The Movement of Head and Cervical Spine During Rearend Impact

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ABSTRACT

To gain a better understanding of the movement of head and cervical spine experiments were performed based on PMTO´s (Post Mortal Test Objects) and Volunteers. All experiments were performed on a crash sled. The change of velocity during the impact was varied between 6 km/h and 15 km/h. The acceleration behaviour of the sled was based on measurements from real collisions from cars equipped with Kienzle UDS™ (Unfalldatenspeicher = Accident Data Recorder). The mean accelerations varied between 2 and 8 g. All experiments were documented with High Speed Video (1000 pps). The accelerations of the sled were measured with two Kienzle UDS. For some experiments, the accelerations of head and chest were measured by three axis accelerometers. To visualise the movement of the cervical spine, during the impact, two vertebra bodies of the PMTO´s were marked with targets. Their movement was observed during the impact phase for various boundary conditions.

These studies have shown that improvements in the construction of seat and head restraint could reduce the risk of neck injuries during rearend impact.

INTRODUCTION

Due to increased traffic density the importance of rearend impact has increased during the last years. Latest studies [1,3] show, that more than 50 % of all accident situations includes rearend impacts. In many cases injuries of the cervical spine occur.
Several studies were published to analyse and improve the passenger protection during this type of impact.
Comparing human and Hybrid III dummy head kinematics during low-speed rearend impacts, Scott et. al [4] concluded that there are significant differences. Svensson [5] investigated the influence of the seat-back and head restraint properties on head-neck motion during rearend impact using a special dummy neck developed and validated for rearend collision. Experiments with Volunteers were performed and published by Ono and Kanno [3] as well as McConnell et. al [2]. They analysed the kinematics of head motion during this type of accident.

For this publication experiments were performed based on PMTO´s and Volunteers. The major target was the analysis of the movement of head and cervical spine during impact phase.

METHODOLOGY OF EXPERIMENTS

Test-base

All experiments were performed on a test-sled with the specifications listed in Table 1.

Table 1: Mean Specification of the Test Sled

dimensions:	11x1.5x1.0 m
net weight:	200 kg
max. load:	300 kg
power supply: electric engine: frequency converter:	Δ 380 V 18 kW 30 kW
max. speed:	25 km/h
max. deceleration:	up to 50 g

The sled is accelerated up to the adjusted speed by an electric engine. This electric engine is powered and controlled by an electronic frequency converter which allows to predefine the crash-velocity in a limit of ±0.5 km/h. By increasing the length of the rails crash-velocities up to 60 km/h are possible.

The whole sled plant was developed in a way that it is easy to transport. The brake-force can be adjusted by special longitudinal friction-brake element. This element implements a predefined brake-force by setting a certain air-pressure on a compressed-air cylinder. Using multiple brake elements well defined deceleration-characteristics can be created.

Due to the rather simple technology reproducibility of all experiments regarding impact-velocity and deceleration-characteristics is very good. The velocity of the sled immediately before impact can predefined within a maximum tolerance of ±0.5 km/h. Based on the accurate definition of the brake-force, the mean sled deceleration can be predefined to ±3 m/s^2 if the total-weight of the sled is known.

Figures 1 and 2 show the deceleration characteristics for a constant brake-force with two different passenger - sled mass ratios. In some way this curves also indicate the interaction forces between passenger and sled. This results from the fact that due to the seat elasticity time resolved accelerations for sled and passenger differ.

The UDS

To base the experiments on realistic deceleration characteristics, measurements from real accidents were used for the definition of the sled deceleration characteristics. During the last few years a black box was developed by the European company Mannesmann KIENZLE which measures the longitudinal and transversal acceleration of the car body. Currently approximately 3000 of these boxes are mounted on various cars moved under normal driving conditions. Based on these measurements the experiments were defined.

As the main target of this project is the rearend impact (without big car rotation) only UDS data satisfying this criterion were used.

