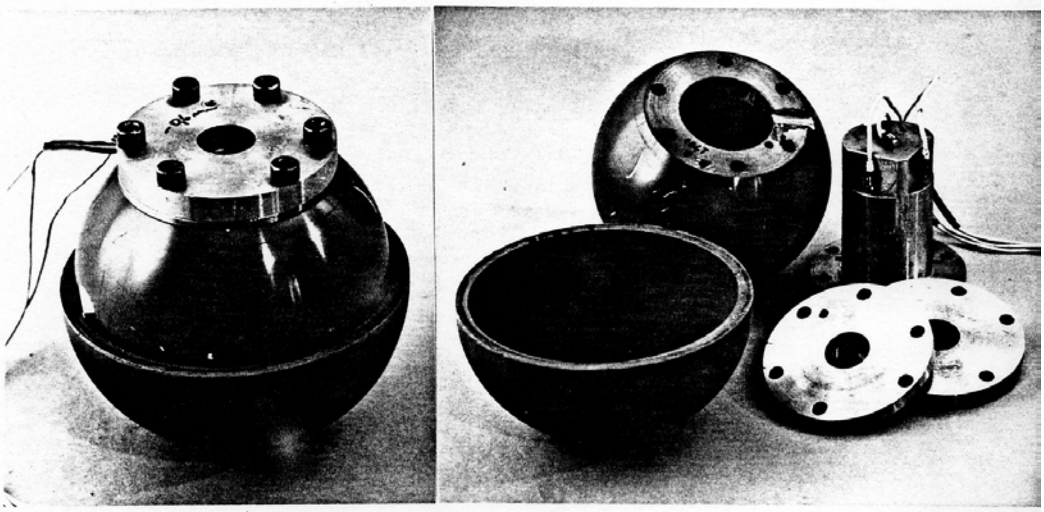

Fig. 8: Head Impactor for Adult Pedestrian Tests

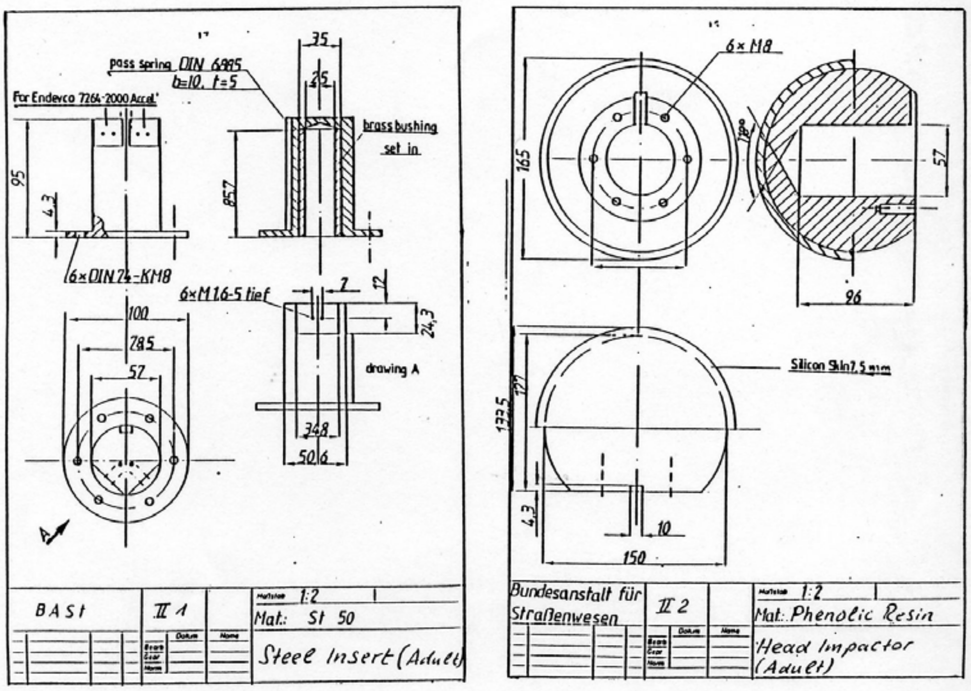

Fig. 9: Technical Drawings of the Adult Head Impactor

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3.3 Child Head Impactor Development

The impactor for the simulation of a child head impact should be based on a 6-year-old child. The development of the impactor was based on the proposal in [13] for an external diameter of 130mm and a weight of 2.5kg.

