

COMPARISON OF DIFFERENT CAR SEATS REGARDING HEAD-NECK KINEMATICS OF VOLUNTEERS DURING REAR END IMPACT

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ABSTRACT

Various research studies performed at different institutes (Deutscher 1994, Geigl et al 1994) have shown that current car seats are by no means optimized regarding the protection of occupants during rear end impacts. Sled tests performed with volunteers and PMTO's (Geigl et al, 1994) have shown some weak points of selected seats. In order to obtain more information on problems within the construction of current car seats, a comparison of standard seats seemed to be important.

In a collaboration between Graz University of Technology and the VdS (Verband der Schadenversicherer, Munich) approx. 7500 rear end impacts with personal injuries were investigated. The data was taken from the "Vehicle Safety 90" (VdS, 1994), a statistic which contains 15,000 actual car to car accidents with at least one occupant injured during 1990 in Germany (old states only). From these investigations several factors which influence neck injuries in rear end collisions could be evaluated.

On the other hand sled tests with volunteers were performed for some selected car seats. The head-neck kinematics of the occupants was measured and visualized. Identical test conditions as far as possible have been chosen in repeated tests to ensure a fair comparison of the different tests. Nine different types of car seats were used at sled impact velocities of 8 and 11 km/h. The mean sled decelerations were settled at a level of 2.5 g.

The comparison of the statistics with the measurements showed a fair correlation between both approaches. So a "ranking" of the different seats regarding their risk of a neck injury during rear end impacts could be defined and the biggest problems in seat construction could be summarized.

METHODOLOGY

REAL CRASH INVESTIGATIONS - The data of the "real crash study" were taken from "Vehicle Safety 90" (VS 90) (VdS, 1994). This material includes 15,000 accidents where at least one occupant was injured in Germany (old states only) in 1990 and covers approximately 15% of the car collisions with personal injury claims.

The characteristics of these collisions were compiled in a data base. These characteristics are: car model, car mass, passengers, injuries, angle and offset of collision, etc. Approx. 50% of these collisions were rear end collisions. Due to an extended investigation 520 rear end collisions were taken from this data base and reconstructions of the accidents were performed.

Influences on neck injuries dealing with the car (mass, model, structure, head restraint adjustment), the occupant (age, sex, pretended injuries) and situation of the crash (ΔV , angle and offset of collision, etc.) were evaluated.

SLED TESTS - To validate the statistic data and the influence of the car seat construction, 34 sled tests were performed with 9 different car seats. The sled and other hard- and software used are described in more detail by Geigl et al (1994). Due to the fact that Hybrid-III-Dummies do not show realistic head-neck-kinematics in rear end collisions (Geigl et al 1994, Scott et al 1993), only sled tests with volunteers were performed. The impact speed of the sled was selected between 8 and 11 km/h and corresponded with the change of velocity (ΔV) of the struck car in reality. All tested seats have been taken from used cars and were in good condition. Most of the selected seats (See table 1) were taken from frequent cars in 1990. The Golf III seat was selected for comparison purposes.

Table 1 - List of tested car seats

Car Model	year of production
AUDI 80	1988
BMW 5..	1992
FORD Escort	1985
MAZDA 323	1989
MERCEDES W124	1987
OPEL Corsa A	1985
PORSCHE 911	1988
VW Golf II	1989
VW Golf III	1993

The deceleration behavior of the sled was defined as a nearly rectangular pulse at a level of approx. 2.5 g. Test conditions have been kept identical as far as possible to ensure a good reproducibility and comparability of the different tests.