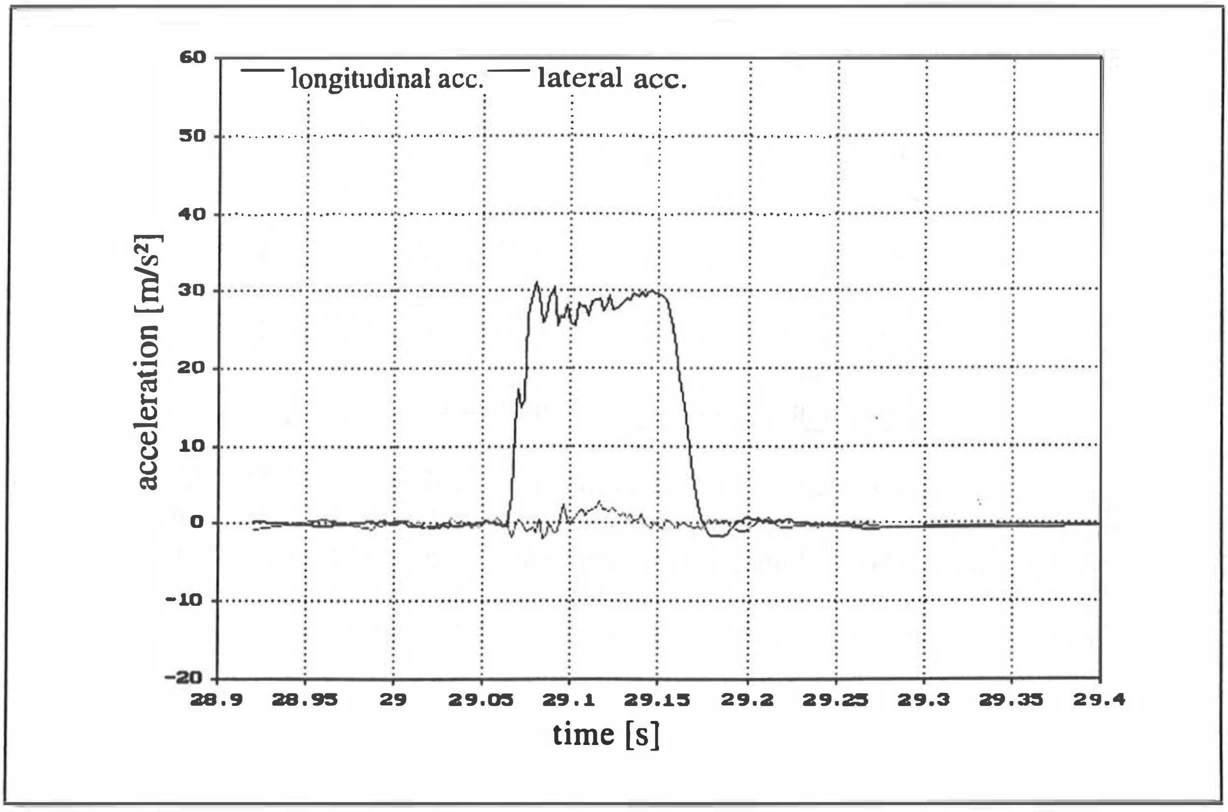


Fig. 1: Acceleration of the sled without passenger

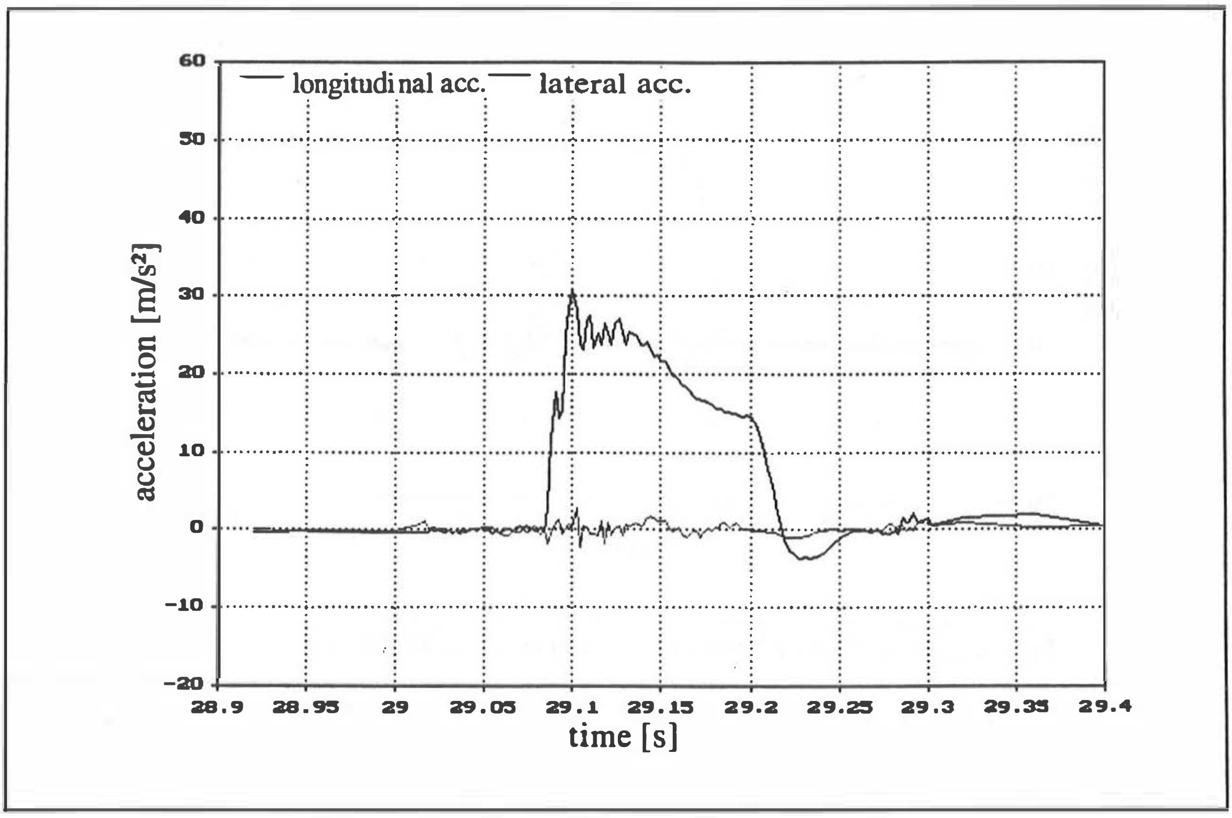


Fig. 2: Acceleration of the sled with passenger (100 kg)

The UDS measures the acceleration during the impact phase at a frequency of 500 Hz. The maximum measurable acceleration is 500 m/s² with a resolution of ±0.1 m/s² (Table 2).