Fig. 10 shows the impactor with skin and steel insert for taking up a 3axis accelerometer. As in the adult impactor, the skin had a thickness of 7.5 mm and a hardness of 50 shore. The diameter of the sphere, again made of Leukorit (a phenolic resin), as simulator thus was 115 mm. The technical drawings are shown in Figure 11. The head meets the test requirements for head impact calibration according to part 572, Hybrid II.

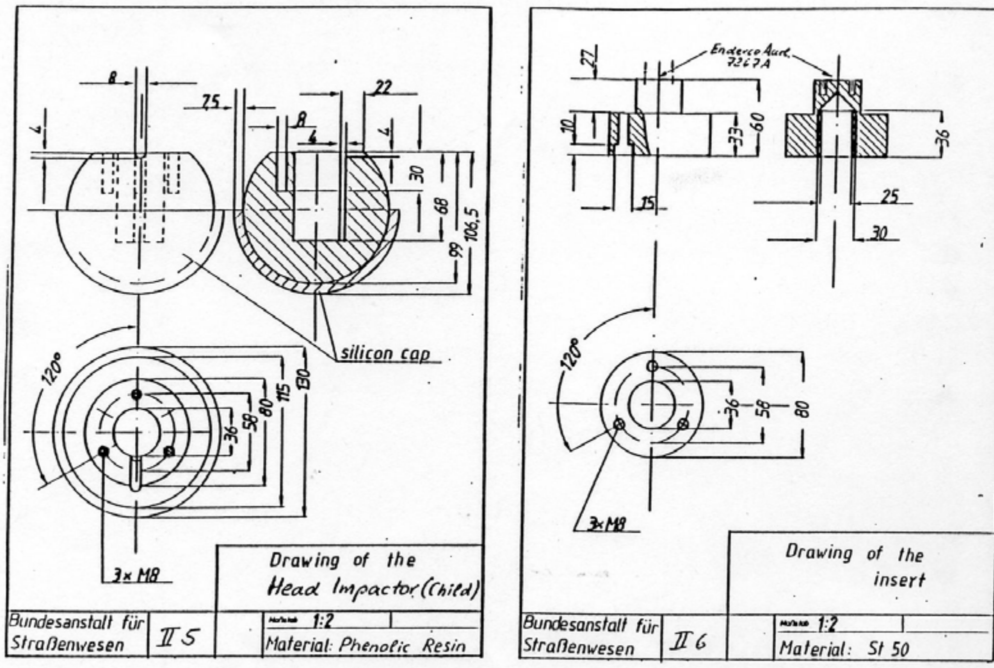

Fig. 10: Technical Drawing of the Child Head Impactor

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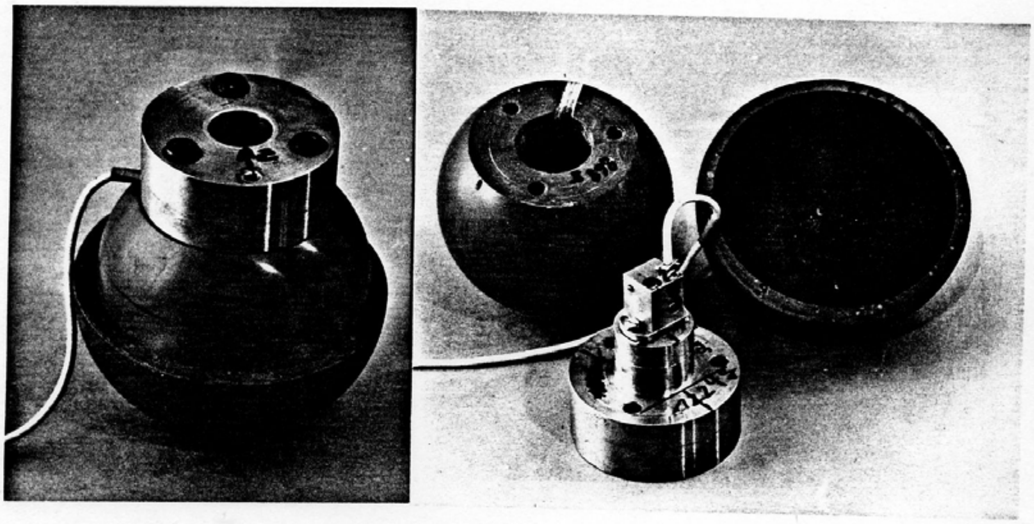