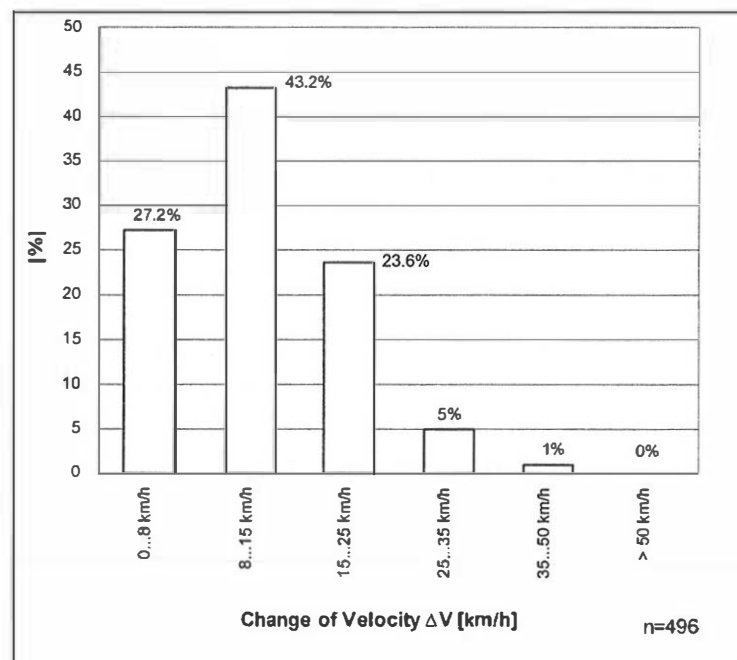
The following parameters were used for the sled tests:

- The inclination of the seat back was adjusted to 25° against the vertical for all tests.
- Sled impact velocity: 10.5 \pm 0.2 km/h (Test no. 1 to 17), 8.5 \pm 0.2 km/h (Test no. 18 to 34).
- The deceleration level of the sled was kept as constant as possible (average deceleration approx. 2.5 g)
- Adjustment of the head restraint was as "good" as possible (average distance between the top of the head and the top of the head restraint approx. 60 mm).
- The volunteers were told to sit relaxed in the position they prefer in their own car.
- Since the sled was towed up to constant test speed against the line of sight, the volunteers were not able to predict the moment of the sled impact.

RESULTS AND DISCUSSION

REAL CRASH INVESTIGATIONS - Within 93.5% of all rear end collisions with personal injuries, at least one of the passengers claimed a neck injury (VS 90). Other injuries are comparatively rare (Münker et al, 1994). The change of velocity (Δv) of the struck car is often at a low level (Fig. 1).

Fig. 1 - Distribution of ΔV of the struck car at rear end collisions



The change of velocity was determined by reconstruction of approx. 500 rear end collisions. This was realized by evaluating the EES* of the involved cars (using pictures of the crashed vehicles) and an assumption of the elasticity of the impact (Eichberger, 1995). Fig. 1 shows that most rear end impacts with neck injury claims occurred at low velocity changes.

Further investigations on real crash material confirmed that the most important influences regarding neck injuries are:

- car model (especially car mass, car structure and car seat)
- change of velocity (ΔV) of the struck car.

To get the influence of the car model for the risk of neck injuries approx. 50 cars were statistically investigated. From this data the "Neck Injury Factor" (NIF) for the considered cars was defined. The NIF describes the frequency of neck injuries claims for a car regarding the number of registrations of this car. It was calculated by the following formula:

$$NIF = \frac{n_{\text{neck}}}{n_{\text{FS90}}} \cdot \frac{m_{\text{Germany}}}{m_{\text{car}}}$$

