PEDESTRIAN HEAD IMPACT ON THE WINDSCREEN OF COMPACT CARS A NEW TEST RIG AND FIRST RESULTS

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ABSTRACT

Based on the kinematics in car/pedestrian-dummy accident simulations a new test rig was pre-developed to create a reproducible head impact on the windscreen of compact cars. During the test head accelerations as well as forces and bending moments to the neck of a Hybrid-III dummy were measured.

The new test procedure and first test results are shown here. They are discussed with regard to the current test procedure to assess the injury risk of pedestrians with impactors for bonnet, upper leading hood edge as well as hood and a possible future integration of the head impact on the windscreen of compact cars.

KEY WORDS

AUTOMOBILES, PEDESTRIANS, WINDSHIELDS, HYBRID III, NECK

ACCIDENT STATISTICS

In EU Countries, more than 9,000 pedestrians and cyclists are killed each year (ETSC Press Notice, 18th February 2000). Most of them are children or older road users and they are mostly involved in crashes in urban and residential areas.

Figure 1 shows the situation in Germany in the year 1998 (Federal Statistics, 1999). Inside and outside urban areas 7,792 road users were killed in crashes, the majority are car occupants with a share of 61 %, pedestrians are on rank 2 with 14 %. Looking at the situation inside urban areas only, 1,908 road users were killed, pedestrians with a share of 38 % are the majority, car occupants are on rank 2 with 27 %.

As shown in Figure 2, the number of killed pedestrians in the Federal Republic of Germany was rising till the beginning of the 70ties and then it decreases every year during the 70ties and 80ies. After the reunion in 1990, the figure of killed pedestrians grows because of the larger area, but it falls again in the years after. In 1998 1,084 pedestrians were killed in crashes on German roads, 352 of them outside and 732 inside built-up areas.

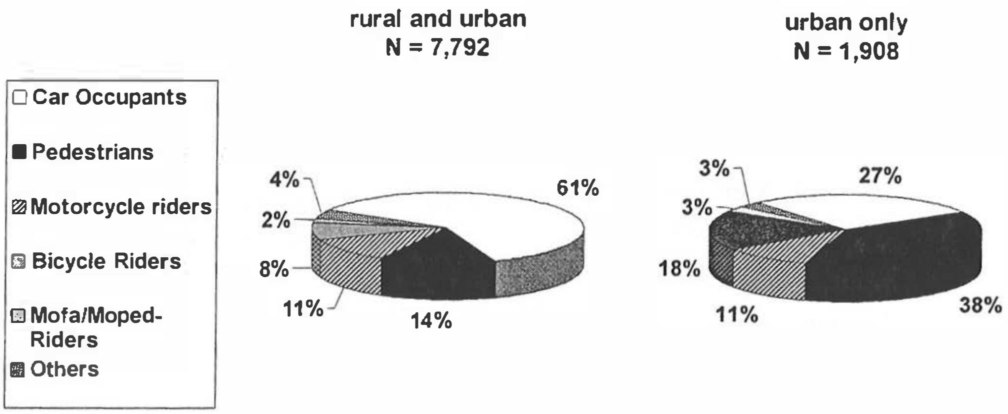


Figure 1 – Shares of killed road users in Germany in the year 1998 (Source: Federal Statistics, 1999)

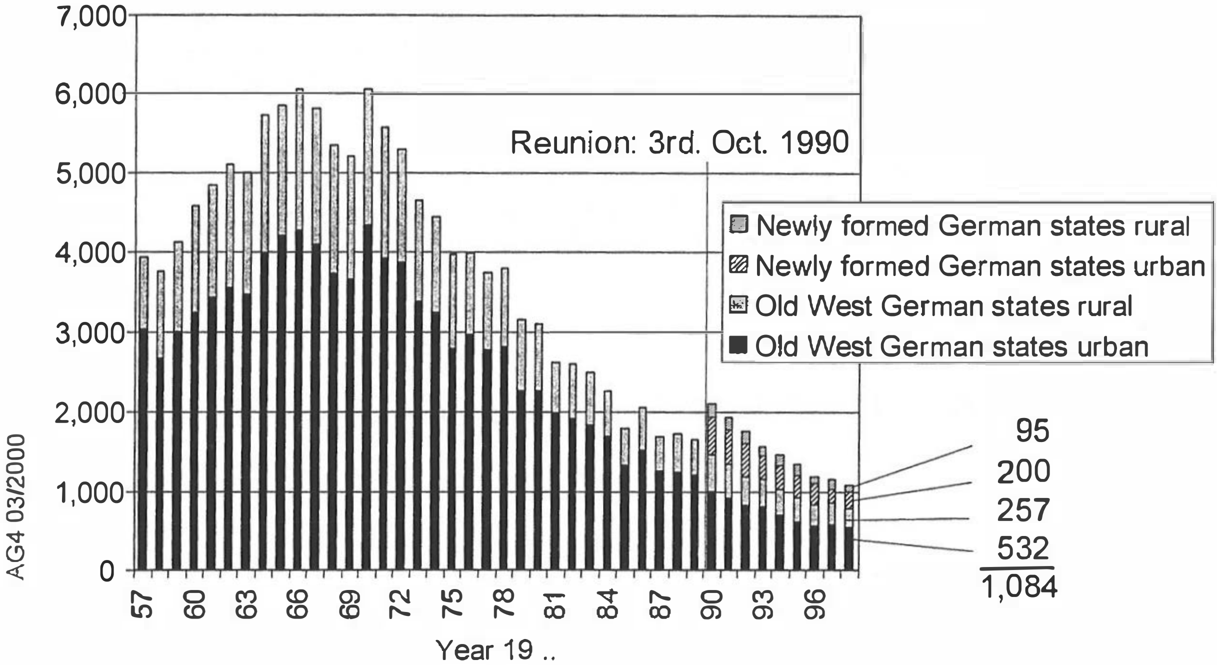


Figure 2 – Numbers of killed pedestrians per year in Germany from 1957 to 1998
(Source: Federal Statistics, 1999)

Figure 3 shows the age distribution of the killed and severely injured pedestrians in Germany in the year 1998. It is obvious that most of the pedestrians killed inside urban areas are more than 75 years old (289 from 732 resp. 39.5 %). This age-group is also of importance amongst the pedestrians severely injured inside built-up areas (1,744 from 12,046 resp. 14.5 %). Impressive is also the number of the infants under 6 years (1,055 resp. 8.8 %) and the children within the age groups 6...10 years (1,780 resp. 14.8 %) and 10...15 years (1,479 resp. 12,3 %).