Fig. 11: Child Head Impactor

4. Method Verification for the Impactor Tests

Since none of the previously published data from cadaver tests permit any conclusions to be drawn about the depth of the dents in the bonnet caused by a head impact, the original plan had discarded, and new cadaver tests were carried out. The object was to obtain an equal dent pattern using component tests. Assuming equal dent depth, the same input energy would have been necessary, ensuring comparability of cadaver and component tests.

4.1 Test Conditions

The Hannover Medical College was commissioned to make the cadaver tests [15]. The Federal Highway Research Institute made a buck of an Audi 5000, see Fig. 12. A vehicle with a long bonnet was selected to make sure that a head impact area was obtained on the bonnet. The bumper was drawn forward 16 cm in some of the tests. The object was to examine whether such a change in front angle from 63° to 53° has any effect on head impact velocity.

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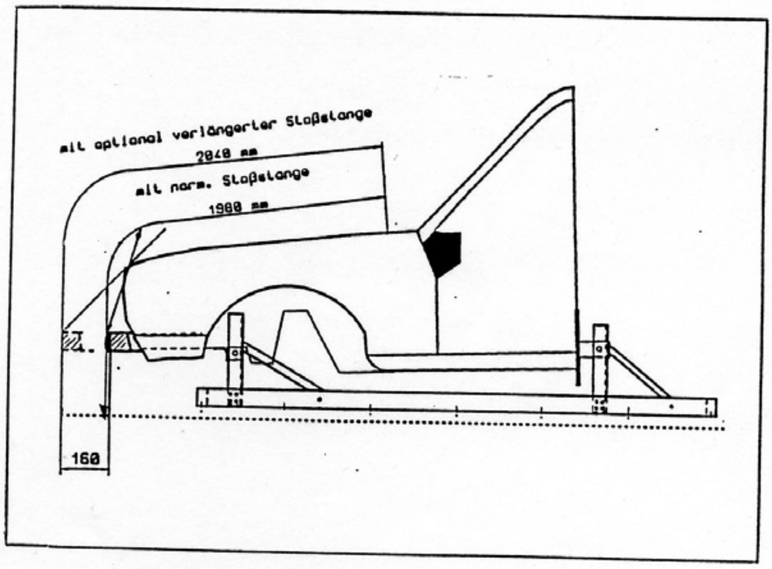

Fig 12: Audi 5000 Buck

Table 5 shows the cadaver test programme. The cadaver standing position was sideways but facing the car without possible arm support on the hood.

Test no.	VO [km/h]	Front angle
PAV 1	40	53°
PAV 2	40	53°
PAV 3	40	53°
PAN 4	40	63°
PAN 5	40	63°
PAN 6	40	63°

Table 5: Test programme for cadaver tests

4.2 Test results

Although a vehicle with a long bonnet was selected for the tests, the head impacted in two tests the windscreen (PAN 05 and PAN 04). One impact was with the windscreen frame and three with the bonnet at the level of the fresh air grill. Fig. 13 shows the positions of the various head impact points.