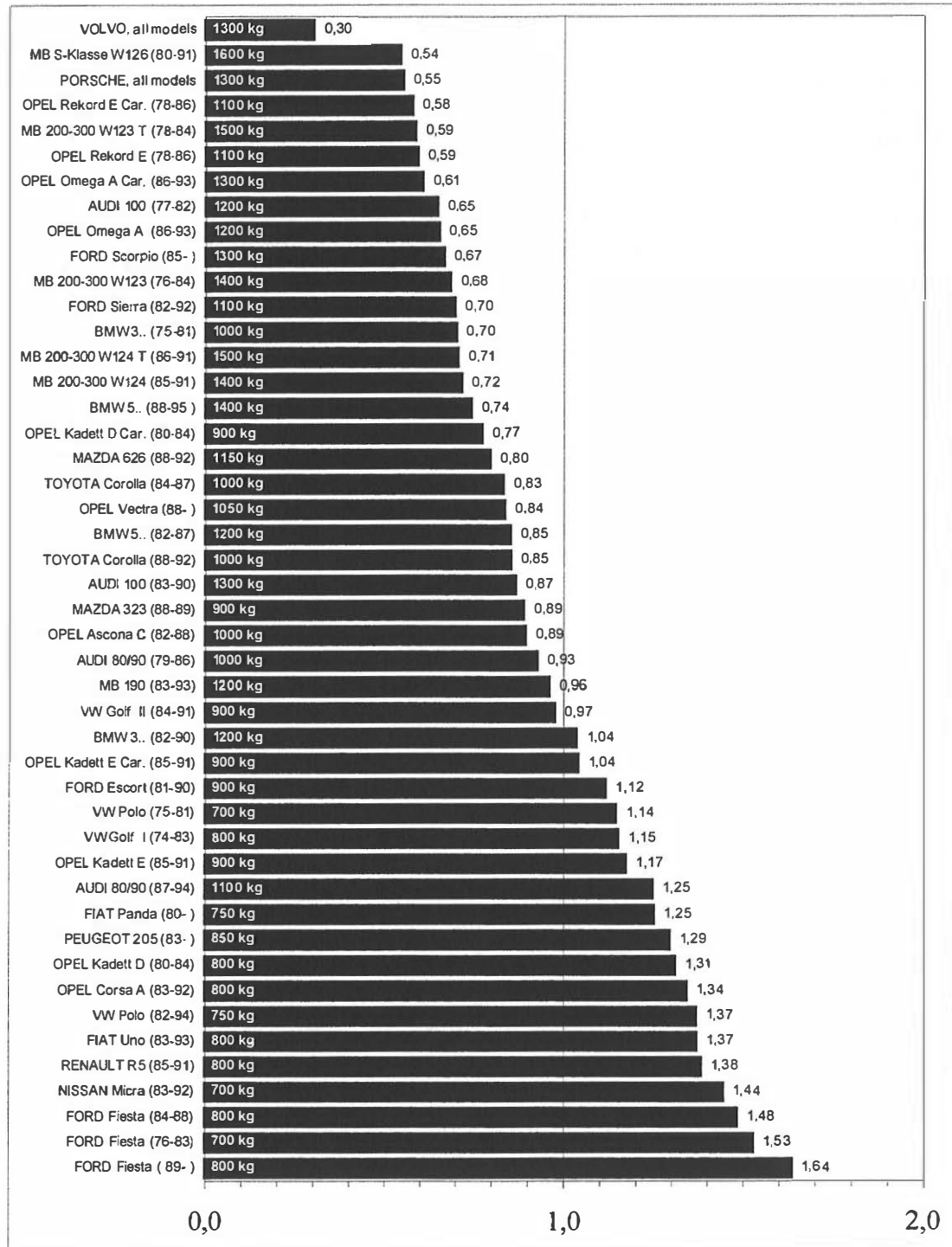
- n_{neck} : number of neck injury claims of the considered car model (rear end impact) at Vehicle Safety 90 (VS 90) data base
- n_{FS90} : number of rear end impacts at the VS 90 data base ($n_{\text{FS90}}=7482$).
- m_{Germany} : number of registered cars in Germany 1990 ($m_{\text{car}}=30.684.811$).
- m_{car} : number of the considered car in Germany 1990

NIF=1 means that the frequency of neck injury claims of the considered car is equal the frequency of the car on the road. Therefore NIF =1 can be classified as average. Cars with NIF greater than 1 represent a higher risk, a NIF lower than 1 indicates a safer car regarding neck injuries.

The NIF for frequent car models are shown in Fig. 2.