The statistics also show that in most of the cases a car is the pedestrian´s opponent. For example inside built-up areas in 1998 there were 648 fatal crashes with two involved parties, one of them a pedestrian. In 422 (65.1 %) of these crashes a car was the opponent of the pedestrian.

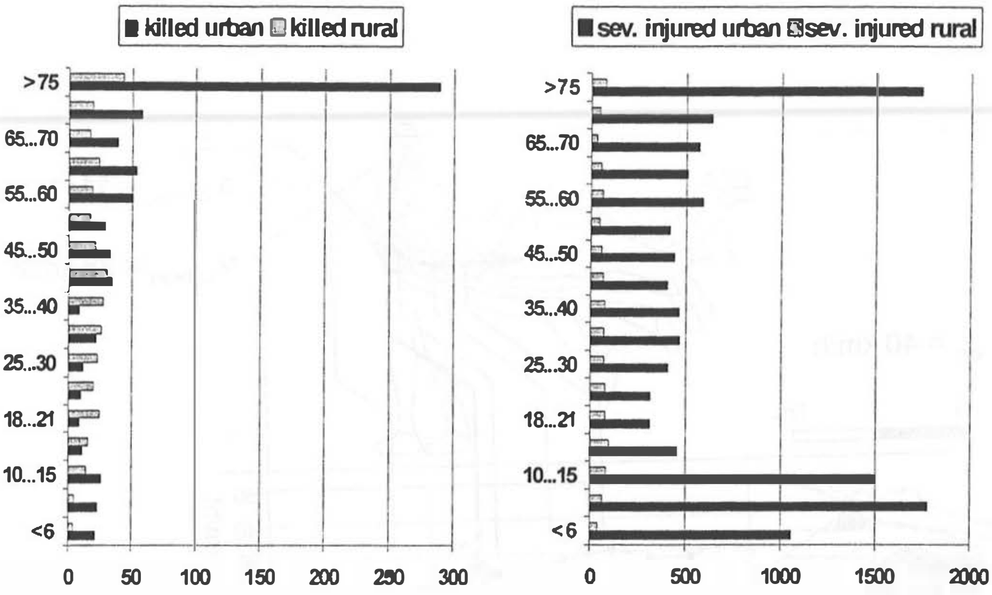
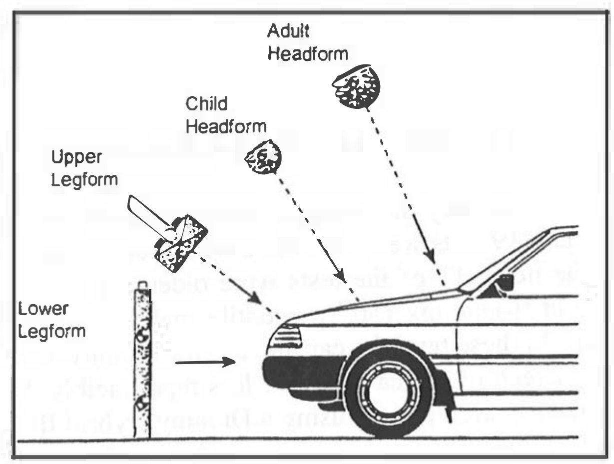


Figure 3 – Number of killed and severely injured pedestrians inside and outside built-up areas in Germany in the year 1998 within separate age-groups (Source: Federal Statistics)

CURRENT PEDESTRIAN PROTECTION TEST PROCEDURE

Regarding the protection of pedestrians in a frontal crash to a car, Harris and EEVC WG 10, 1991 were the first to propose the current test procedure which is not part of the legislation yet, but used in practice, for example within the EuroNCAP. This procedure is supposed to assess the injury risk of pedestrians with impactor tests for the bonnet, upper leading hood edge and hood of a car with a simulated impact speed of the car of 40 km/h against a stationary passenger, Figure 4.

Figure 4 - Current pedestrian test procedure as proposed by EEVC WG 10 (WG 17)



The windscreen is excluded because at 40 km/h collision speed no relevance was seen of a head impact on the windscreen of a car at that time. Since then a lot of compact cars have entered the market. These modern cars are characterized by shorter bonnets. That is why the head impact on the windscreen of such a car at 40 km/h seems to be more relevant. An example is given in Figure 5.

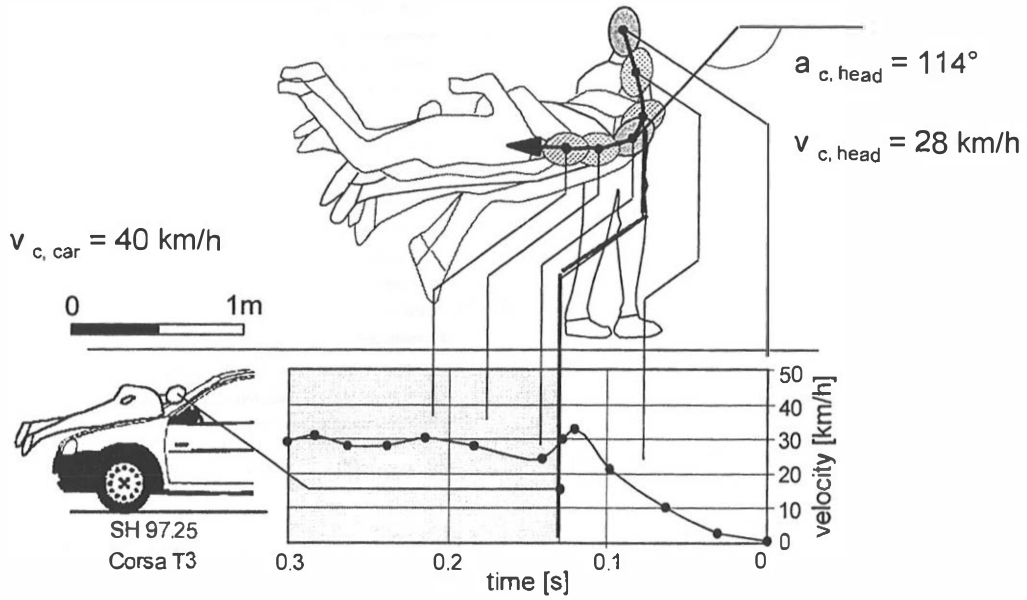


Figure 5 – Head impact of a pedestrian dummy Hybrid III (50th percentile male) on the windscreen of an Opel Corsa which impacts at 40 km/h the stationary dummy (movement and head velocity related to the absolute coordinate system)

To study the possibilities of including the windscreen of compact cars into the current pedestrian test procedures, a research project was funded by the German Federal Highway Safety Institute (BASt). It was decided not only to measure the load of the head but also of the neck while impacting the windscreen equivalent to a 40 km/h car to pedestrian crash.