Table 2: Mean Specification of the UDS™

dimensions:	13.5x11.5x4.5 cm
power supply:	= 12V / = 24 V
saved acceleration data:	longitudinal & lateral
range / precision:	± 50 g / ± 0.1 m/s²
frequency:	500 Hz
zero adjustment:	automatic

Figure 3 shows an example of a rearend collision measured with UDS. Comparing the accelerations of the sled with the real impact it can be seen that the initial jerk of the sled is a little bit higher. This can be explained by the fact that for the first few centimetres of the real impact phase only smooth parts like plastic are involved. Only when the metallic parts start to deform, a rather constant acceleration level of approximately 40 to 60 m/s² can be seen.

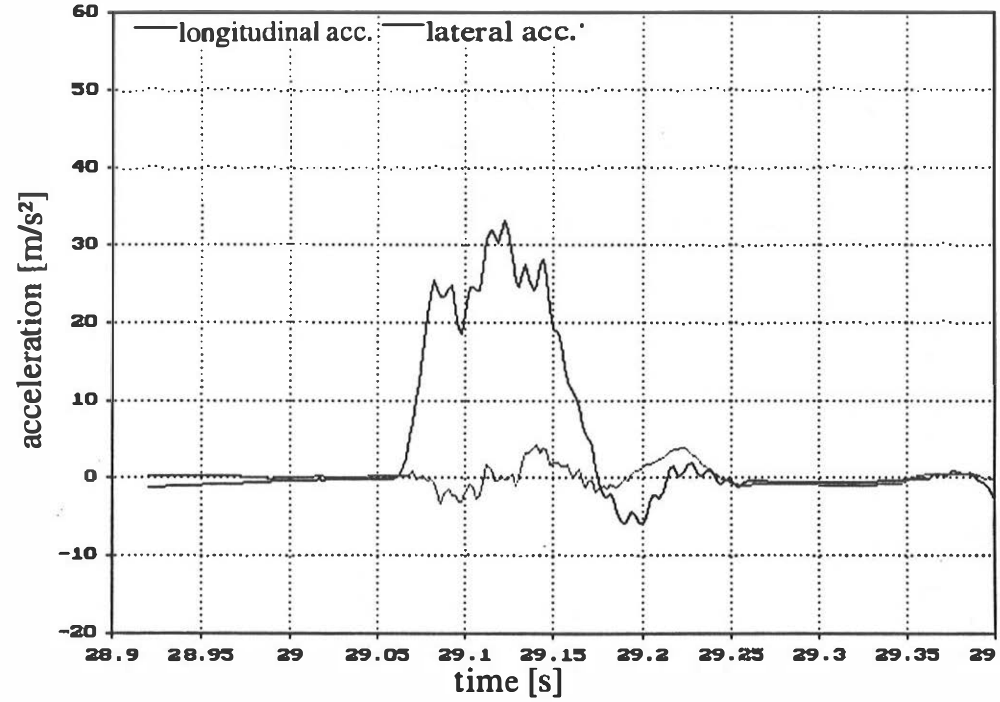


Fig. 3: Car body acceleration during a rearend impact (Δv = 8 km/h)

Seats

Already within the very first tests the big importance of the seat construction for the acceleration behaviour and the imposed forces for the car passengers could be seen. To get a good compatibility between the tests and the real accident situations the following configuration was used.

Most tests were performed with a seat from a VW Golf (Series II). To ensure a close compatibility to real accidents, seats from used cars were mounted on the sled. To consider the influence of the elasticity of the seat suspension a part of the Golf II (including the section from the A-pillar to the B-pillar without roof) was used. This section included the seat rails. So all elasticity's within the seat mounting were included. Whenever a change of the seat elasticity or a plastic deformation was seen the seat was exchanged.

During the experiments it pointed out that the Golf II-seat is a rather smooth and rather soft seat. Later on a BMW 525 seat was used for comparison.

EXPERIMENTS

PMTO Tests:
49 tests were performed with six PMTO´s (Table 3). The impact velocities varied between 6 km/h and 15 km/h. Mean sled deceleration's were generated between 13 m/s^2 and 85 m/s^2. All these experiments were performed with the same seat type (Golf II) and documented with a Kodak EktaPro 1000 high speed video camera with a rate of 1000 pps (pictures per second). Additionally some of the experiments were documented with two 3-axis accelerometers (Endevko). In all cases more than one test were performed with each individual PMTO. In addition to the parameter variation of impact velocity and acceleration characteristic the seat positions of the PMTO´s was varied. Influences like forward bending of a passenger or various distance variation between head and head restraint were investigated. For all test configurations the head restraint was fixed in a position which should provide an optimum protection.

Table 3: Mean Specification of the Experiments

Experiments with:		PMTO´s	Volunteers
number of objects		6	25
number of tests		49	37
sex of test objects	f/m	2 / 4	2 / 23
age of test objects		50 - 79	20 - 60
impact velocity	[km/h]	6 - 15	6 - 12
mean acceleration	[m/s^2]	13 - 85	12 - 40
initial head rotation	[deg]	±45	±15
gap head - head restraint	[cm]	0 - 16	0 - 8

To gain a better understanding of the movement of the cervical spine (especially the rotation) during the impact two vertebra bodies were marked with extra targets by means of two screws for most tests. A principle scheme of the mounting of these screws is shown in Figure 4. The movement of these targets was documented with the high speed video camera mentioned above. As no shear forces could be measured, it is difficult to comment on shear forces in the neck out of these experiments.