* Energy Equivalent Speed: Deformation energy expressed as velocity

Fig. 2 - Neck Injury Factor of various car models

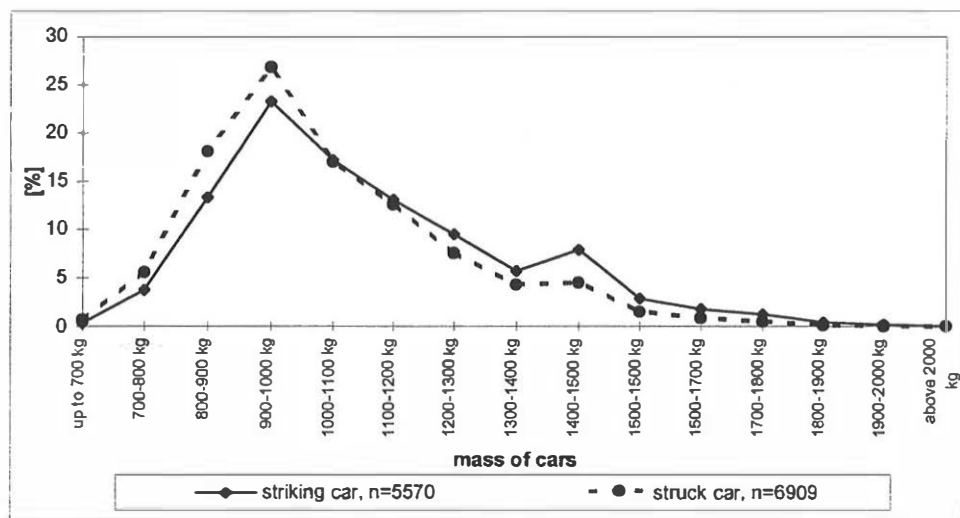


The NIF of the worst car is 5.5 times higher than the best in this study. This means that in the case of a rear end impact the risk of neck injuries is 5.5 times higher for the worst than for the best car.

Comparing the results to v Koch et al (1995) a correlation coefficient between NIF and the “relative injury risk” $r=0.77$ can be observed (considering 21 car models which can be compared directly). The problem is that the factors are evaluated with different methods and do not belong to the same sample. Nevertheless both studies show similar tendencies and illustrate the fact that there is a clear influence of the car model on the risk of neck injury.

The NIF includes the influence of the car mass. The ratio of the masses of the two involved cars influences the change of velocity of the struck car. Fig. 3 shows the mass distribution of the struck and the striking car. 100% corresponds to all rear end collisions with neck injury claims in VS 90.

Fig. 3 - Mass distribution of striking and struck car



Among cars of low mass (1100 kg or less) more struck than striking cars can be observed. Among heavy cars (1100 kg or more) the situation is turned upside down, consequently the risk of neck injury is higher when a heavy car strikes a car of low mass. The ratio of car masses is an important factor regarding the risk of neck injury but improvement can only be achieved by producing cars of equal mass which is an unrealistic scenario.

A lot of further influences like age and sex of the injured person, impact direction and offset of the collision, stiffness of car structure etc. were also investigated (Eichberger, 1995), but it was not possible to isolate the influence of the car seat which was considered to be the most important factor. For this reason sled tests with volunteers were performed.

SLED TESTS - The aim was to get a ranking of the tested seats and to compare it to the Neck Injury Factor (NIF) of the statistics. Sled deceleration was measured using a Kienzle UDSTM, an accident data recorder mounted on the sled. The volunteers were equipped with two 3-axis accelerometers. The head accelerometer was mounted near the estimated center of gravity of the head. The torso accelerometer was mounted in front of the chest, approx. the

same area as the torso accelerometer of the dummy (Geigl, 1994). At the same locations targets for the high speed video analysis were fixed.

Fig. 4 shows the acceleration behavior of sled, torso and head for one test. Head and torso accelerations are resultant of the triaxial accelerations. The corresponding relative angular displacement between head and torso is shown in Fig 5. The angular displacement was measured by analyzing the High Speed Video. The angle between head and torso at t_0 (first contact of sled and deformation element) was defined 0 and the relative angle between head and torso was calculated for the whole impact.