CAR TO DUMMY TESTS AS A BASIS TO STUDY KINEMATICS AND LOADS

To study the kinematics and loads of a dummy which represents a pedestrian in a frontal crash to a car, 19 tests were examined with special regard to the head impact at the windscreen and the loads of the head. 13 of the tests were older and done initially for accident reconstruction studies with a Hybrid-II-Dummy (50th percentile male) without flexible neck and no possibility to measure neck loads. In these tests the car impacts the dummy at 33 to 43 km/h. In each case the dummy head hits the windscreen of the car more or less reproducibly. Six of the tests were new and carried out especially for the research project using a Dummy Hybrid III (50th percentile male) with its flexible instrumented neck (6 load channels: 3 forces and 3 bending moments). Figure 7 shows side views of some of the used cars. The new tests were done with Opel Corsa, Ford Ka and Horlacher City 3.

In the older tests it was the aim to cover a wide field of possible impacts which are of interest for real world accident reconstruction. In the new six tests using the Hybrid-III-Dummy a reproducible head impact on the windscreen was supposed to occur. Figure 7 shows the impact configurations and the posture of the dummy in the new tests immediately before crash.

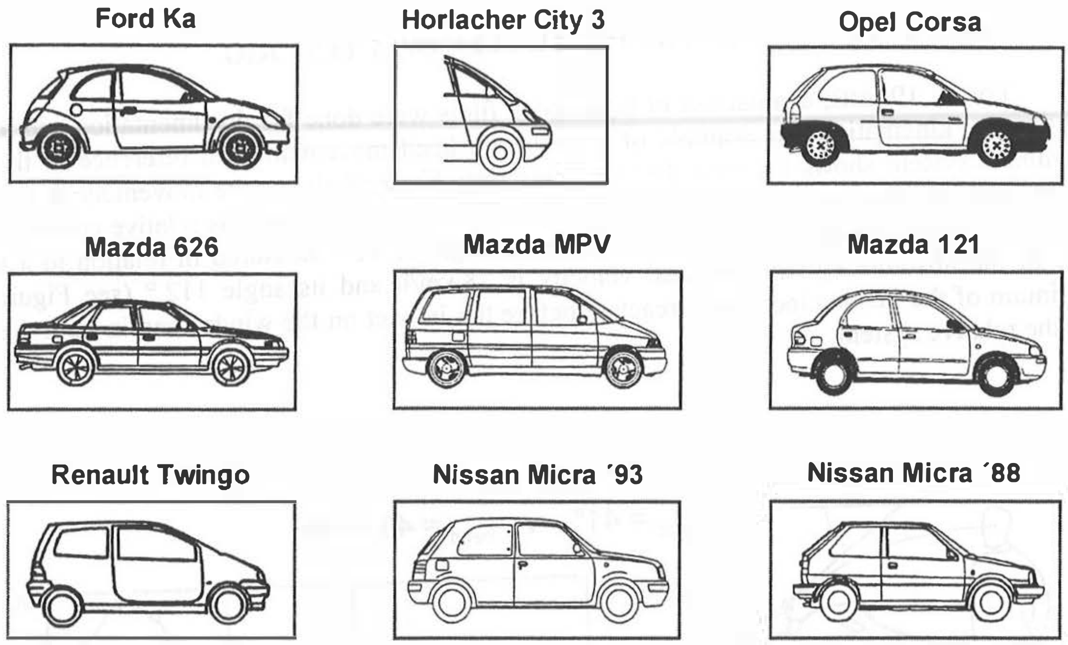


Figure 6 – Some examples of cars used in the tests with impacting a stationary dummy at impact speeds of 33 to 40 km/h and the head impacting the windscreen

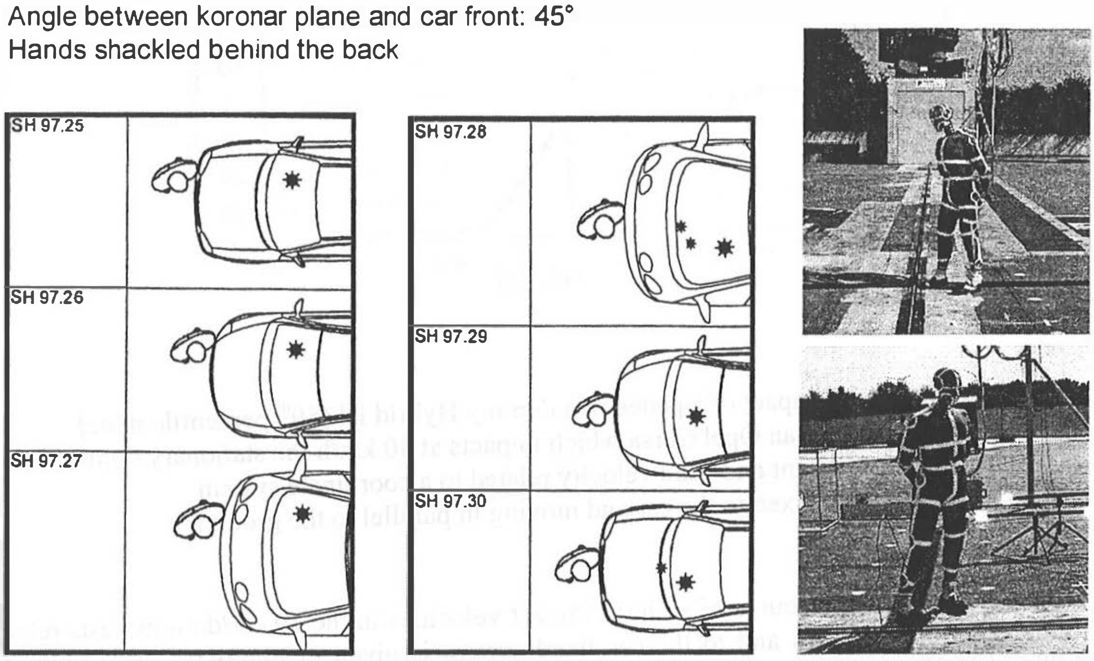


Figure 7 – Configuration of the six new tests carried out with regard to a good repeatability of the head impact on the windscreen of Opel Corsa, Ford Ka and Horlacher City 3