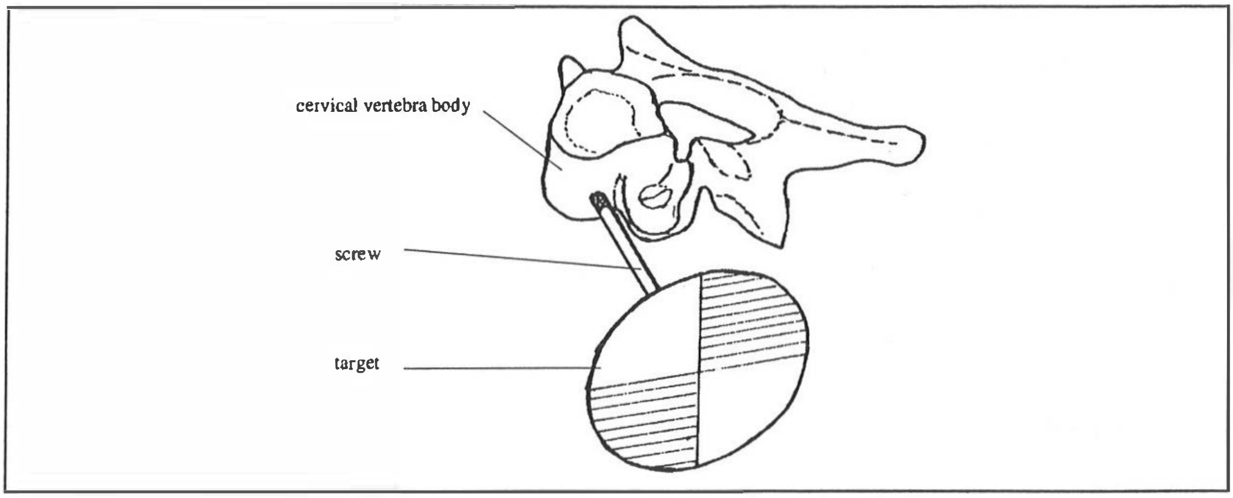


Fig. 4: Target mounting at cervical vertebra body

Volunteer Tests:

In addition 37 experiments with volunteers were performed. Minimising the injury risk of the volunteers, maximum impact velocity and mean sled deceleration of these experiments were limited to 12 km/h and 40 m/s² (see Table 3). During these tests all volunteers remained uninjured and no subjective neck pain were reported.

RESULTS AND DISCUSSION

All results discussed here are based on measurements with the seat of a Golf II series.

Head rotation

Regarding the rotation of the head the following characteristic movement could be seen for all tests.

Independent of initial seating position no head rotation could be seen during the first 60 to 100 msec. After this period the head starts to rotate backward. In this phase the shoulders are already reflected forward and the head moves with a very low translatoric movement still backward.

This rotation ends after appr. 100 - 160 msec and forward rotation is initiated.

The rotation angle for the backward rotation varied in a range from 10 to max. 75 degrees.

When comparing the different experiments, the following dependencies could be seen.

The magnitude of the head rotation mainly depends on the initial distance of head and head restraint. The larger the initial distance, the bigger is the degree of rotation. In case of an initial contact between head and head restraint, a maximum rotation of 15 deg could be seen, compared to an rotation angle of 75 degree for an initial distance between head and head restraint of 16 cm.

All other parameters like initial head-rotation, impact velocity (range: 6-15 km/h) and mean deceleration showed a minor influence on head rotation.