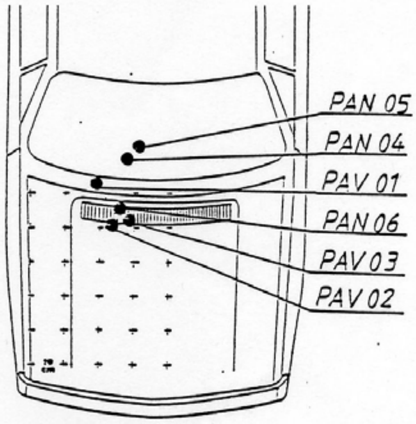

Fig 13: Head Impact points in Cadaver Tests

Injuries and the anthropometric cadaver data are compiled in Table 6. Table 7 contains particulars on test reproduction by the impactor tests. Tests PAV 02, PAV 03 and PAN 06 were followed three times each and PAV 01 once as impactor tests with the adult impactor described above.[19]

Apart from an upper oscillation on the signals, good reproducibility was obtained with the selected impactor weight of 4.8 kg as regards the curve for the signal. The results of measuring values are compiled in Table 7.

At an impact velocity between vehicle and pedestrian of 40 km/h, a head impact speeds of 12 - 14 m/s (43 - 50 km/h) occur if there is no arm support. In the cadaver test, HIC values of 1,000 to 2,500 were obtained. Except for one test (PAV 02), the HIC values from the impactor tests are above the HIC values from the relevant cadaver tests and, depending on the impact point on the bonnet, are between 1,500 and 2,500. On the windscreen

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frame, an HIC value of 3,300 was obtained. The scatter of the a_{3ms} and HIC values is satisfactory, higher scatters are present at the max. acceleration value because of the aforementioned signal oscillation.

In the nature of things, dent shape and depth show greater variations; they depend on material and form. Some very good agreements were obtained, so that, under the given circumstances, satisfactory results for the agreement between "curve shape for acceleration signal" and "dent pattern" were obtained.

Test No	bumper	V_o	head impact location	cadaver			head* injuries	reproduced by impactor test
				height	age	weight		
PAV 01	pro-truded 16cm	40.3	lower WS frame	180	76	81	skull fracture 7cm	489
PAV 02		39.7	upper bonnet	180	57	74	—	480,481,482 483,484,485
PAV 03		40.2	upper bonnet	170	89	84	multiple lacerations and abraision nose fracture	
PAN 04	normal	39.3	windscreen and frame	175	68	88	skull fracture, 10cm	no
PAN 05		40.1	windscreen and frame	177	82	78	laceration 3cm	no
PAN 06		39.5	upper bonnet	166	36	54	—	486,487,489

* no obduction was made, therefore brain injuries could not be identified

Table 6: Cadaver Tests, Anthropometric Data and Injuries

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Test no	v_{head} [m s]	$a_{max\ res}$	a_{3ms}	HIC	Bonnet deformation Stat. [mm]
PAV 01	13.3	291	168	2453	22*
489	12.9	287.6	183.2	3328	32*
PAV 02	12.5	173	142	1894	37
480	--	---	---	---	---
481	12.3	144.2	116.8	1545	32
482	12.4	133.8	111.6	1377	37
Mean Value	12.3	139.0	114.2	1461	34.5
Coefficient of variation	0.4%	5.3%	1.4%	8.2%	10.2%
PAV 03	11.9	182	109	1034	29
483	12.3	220.8	147.9	1660	22
484	12.5	226.3	148.1	2232	30
485	11.9	285.4	158.3	2179	25
Mean Value	12.2	244.2	151.4	2024	25.6
Coefficient of variation	2.5%	14.7%	3.9%	15.6%	15.8%
PAN 06	14.0	230.5	137.4	1687	19
486	13.6	191.8	143.1	2392.1	25.5
487	13.3	230.7	156.8	2605.1	37
488	13.4	181.4	156.5	2600.2	37
Mean Value	13.4	201.3	152.1	2532.5	33.1
Coefficient of variation	1.3%	12.9%	5.1%	4.8%	20%

(--) no measuring value available
*   deformation of the windscreen wiper

Table 7: Test results of Cadaver tests and Impactor Tests (4.8kg)

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An HIC below 1,000 presumably cannot be reached in head impact velocities of 45 - 50 km/h. The impact points at the air grill were without stiffening below or hard sections of the engine. Previous tests at BASt show that an HIC of 700 - 900 can be obtained at such impact points at impact velocities of 40 km/h [8].