Pre-impacts of hands, arms and shoulders of the dummy on the windscreen or hood occurred in some of the older tests. To avoid this, in the new tests the hands of the dummy were shackled behind its back. The angle between the koronar plane of the dummy and the car front was 45 °. This finally leads to a free facial head impact. In the older tests the angle between the koronar plane and the car front was approx. 90°. In all tests the dummy was standing free without any support in the region of the head which would probably have influenced the head movement. To balance the dummy, its links were tightened well, but not fixed. To avoid it to fall over due to a breeze immediately before crash, two thin strings were used, tied at the pelvis of the dummy and fixed with pins at the road surface.

DUMMY KINEMATICS AND THE PROTOTYPE OF A TEST RIG

For all 19 tests, evaluations of high speed films were done for documentation and analysis of the dummy kinematics. An example of the relevant head movement with reference to the absolute coordinate system shows Figure 5. For the same tests Figure 8 shows the movement in a coordinate system which is fixed to the car and moves in parallel to the ground. In this relative coordinate system the head hits the windscreen at 40 km/h under an angle of 41 ° measured in relation to a horizontal line. In the absolute system the head velocity is 28 km/h and its angle 112 ° (see Figure 5). The maximum of the head velocity was reached before the impact on the windscreen in both the absolute and the relative system.

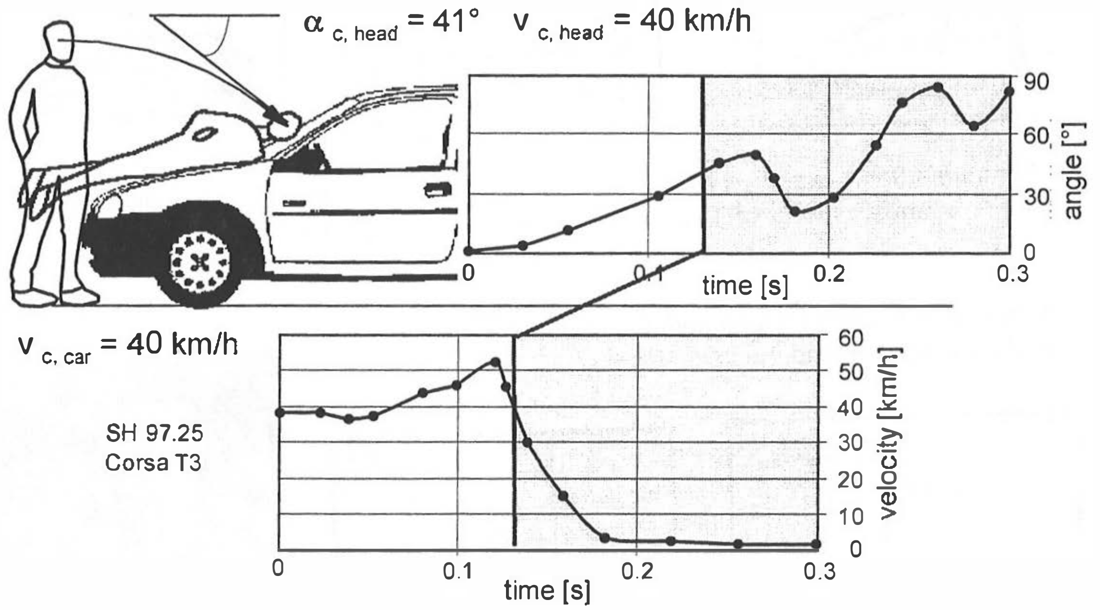


Figure 8 – Head impact of a pedestrian dummy Hybrid III (50th percentile male) on the windscreen of an Opel Corsa which impacts at 40 km/h the stationary dummy (movement and head velocity related to a coordinate system which is fixed to the car and moving in parallel to the ground)

An overview of the amounts of all head impact velocities in the 19 car/dummy-tests related to the absolute coordinate system and to the car fixed system is given in Figure 9. The 13 older tests (WH 94.08 to SH 97.06) with only one exception (SH 94.28) are characterized by higher head impact speeds in the absolute system than in the car fixed system. The six new tests (SH 97.25 to SH 97.30) always show higher head impact speeds in relation to the car fixed system.

For proposing the test rig which has to be pre-developed within the research project, these results were used to predict the range of head impact velocities to be reached by a head impactor relatively to the windscreen of a stationary car. Regarding this, the six new tests with a free head impact represent a "worst case". To simulate the head impact as it occurs in these six tests with a car impact at 39 to 40 km/h (Opel Corsa, Ford Ka, Horlacher City 3) on the stationary dummy, it was necessary to build a test rig that can reach head impact speeds between 35 and 50 km/h.