Fig 4 - Acceleration behavior of sled, torso and head

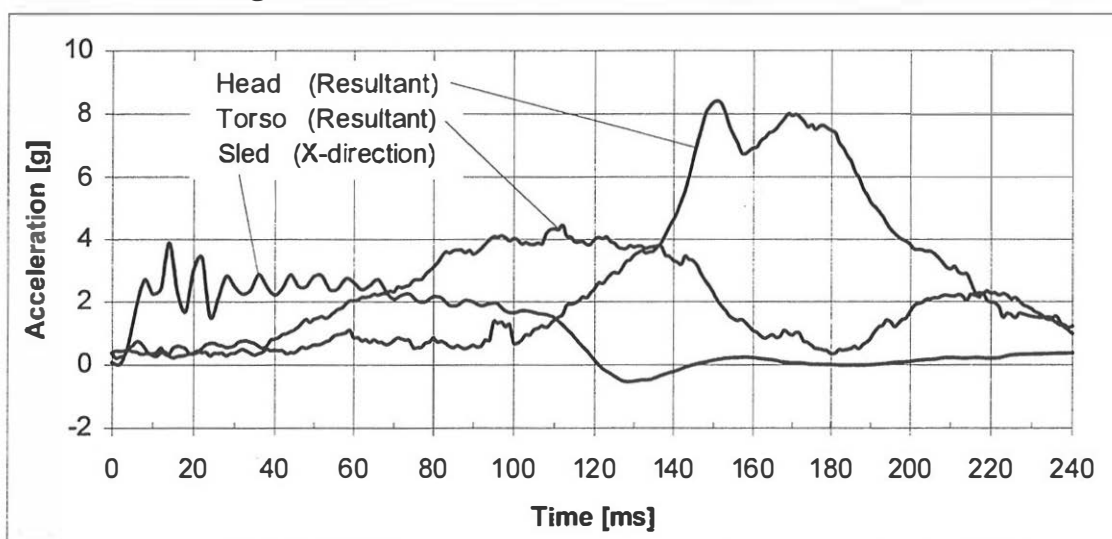
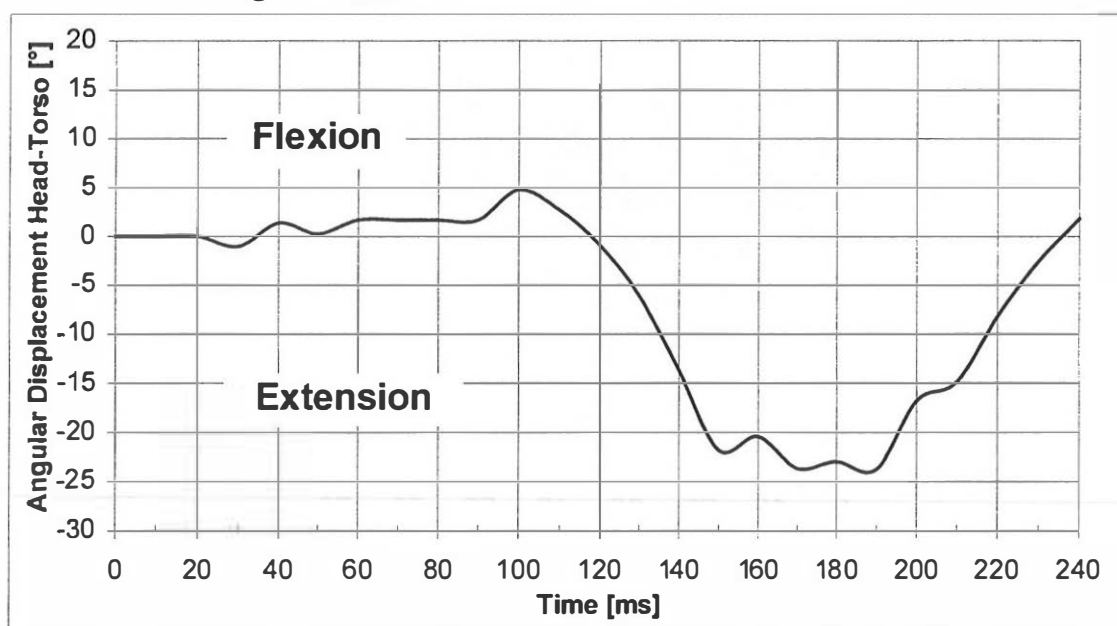


