CONSEQUENCES FOR SEAT DESIGN DUE TO REAR END ACCIDENT ANALYSIS, SLED TESTS AND POSSIBLE TEST CRITERIA FOR REDUCING CERVICAL SPINE INJURIES AFTER REAR-END COLLISION

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ABSTRACT

Proposals for head restraint improvement will be outlined on the basis of current research activities. New results from accident analysis will be discussed like QTF injury scaling depending on gender and delta v. It appears that women show a significantly higher risk of neurological QTF Grade 3 Cervical Spine Distortion (CSD) injuries in both front seating positions (driver and passenger) than male occupants. A sled test series based on different anthropometric measurements will be discussed. Moreover, muscular electrode measurements for the deep and superficial cervical musculature during a rear end impact sled test series with volunteers (delta v 6.5 and 9.5 km/h) are presented. This test series also integrates the deep Musculus semispinalis capitis, which could be associated with common muscular pain after CSD.

In addition, current rear end impact test methodologies will be evaluated, and a dynamic test standard proposal presented.

CERVICAL SPINE DISTORTION -AIS1(AAAM, 1990)- injuries after rear end collision represent a major impact on modern countries (Langwieder, 1996, 1999, Minton, 1997). CSD is one of the most common injuries in car accidents (about 50% of all car/car accidents with injuries). In connection with its costs and incidence CSD is a primary goal of efforts in prevention, although the origin of injury is still not fully clear. A recent paper (Hell, 1998) has described the results of an accident investigation sample using the new QTF injury scaling (Spitzer, 1995). The Quebec Task Force (QTF) Classification is based on the clinical presentation of the CSD injury (AIS 1). QTF degree 1 describes neck complaint without physical signs, QTF2 adds musculosceletal signs, QTF3 adds neurological signs. QTF4 is used for additional cervical spine fracture or

dislocation (AIS 2+) (for a definition, refer to the Appendix). Although still lacking medical definition and documentation might bias the accident sample with fraud injury, it was concluded that high head restraint adjustment showed a better injury outcome than medium or low adjustment. But also the factor of seat/head restraint construction has to be taken into account, where different car types of the same weight class perform differently in accident statistics (Gustafsson, 1984, Hell, 1998), see also Krafft (1998). The highest risk population appears to be female with a risk of injury 1.4-2 times higher (Hell, 1998, Temming, 1997). Therefore a more detailed accident analysis as well as additional sled tests have been analysed in this study to focus on this phenomenon.

The importance of soft tissue especially of the muscular system on the development of pain syndromes after CSD-acceleration-injuries is not denied, but was not able to be proved for a long time. EMG examinations (Kramer, 1999, Hartwig, 1998) showed malfunction of the neck muscles after acute and chronic pain syndromes being regressive with successful therapy. These changes in electric activity are obviously connected with the complaints of the patients.

There is an awareness of the importance of the muscles as a motion influencing element in the development of CSD-Dummies (Davidsson 1998, Linder, 1998) But in spite of its evident relevance, this factor is still neglected today, often with the argument that the muscle reflex–time is too long to react to quickly acting loads. However, a dummy of a weight comparable to a living test person shows greater head acceleration and greater motion amplitudes at equal loads. It can be assumed that these differences are conditioned due to the muscle activity.

Information about the mode of function of the neck muscles would therefore be desirable.

NEW DATA ANALYSIS ACCIDENT INVESTIGATION

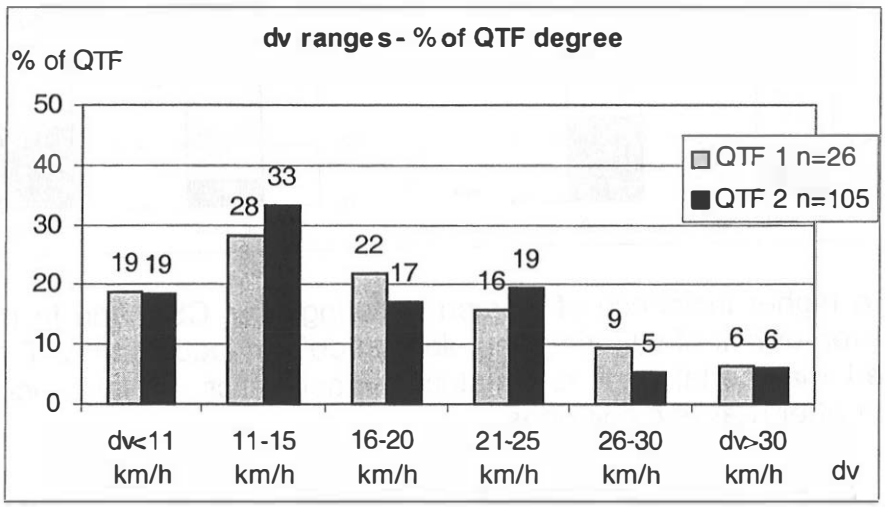
All 15.000 GDV "Vehicle Safety-90" (VS 90) (GDV, 1994) cases (18% of all car-car collisions with injuries in the year 1990 in West-Germany) were screened to obtain defined cases involving: rear-end collision, single impact, claimed cervical spine injury (CSD), good medical documentation and if possible photographic documentation, so that it was ultimately possible to investigate a total number of 517 cases of rear-end collisions involving 833 persons, 673 (80,8%) of whom claimed CSD injury (Hell, 1998). An initial analysis of this material has been already presented at the IRCOBI Conference 1998; this analysis focuses on new research questions. PC-Crash analysed 170 cases to obtain more accident related information like delta v.