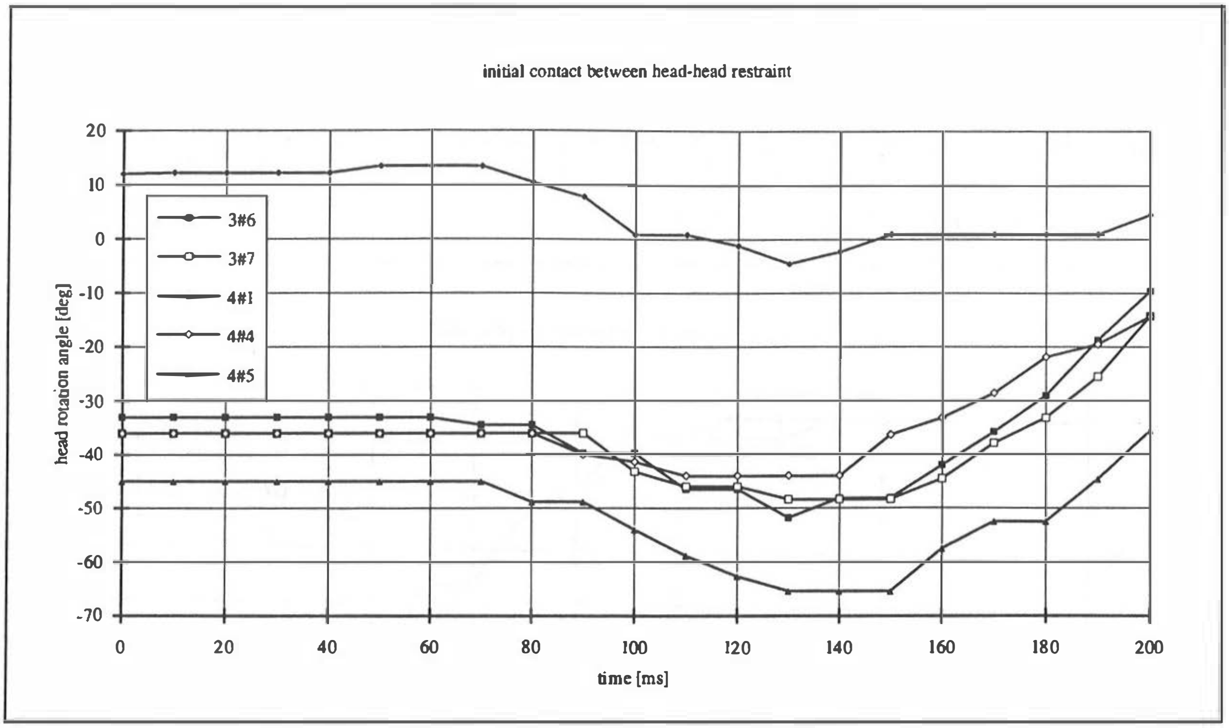


Fig. 5 shows a *comparison of different experiments with initial contact between head and head restraint*

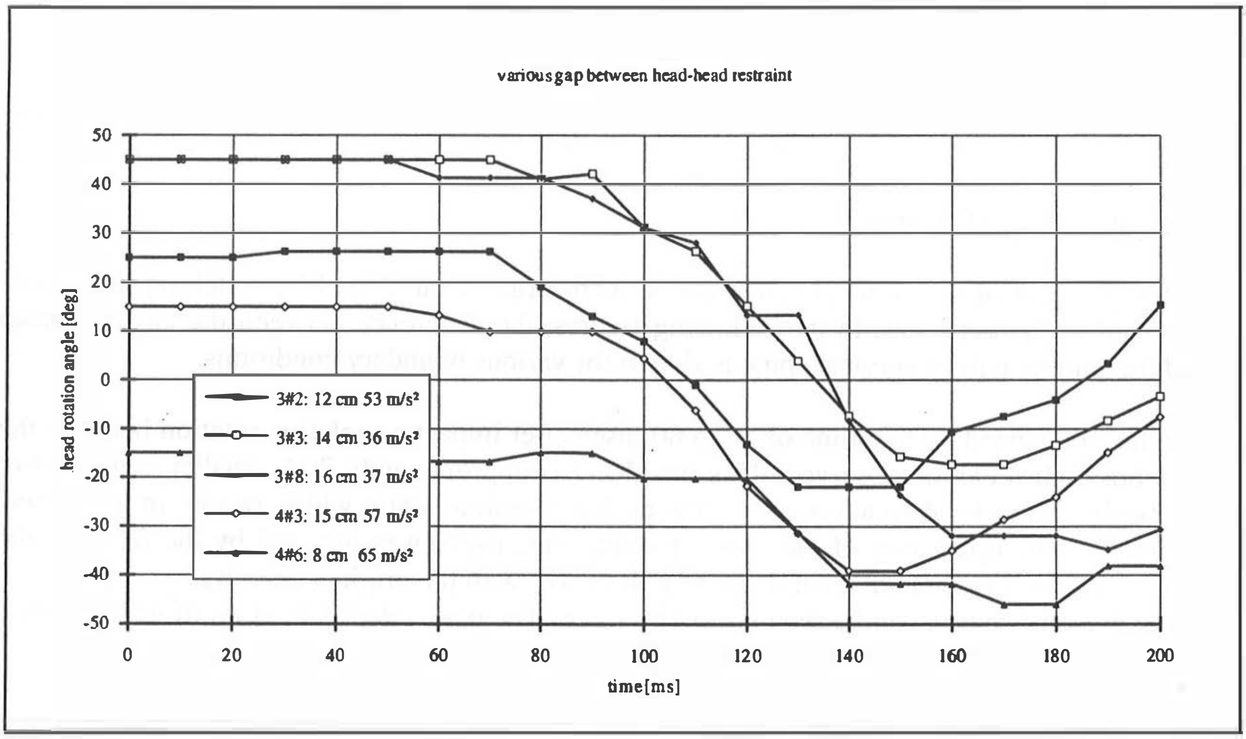


Fig. 6 shows a comparison of *different experiments with an initial distance between head and head restraint* of 11 to 16 cm

When comparing the rebound between PMTO´s and Volunteers, a kind of muscle reflection could be seen for the Volunteers 200 msec after impact. This muscle tone heavily influences the degree of the rebound. Therefore the rebound was not measured for the PMTO´s. In general it could be seen, that for this seat the rebound velocity was rather high for both, PMTO´s and Volunteers. This resulted from the high elasticity of the seat. The post impact velocity of the sled was below 1 km/h for all experiments.