Fig. 5 - Relative rotation between head and torso



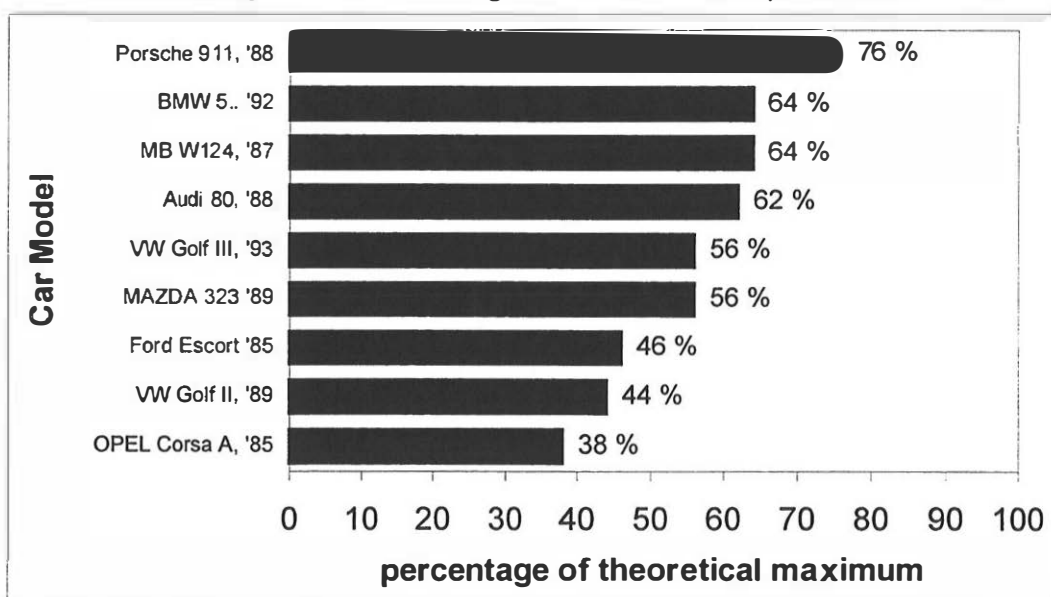
After full contact with the seat back (40 ms) the torso is accelerated while the head remains in its initial position. Significant head acceleration starts after 100 ms. This delay of head and torso acceleration results in a relative motion between head and torso (Fig. 4). From the high speed video analysis, it can be observed that head - head restraint contact occurs at approx. 130 ms. This means that the forces and moments causing the head acceleration (up to 4g before contact) and head rotation between 100 and 130 ms have to be exerted by the neck (Fig. 5). The maximum head acceleration is reached after head - head restraint contact. Elasticity of the seat leads to a rebound after approx. 200 ms.

A ranking of the tested seats was evaluated by a point system (Eichberger, 1995). The following characteristics were taken into account by grading, using a scale from 0 to 50 (50 points = theoretical maximum):

- the height of the head restraint (distance between top of the head and top of the head restraint of various volunteers): 0 to 15 points
- the horizontal gap between head and head restraint (for a realistic seating position): 0 to 10 points
- the shape of the head restraint (size, curvature): 0 to 5 points
- padding of the head restraint (hard-soft): 0 to 5 points
- kinematics of the volunteers (angular displacements, accelerations): 0 to 10 points
- characteristics of the seat back (elasticity, stiffness): 0 to 5 points

Fig. 6 shows this ranking as percentage of the theoretical maximum:

Fig. 6 - Seat ranking of the sled test experiments

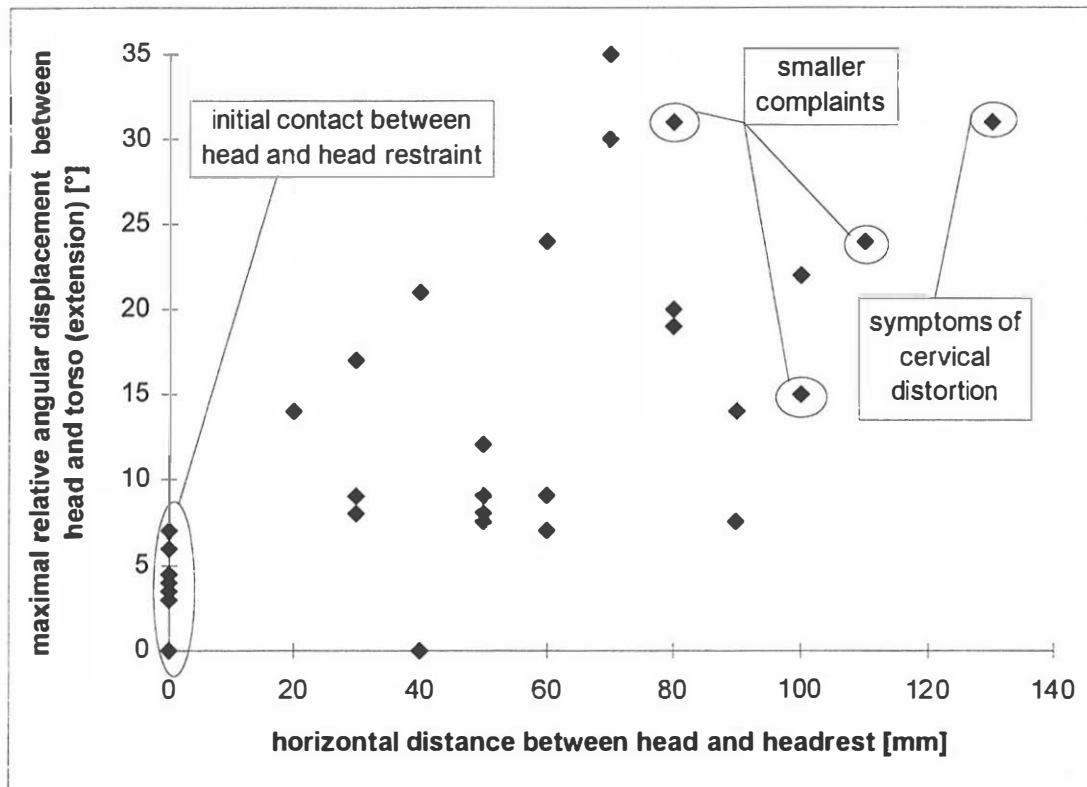


No tested seat was considered to be optimal (100 %). Due to the comparatively high mounted integral head restraint, the low horizontal distance

and other construction details, the seat of Porsche 911 was the best of the tested seats. In several tests of lower ranked seats the volunteers suffered from smaller neck complaints the next day which lasted for approx. 24 hours. For one test the volunteer complained about symptoms of cervical distortion for about two weeks.

Due to their poor seat design four additional seats could not be tested since the neck injury risk for the volunteers was obviously too high.

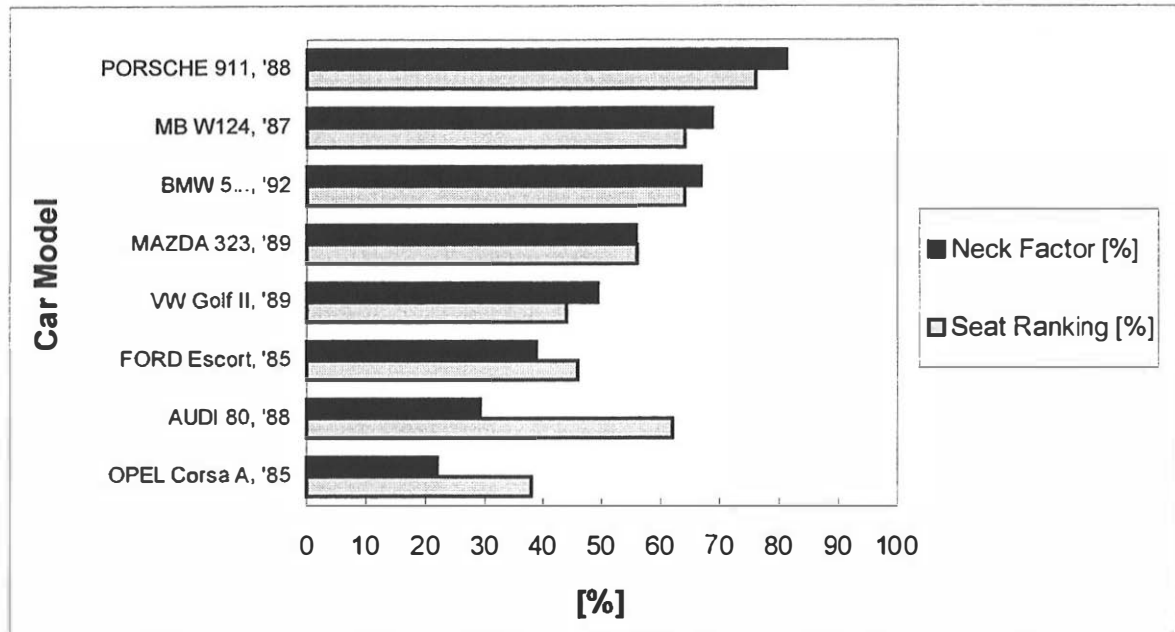
Fig. 7 - Correlation between horizontal distance and angular displacement