In 68,7% the patients with reported CSD suffered only from this injury. Another 20% had another injury rated AIS 1, the maximum injury severity reached ISS 8 (maximum AIS 2) in 0,3 % of the cases (n=611).

It is important to note that all reported CSD injuries were included in the sample. The proportion of aggravated cases, in which the reported symptoms are not or only partly accident-related, could not be identified and may attain 30-50% (IIHS, 1999, Münker, 1994, Hell, 1998).

The following figure shows the delta v distribution for different QTF degrees. QTF3 was excluded due to a low case number (n=3). Only cases with known dv and CSD severity could be regarded. 10 cases occurred in the range above 30 km/h, the maximum dv was 42 km/h.

Figure 1: Connection between delta v and QTF injury degree



In figure 1 it can be seen that the dv distribution is nearly similar for QTF1 and QTF2. The lower changes in velocity present the greatest risk to passengers in the struck car of suffering CSD. In about 50 % of the cases the velocity change was up to 15 km/h no matter what kind of QTF degree. There have to be other parameters that define the actual degree of injury, e.g. head-restraint position, seat inclination or occupant characteristics.

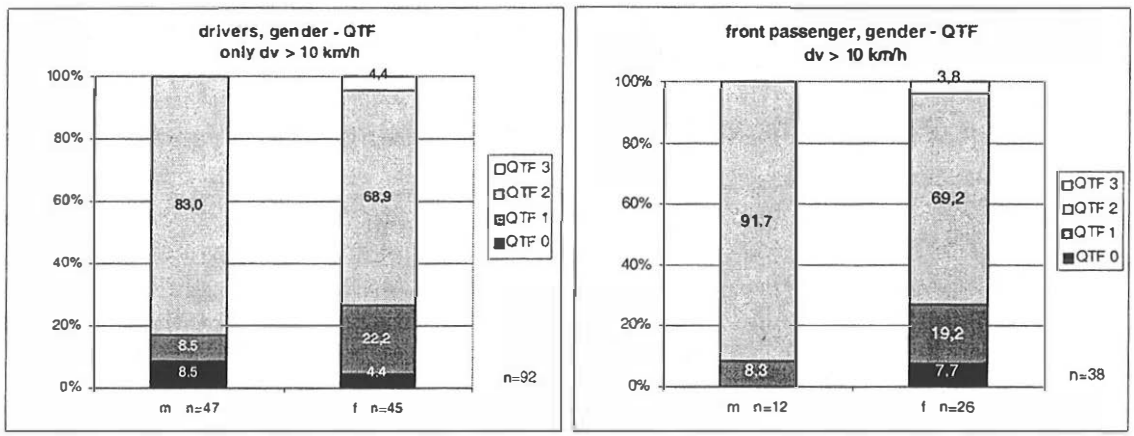
Recent examination of rear-end accidents showed a greater risk to female passengers of sustaining a cervical spine distortion in rear-end accidents (Hell, 1998, Temming, 1997).

Again the data material had been analysed, but only accidents with a change of velocity (dv) of over 10 km/h for the struck car were taken into consideration in order to reduce the number of possibly aggravated cases; here all front passengers with known gender and CSD severity degree were considered.

Figure 2 shows that a higher percentage of men remains uninjured and QTF 3 is only seen in women. The influence of age can be excluded in this sample due to the homogenous distribution.

No difference between the severity of CSD can be found when female drivers are compared with front passengers. Since the data sets were very small, more cases should be analysed in the future.

Figure 2: QTF and gender



With a higher incidence of women suffering from CSD and in the event of injury a greater risk of suffering neurological deficits leading to QTF 3, it can be concluded that certain anthropometric characteristics do influence kinematic behaviour after rear-end collisions.