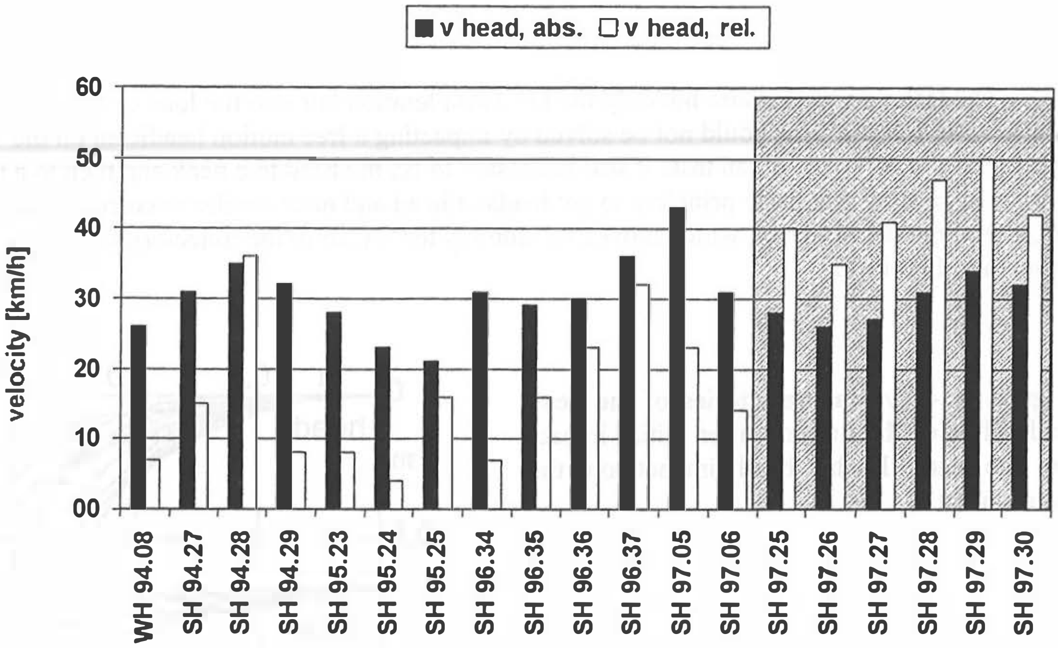


Figure 9 – Impact velocities of the dummy head in the absolute coordinate system ($v_{head, abs}$) and in a system that moves parallel to the ground and fixed to the car ($v_{head, rel}$) while impacting the windscreen after a car crash with 33 to 43 km/h to the stationary dummy in all 19 tests

Figure 10 gives an overview of the angles of the head velocity vectors in all 19 tests related to the horizontal line at the time of first contact of the head impacting the windscreen. For all of these tests this angle was significantly higher in the absolute coordinate system ($\alpha_{head, abs}$) than in the system fixed to the car ($\alpha_{head, rel}$). Looking only at the six new tests (with Opel Corsa, Ford Ka and Horlacher City 3) a very constant angle near to 40 ° in the relative system was given.

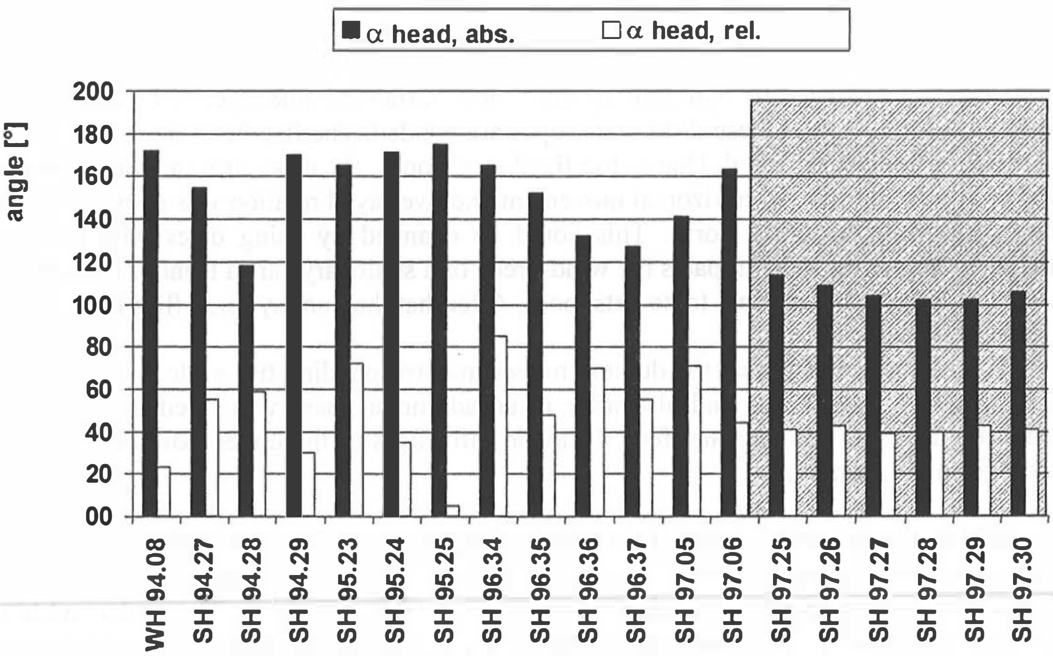
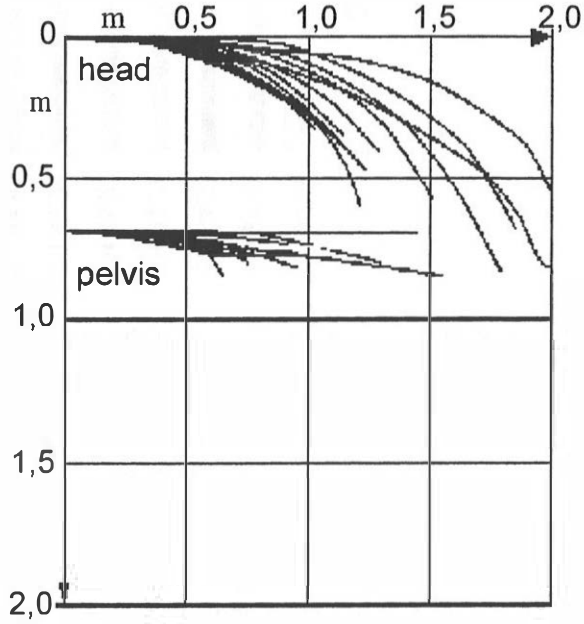


Figure 10 – Angle of the head velocity vector related to a horizontal line in the absolute coordinate system ($\alpha_{head, abs}$) and in a system that moves parallel to the ground and fixed to the car ($\alpha_{head, rel}$) during first contact of the head impacting the windscreen after a car crash with 33 to 43 km/h to the stationary dummy in all 19 tests

The task was to measure not only the head acceleration but also the load of the neck (bending moments and forces). This could not be solved by impacting a free motion headform on the windscreen. To solve the given task, it was necessary to fix the head to a neck and then to a torso of a dummy. Regarding this basic principle to get loads of head and neck similar to corresponding dummy tests, a test rig was designed, which moves the dummy torso near to the trajectories of pelvis and head as shown in Figure 11.