5. Conclusions and Proposal for a Test Method for Pedestrian Head Impacts

An analysis of the literature yielded a zone of possible head impact points for pedestrians involved in accidents (children and adults) involving head/bonnet impact. For the vehicle impact velocity of 40 km/h specified in the award of this project, it was possible to obtain impact velocities and dent patterns for cadaver tests using full-scale tests.

One head impactor each for child and adult were designed and built, and calibration requirements deduced. Satisfactory results were obtained in a comparison of impactor tests and full-scale cadaver tests. Basic tests were performed on the influence of impactor weight, shape, the necessity of an outer skin, min. bonnet deformation, etc.

The underlying conditions for a test of possible head impact points for pedestrians involved in accidents are as described below.

The impactor velocity of 40 km/h chosen for test and acceptance purposes of vehicles is due to the fact that HIC values of below 1,000 at this speed appear to be structurally possible in the development of bonnets.

However, a head impact speed of 40 km/h is equivalent to a vehicle driving speed of only approx. 35 km/h in an adult pedestrian impact.

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A test procedure for pedestrian safety in vehicles, specifically the head impact on the bonnet in the present case, should contain the following conditions (Table 8) [20]:

Adult head impactor test

impactor velocity	40 km/h
zone on test car*	wrap-around length 1500-2100mm or windscreen complete car width
impactor material	free flight skin covered sphere Leukorit (phenolic resin)
impactor diameter	165 mm (incl. skin)
skin	7.5mm silicon skin 50 shore hardness
measurement	accel. X.Y.Z in sphere centre
tolerance criteria	HIC $\leq$ 1000
impact angle	65° to horizontal
calibration requirement	PART 572 Hy III a_{RES} = 225-275 g h = 376 mm falling height

*** No. of test not yet specified**

Child Head Impactor Test

impactor velocity	40 km/h
zone on* test car	wrap-around length 1000-1500 mm or windscreen complete car width
impactor material	free flight skin covered sphere Leukorit (phenolic resin)
impactor diameter	130 mm (incl. skin)
skin	7.5mm Silicon skin 50 shore hardness
measurement	accel. X.Y.Z in sphere centre
tolerance criteria	HIC $\leq$ 1000
impact angle	50° to horizontal
calibration requirement	PART 572 Hy II a_{RES} = 210-260 g h = 254 mm falling height

* No of test not yet specified

Table 8: Impact Conditions for Pedestrian Head Impactor Tests

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The decision on a (min.) number of tests and on whether and how often the limiting value of HIC 1,000 may be exceeded is a political decision and will not be discussed any further in the present context.

In the appendix a list of impactor tests carried out up to now and the plots of cadaver and comparable impactor tests are shown.