To show the influence of the preparation one experiment was repeated for the same PMTO under similar conditions, before and after preparation. (See fig. 7: line 3#3 shows the experiment before preparation, 3#8 after)

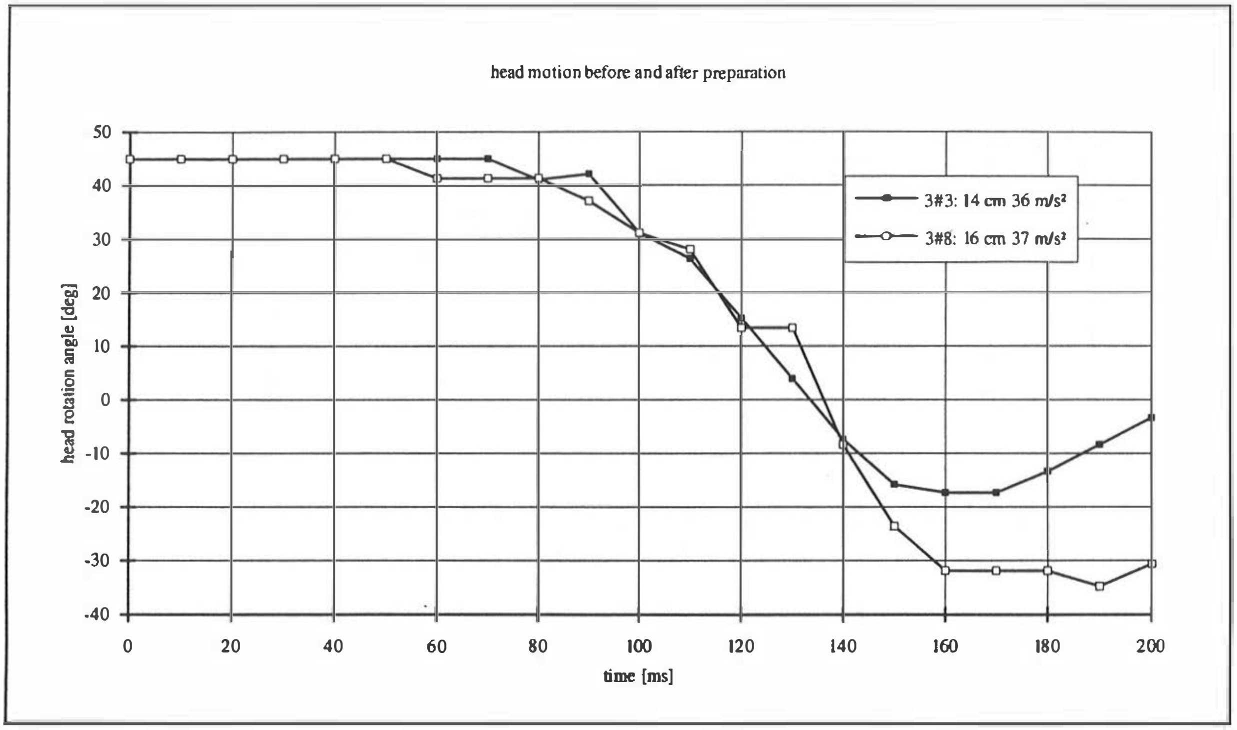


Fig. 7: Influence of preparation

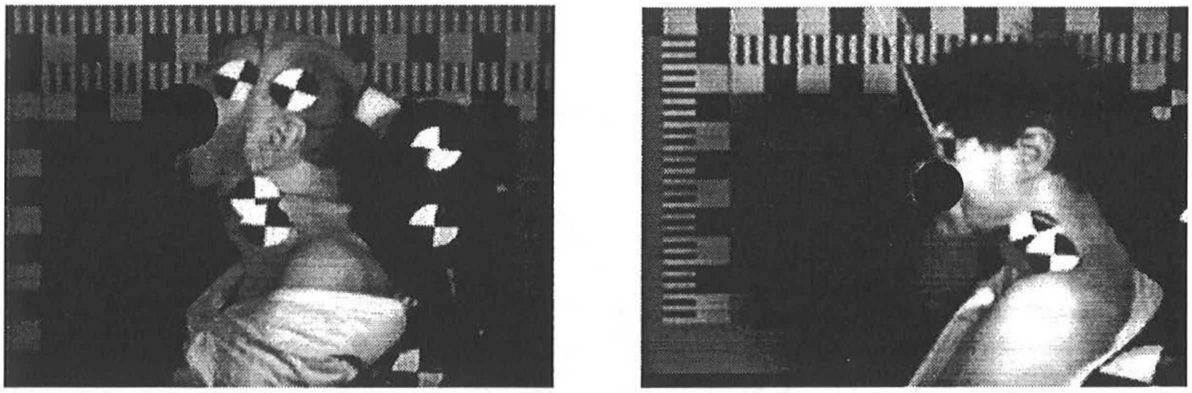
Movement of cervical spine

The movement of the cervical spine can be reconstructed quite well by watching the targets mounted to the vertebras. In the following figures, the difference between the angle of head and the middle part of cervical spine is shown for various boundary conditions.