Figure 11 - Typical trajectories of the head and pelvis of the dummy after initial impact on the car till the head impact on the windscreen



The prototype of the test rig called "dummy torso catapult" is shown in Figure 12. A torso of a dummy Hybrid III (50th percentile male) is joint to a torque axle. Beginning at the starting position, this axle is pushed forward by hydraulic cylinders in a horizontal guidance. At both ends of the torque axle discs are joint. Round these disks steel ropes are winded. The fixed end of each of the steel ropes is anchored in the test rig stand. Due to the fixed steel ropes, the disks turn the torque axle while it is pushed forward. The ratio of horizontal movement and overlayed rotation was chosen according to the dummy tests with the Opel Corsa. This could be changed by using discs with other diameters. Immediately before the head impacts the windscreen of a stationary car in front of the test rig, a clutch between torque axle and dummy torso gets loose. After that the dummy torso flies free.

To get a movement near the dummy moves in corresponding full-scale tests shortly before the head impacts the windscreen and also after it, an additional mass was fixed to the dummy hip to simulate the inertia of the legs and feet. To avoid influences of the upper extremities, the arms were removed from the dummy.

Within the research project it was decided to carry out first tests only with the Opel Corsa. Two corresponding full-scale tests were used as reference. It was intended to get similar loads of the head and neck in "dummy torso catapult" tests as in the full-scale tests. The peaks and biomechanic values were supposed to be as near as possible to the reference and also the time history of the load signals immediately before and after the head impacts the windscreen.

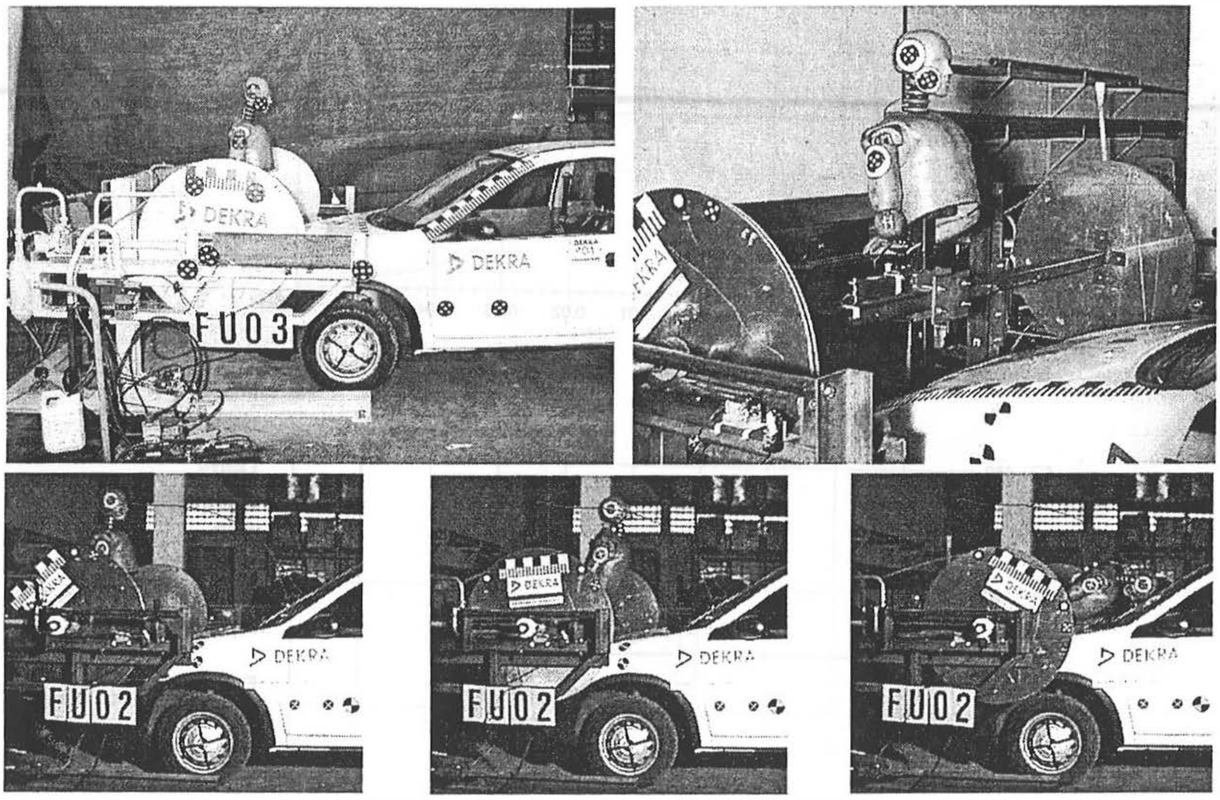
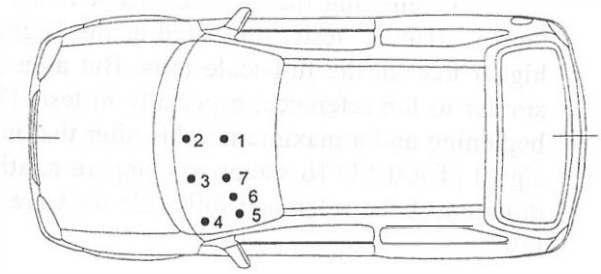


Figure 12 – Prototype of the test rig "dummy torso catapult"

FIRST TEST RESULTS

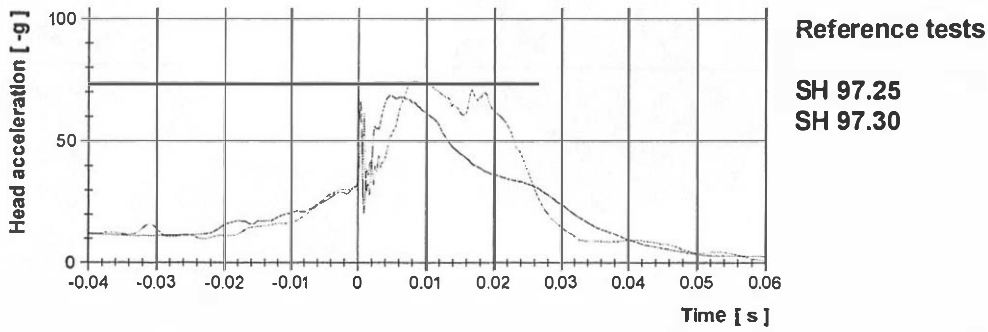
To get first results with the new test rig and look at necessary and possible improvements, 13 tests were carried out with head impact locations at the windscreen of an Opel Corsa as shown in Figure 13.