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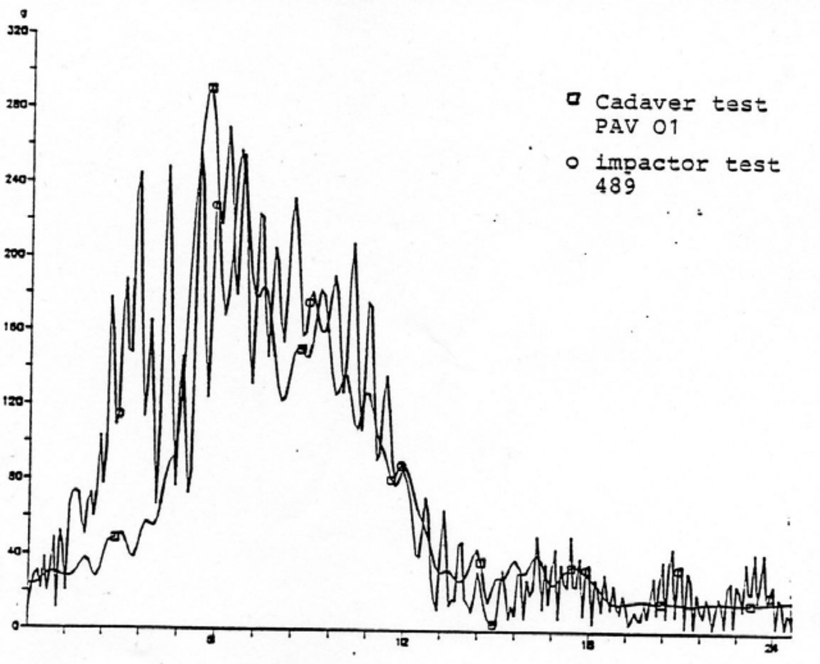
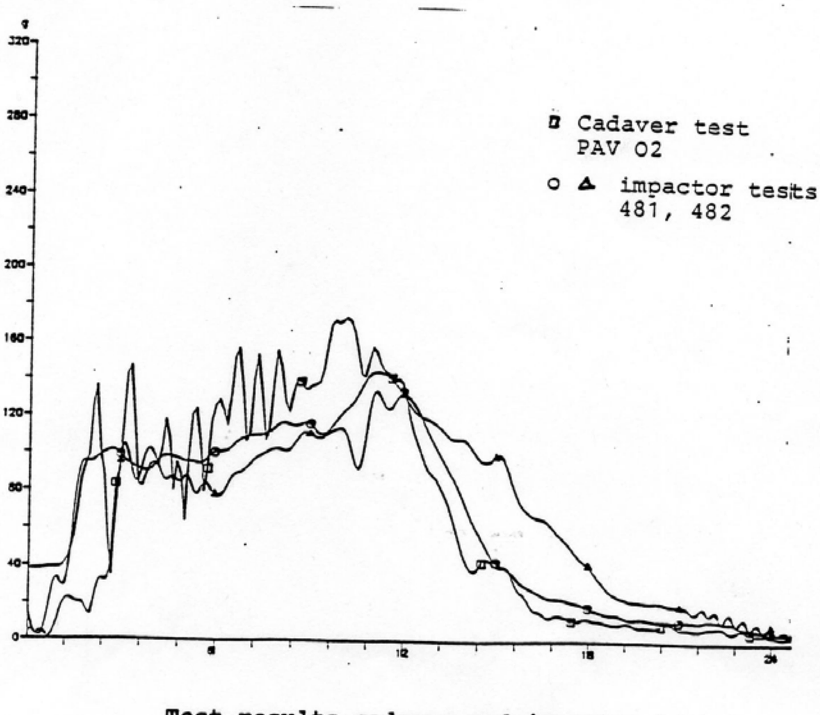
APPENDIX

Summary of the test series conducted for this project

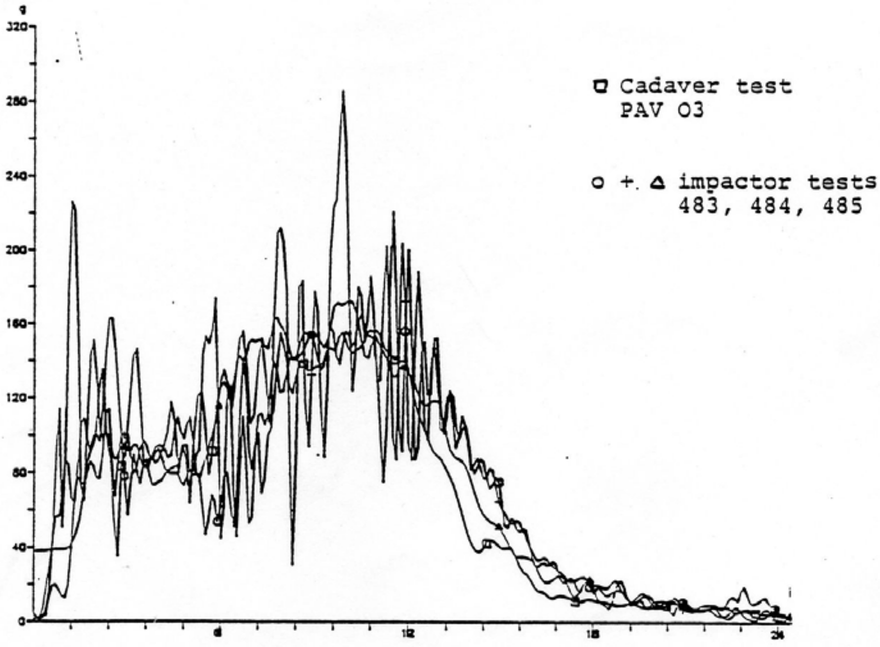
10 different test series were carried out at the Federal Highway Research Institute (BASt) to investigate the subject of pedestrian head impacts in collisions with cars:

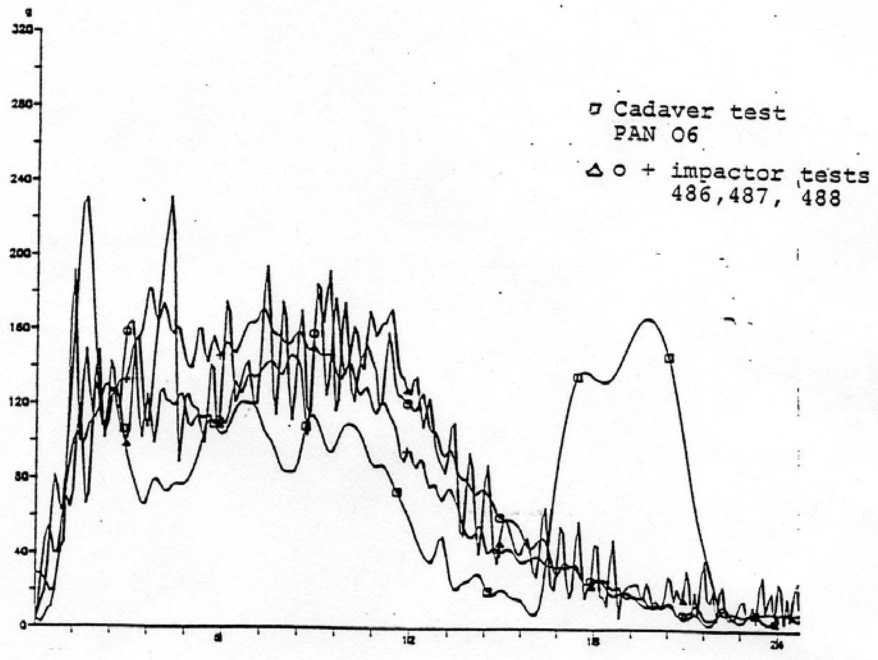
(a) 12 preliminary tests using a dummy head as impactor, m = 4.4 kg and a VW Golf Al as car (impactor selection)
(b) 12 preliminary tests using a spherical plastic impactor, m = 4.4 kg and a VW Golf Al as car (impactor selection)
(c) 4 tests using a skin covered child head impactor, m = 2.5 kg, and a VW Golf Al as car (dummy test reconstruction)
(d) 12 tests using a skin covered child head impactor, m = 2.5 kg, and an Audi 100 as car (dummy test reconstruction)
(e) 6 tests using a skin covered adult head impactor, m = 6.8 kg, and a VW Golf Al as car (dummy test reconstruction, skin selection)
(f) 13 tests using a skin convered adult head impactor, m = 6.8 kg, and an Audi 100 as car (dummy test reconstruction, skin selection)
(g) 17 tests using a skin covered adult head impactor, m = 4.4 kg, m = 6.8 kg and m = 9.2kg and an Audi 100 as car (impactor weight influence, no stiffening, no hard spot beneath the bonnet)
(h) 11 tests using a skin covered adult head impactor m = 6.8 kg and an Audi 100 as car (hard spot identification)
(i) 10 tests, cadaver test reconstructions (see Chapter 4), with adult head impactor 4.8 kg and Audi 100 as car (method verification tests)
(j) 12 leather skin covered dummy head tests into laminated and tempered windscreens (Citroen GS windscreens) (see Chapter 2.1)





Test results cadaver and impactor tests





Test results cadaver and impactor tests