The relationship between the horizontal distance and the peak value of the angular displacement between head and torso can be seen in Fig. 7. The risk of neck injury rises with horizontal distance since all complaints reported by volunteers occurred at high distances. Therefore a low horizontal distance between head and head restraint is very important for a good seat design. Even a head restraint placed high enough can only prevent neck injuries when the head is sustained as soon as possible by the head restraint during rear end collision.

COMPARISON OF STATISTICAL AND EXPERIMENTAL DATA - The relation between the Neck Injury Factor (NIF) from real crash statistics and the seat ranking from the sled tests is shown in Fig. 8.

Fig. 8 - Comparison between Neck Injury Factor (NIF) and seat ranking



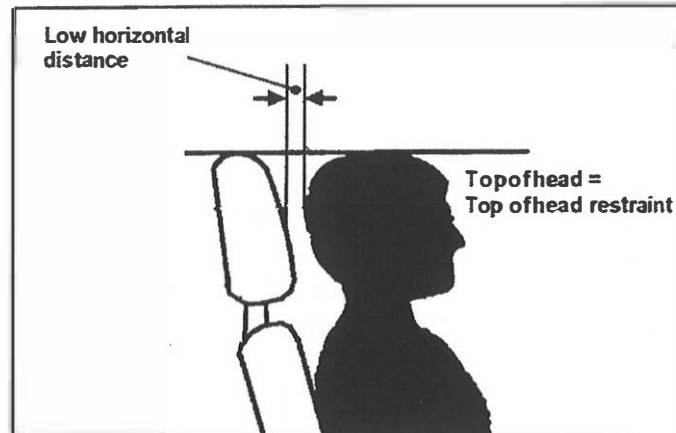
For the purpose of this comparison the best NIF (Volvo: 0.299) was defined to 100% and the worst (Ford Fiesta: 1.635) to 0%. The correlation between the neck injury factor from real crashes and the seat ranking is good.

For one car model (AUDI 80) a considerable difference could be observed. The seat of the AUDI 80 was the only one in the test series with a frame design of the head restraint. This was not considered in the point system of the seat ranking and may increase the risk of neck injury. For the OPEL Corsa A the seat ranking is distinctly better than the NIF which may reflect the influence of the car mass.

SUMMARY AND CONCLUSIONS

It was shown that the relationship between the frequency of neck injuries at rear end impacts in actual crashes and the car seat "ranking" from experimental tests with volunteers was close. Compared to other influences (car mass, physiognomy of the passenger, angle of collision, ...) the seat and its head restraint is the most important fact. Therefore it is possible to decrease the risk of neck injury by optimizing the car seat design (Muser et al, 1994). The most important design parameters are a low horizontal distance between head and head restraint as well as the head restraint height. In Fig. 9 the recommendation of the VdS (VdS, 1994) about correct adjustment of the head restraint is shown.

Fig. 9 - Recommendation of the VdS on correct head restraint adjustment



Unfortunately only a few cars are equipped with seats that allow correct adjustment.

Furthermore stiffness and elasticity of the seat frame, padding of the seat (higher damping rate) and ergonomics are to be optimized. Also the possibility of misadjustment should be reduced, e.g. by integrated head restraints. The fact that the average change of velocity of the struck car is comparatively low (approx. 10 to 15 km/h) makes clear that improvements are possible.

About 20% of the neck injury claims occurred at an ΔV lower than 8 km/h and without thorough medical check-up. In the author's opinion, these cases can be considered as the lower limit of pretended injuries. Therefore a lot of neck injuries can be considered as "extra money" for the crash victim. It is the task of the insurance companies (crash reconstruction, objective medical certificates) to deal with this aspect.

The results of this study suggest that many neck injuries caused by rear end collisions can be avoided simply by optimizing the seat design. Minimum requirements should be specified by regulations for seat and head restraint design. A detailed medical examination and a crash reconstruction for each case will decrease the number of pretended injuries.

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