Figure 13 – Head impact locations at the windscreen of an Opel Corsa in the 13 first tests carried out with the new test rig "dummy torso catapult" as shown in Figure 12



Position:	Tests:
1	FU 02, FU 03, FU 10, FU 12, FU 15
2	FU 05, FU 06
3	FU 09
4	FU 04
5	FU 07, FU 17
6	FU 16
7	FU 08

Figure 14 shows the time histories of the resultant head accelerations measured in the two full-scale reference tests SH 97.25 (head impact on windscreen near A-pillar, similar pos. 6 in Figure 13, see Figure 7) and SH 97.30 (head impact near to centre of the windscreen, between pos. 3 and 7 in Figure 13, see Figure 7) and in tests FU 10, FU 15, FU 16 and FU 17 (head impact locations see Figure 13) using the "dummy torso catapult".



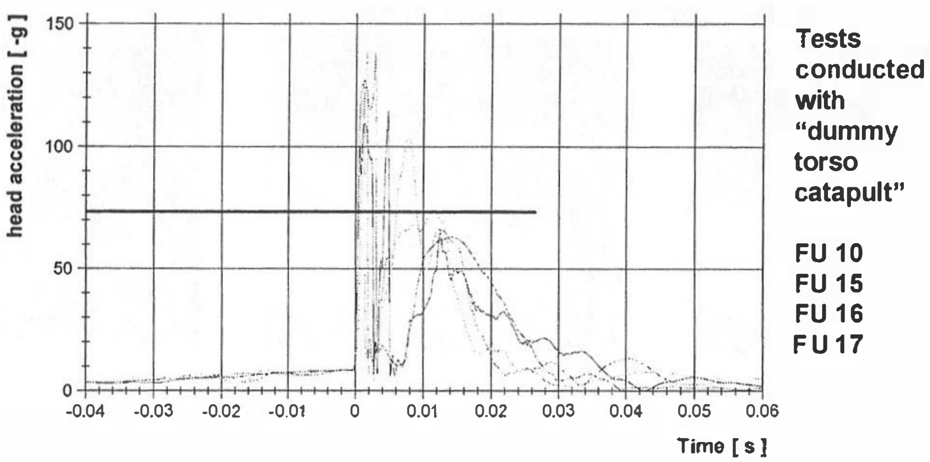


Figure 14 - Resultant head acceleration measured in the two full-scale reference tests SH 97.25 and SH 97.30 compared with the resultant head accelerations in the tests FU 120, FU 15, FU 16 and FU 17 conducted with the test rig "dummy torso catapult"

Comparing the graphs, first it is not very satisfying that the first deceleration peaks in the "torso catapult" tests, measured at the beginning of the head impact to the windscreen, are much higher than in the full-scale tests. But after that, the time history of all the signals are much more similar to the reference, especially in tests FU 15, FU 16 and FU 17. With a very short peak at the beginning and a maximum value after that in the range of 75 g, as in both of the reference tests, the signal of test FU 16 seems to compare relatively good with the references. Nevertheless the impact duration of the reference full-scale tests are longer than the impact duration in the "torso catapult" tests.

With respect to the biomechanical limits, the 3-ms-values of the resultant head acceleration and the Head Injury Criterion HIC are of special interest, Figure 15. Apart from test FU 09, where the head impacts the dashboard behind the windscreen, in all other tests the biomechanical limits of $a_{3\,ms}$ = 80 g and HIC = 1,000 were not reached. Obviously the peaks at the beginning of the head impact on the windscreen do not influence very much these criteria. Nevertheless, HIC and $a_{3\,ms}$ have a great variation in the reference full-scale tests (HIC = 450 and 700) and in the "torso catapult" test (HIC = 166 to 729 except for FU 09 with the head impacting the dashboard).

Looking at both the kinematics and the loads, a good correlation was given between the reference test SH 97.25 and the "dummy torso catapult" test FU 16 (head impact at Point 6, see Figure 13). For these tests Figure 16 shows HIC and $a_{3\,ms}$ for the head and the maximum flexion and extension moment for the neck $M_{y,\,max}$ compared with their appropriate biomechanical limits. HIC (442 and 357), $a_{3\,ms}$ (67 g and 68 g) and extension moment (-55 Nm and -46 Nm) are close together, whereas the flexion moments differ from one another (37 Nm and 143 Nm). In both tests the loads of head and neck lay under their limits.

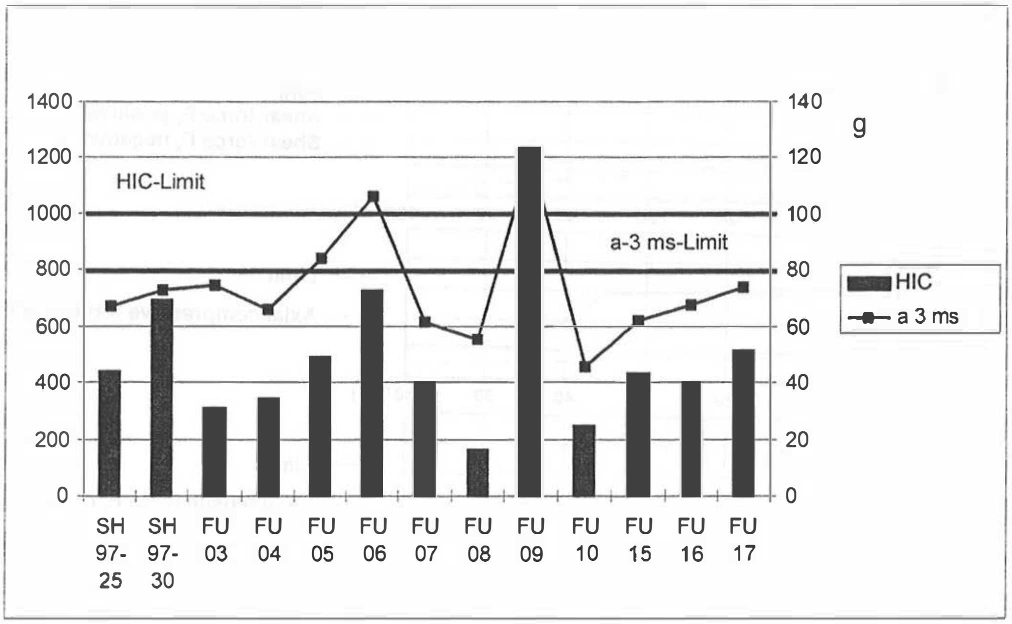


Figure 15 – Head Impact Criterion HIC and 3 ms-Value of the resultant head acceleration for the reference tests 97.25 and SH 97.30 compared with 11 tests conducted with the "dummy torso" catapult