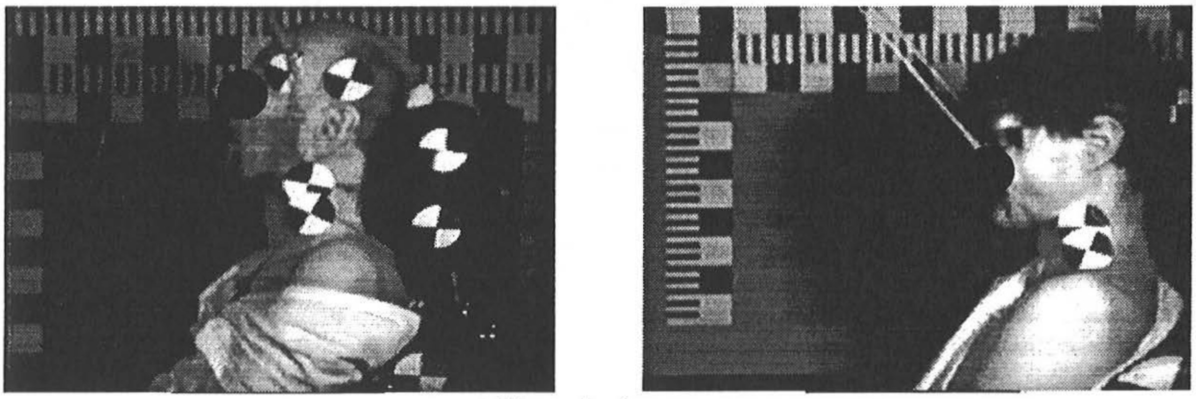
For the first period up to a time of 50 to 80 msec after impact no relative rotation between the vertebra bodies can be observed. This timedelay is approximately 20% smaller compared to the begin of the head rotation. After this period a motion starts which results in a "relative flexion" of the upper part of the cervical spine. This rotation is initiated by the fact that the shoulder starts to decelerate, but the head still moves with the original velocity.
Normally this flexion can be seen up to 180 msec. The peak relative rotation of up to 45 deg. was reached for most cases between 100 and 130 msec.

For the lower part of the cervical spine two types of movements can be seen:

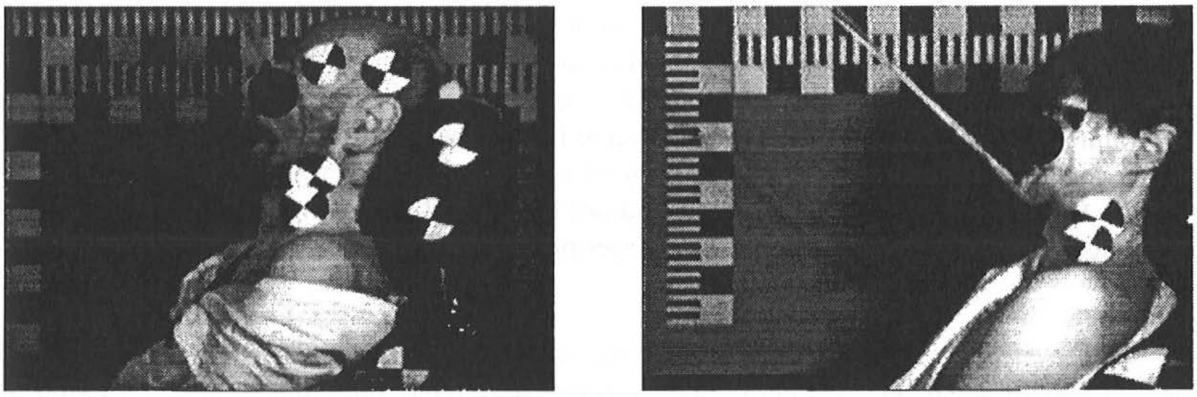
Case 1: Case 2:



70 ms after impact



90 ms after impact



110 ms after impact

Fig. 8: Comparison of different initial seating positions

On the left photo, 90 ms after impact, an increase of the flexion of the lower part of the cervical spine can be seen, which disappears after 110 msec for this testcase. The contact between head and head restraint occures in this experiment 100 ms after impact.

For the second case, shown on the right photos, this increase of the flexion cannot be observed. The movement immediately starts with an extension. The reason for this difference seems to be the initial sitting position. Especially the initial rotation of head and cervical spine could be suspected as major reason.

The contact between head and head restraint occures for the experiment on the left side 100 ms after impact and appr. 120 ms after impact on the right side.