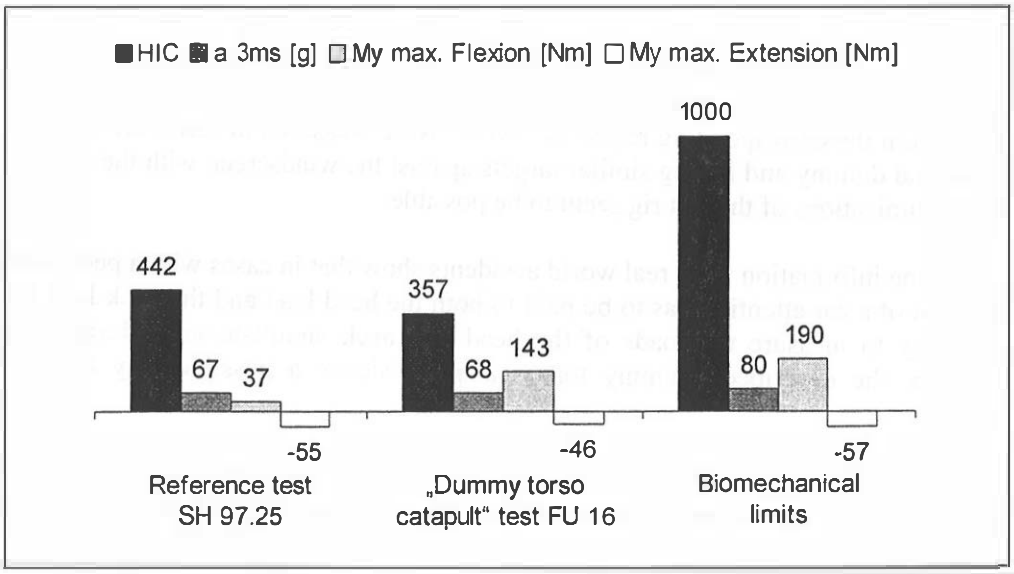


Figure 16 – HIC and a $_{3\,ms}$ for the head as well as maximum flexion and extension moment for the neck for the reference test 97.25 and the "dummy torso catapult" test FU 16 compared with their biomechanical limts

The forces in x- and z-direction of the dummy neck lay clearly under their limits according to Mertz (as published by Faerber, 1995) in the full-scale reference test SH 97.25 as well as in the "dummy torso catapult" test FU 15 shown as an example in Figure 17.

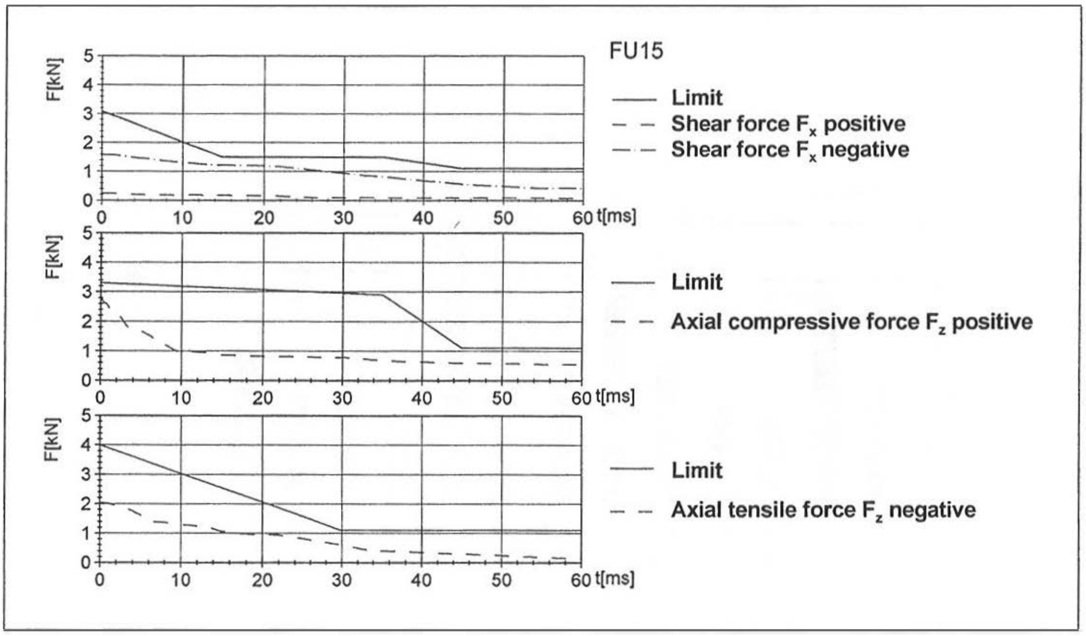


Figure 17 – Neck forces in test FU 15 conducted with the "dummy torso catapult"

SUMMARY AND CONCLUSIONS

To simulate the loads of head and neck of a dummy at a head impact on the windscreen, a new test rig called "dummy torso catapult" was designed and pre-developed. The first test results show that the current version of the test rig is already able to measure loads of head and neck which are of interest to predict relevant injury risks. Some of the measured values and their time history were not far away from the corresponding references which were measured in full-scale dummy tests using the same car and dummy and hitting similar targets against the windscreen with the same impact velocity. Further optimizations of the test rig seem to be possible.

Some information from real world accidents show that in cases with a pedestrian impact on the windscreen of a car attention has to be paid to both the head load and the neck load (Otte, 1999). If it is necessary to measure the loads of the head and neck simultaneously during an impact on the windscreen, the described "dummy torso catapult" shows a possible way to create such a test procedure.

As known so far, the head impact on the glass of the windscreen at 40 km/h impact speed seems not to lead to extremely dangerous head accelerations nor to extremely dangerous forces and bending moments of the neck – if the head impacts only the glass and not the A-pillar partially or fully.

The relevance of measuring neck loads in such a test procedure is still under discussion. Further research is necessary to investigate neck injuries in real world car/pedestrian crashes at collision speeds around 40 km/h.

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