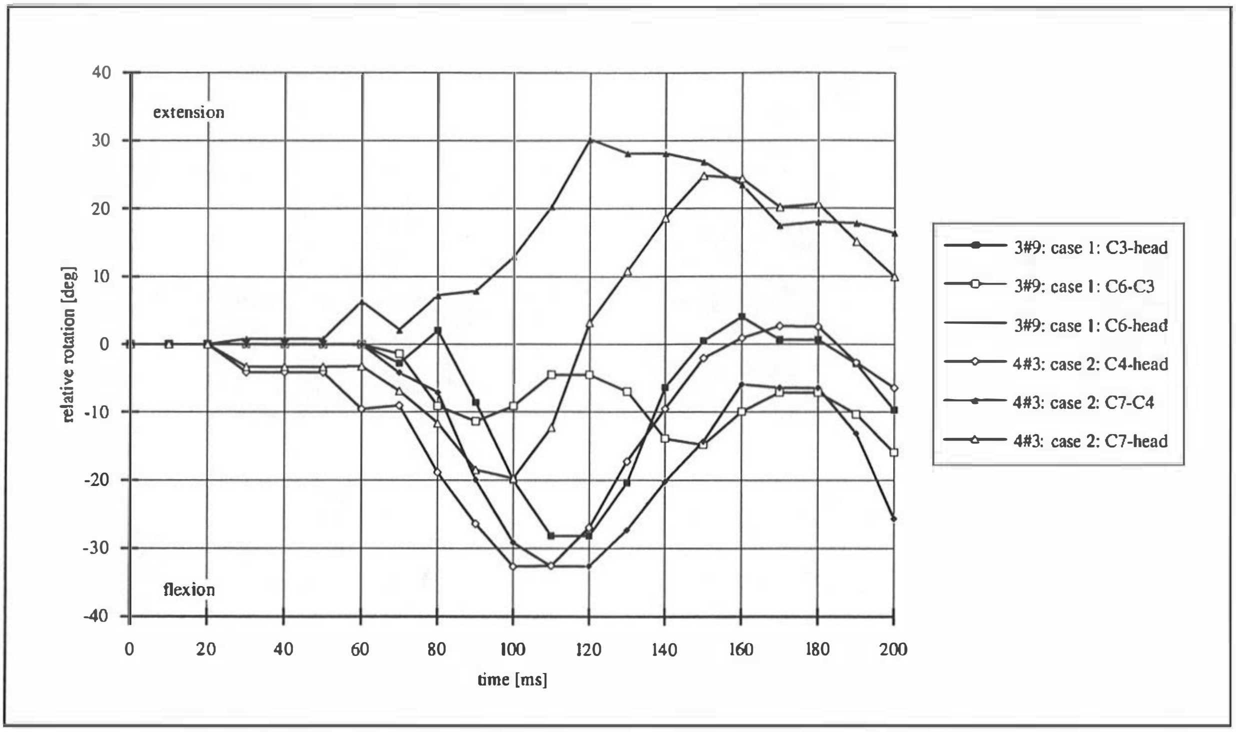
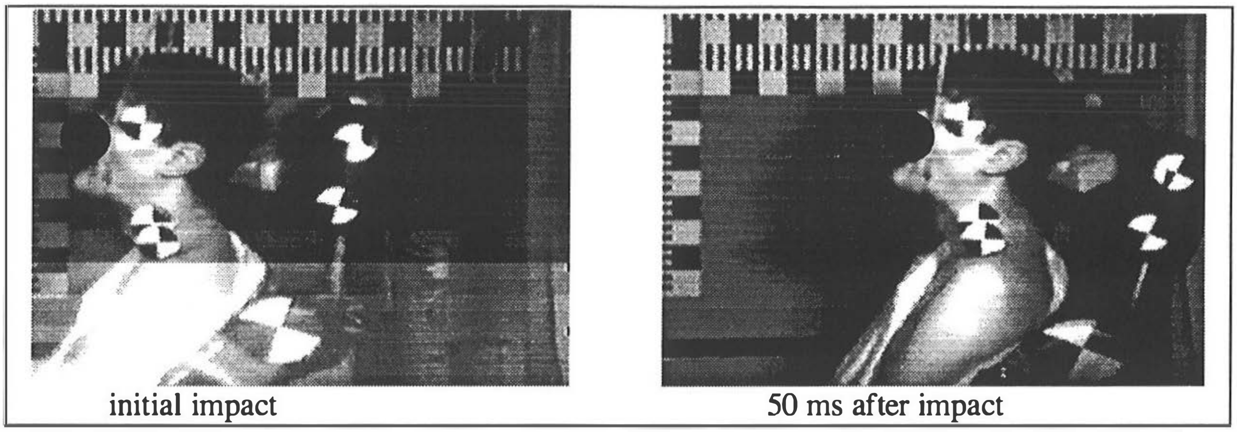


Fig. 9: Relative rotation between head and cervical spine

Special conditions

Several special phenomena could also be seen during these experiments.
If the head restraint cannot be adjusted at a level, which guarantees, that rather horizontal contact forces occur, additional head-rotations are created. To ensure horizontal contact forces, the contact point between head and head restraint must lay approximately at the same height as the centre of gravity of the head. For certain experiments, the length of the head restraint was to short. In this cases the relative flexion between head and C3 ended after 150 msec and a "extension" with a relative angle of up to 40 deg could be seen.
As the head restraint of the used seat could not be fixed at a certain height, the head restraint was pushed down during the impact, for larger persons (> 1.85 m)

In certain cases a plastic deformation of the seat back occurred. This resulted in a similar movement of head and vertebra. In this cases it pointed out, that a higher flexion was observed. This resulted from the fact, that during the plastic deformation of the seat back no head rotation occurred. The problem with this situation was, that the head restraint moved with higher velocity than the seat back and thus even increased the gap between head and head restraint. In addition the increased inclination of the seat back enlarges the risk, that the passenger slides up along the seat back.



initial impact 50 ms after impact

Fig. 10 Possible gap increase between head and head restraint for high seatback inclination

CONCLUSION

Out of the experiments performed, it could be seen, that many used car seats are by no means optimised regarding passenger protection for rearend impacts. The mayor problems can be summarised as follows:

Too small damping of the head restraint
Bolstering of head restraint to stiff
Distance between head and head restraint for sitting position should be reduced
Adjustment of head restraint insufficient (fixable, longer distance)
Neck should be protected by an additional bolstering to avoid extreme relative movement between head - cervical spine - and torso (e.g. integrated head restraint with separate neck protection)
Inclination of the seatback during the impact may enlarge the gap of head and head restraint.

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