SLED TESTS WITH VOLUNTEERS

OBJECTIVE -Regarding the results from accident analysis in this test series, subject related parameters were examined with a view to determining some existing influence on kinematic behavior. The muscular activity of the M. sternocleidomastoid muscle (m.st.) and of the deep semispinalis capitis muscle (m.se.) was measured during the rear-end collision.

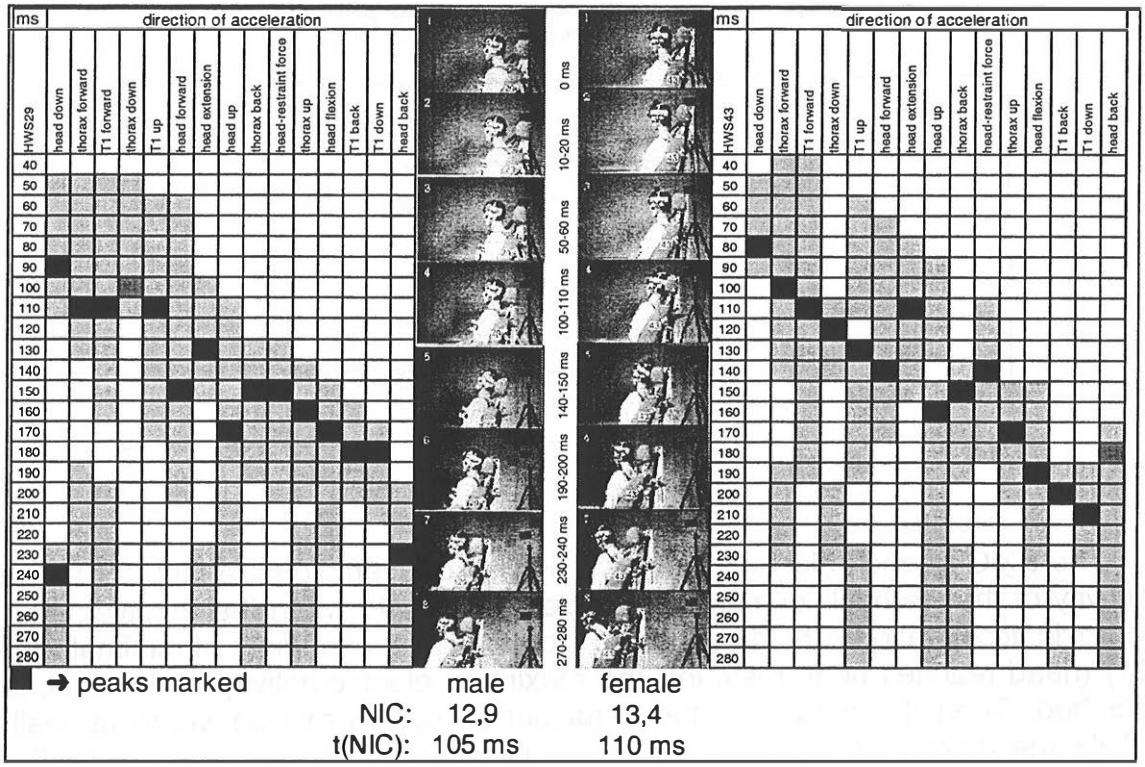
MATERIAL AND METHODS, SLED TESTS -43 tests involving 19 human volunteers with a German standard car seat mostly at design position (a seatback angle of 25° degrees) had been performed at two delta v's of 6.5 and 9.5 km/h. The sled pulses were between 3 and 4 g peak acceleration and expected to be under the injury limit.

The EMG derivation of both muscles was measured in 15 tests. The m.st. was chosen as a representative of strong head flexion. The measurement was derived from superficial EMG electrodes because an intramuscular stinging seemed to be too risky owing to the proximity to important nerves and blood vessels. A cross talk phenomenon between superficial and deep muscles was not to be expected here. The m.se. was chosen for head extension to represent the dorsal muscle group. The activity of the m.se. was derived from intramuscular electrodes according to the Kramer and Hartwig method to avoid cross talk phenomenon between surrounding muscles. Dynamic EMG activity was recorded during rear impact. This was then compared with the relative head-thoracic acceleration A(h-T1) behaviour (head acc. was measured at the centre of gravity, thoracic acc. at the spinous process of the thoracic vertebra1(T1)). In this report the temporal progression between head acceleration and muscle activity shall be described by way of example on the basis of one volunteer.

The age of the subjects ranged between 17 and 51 years (mean 29.9 years), height between 1.64 and 1.94 m, and weight from 56 to 92 kg. 16 male and 3 female subjects were tested, where the anthropometric characteristic of the tested females showed a lower neck circumference, lower head mass and body weight compared to the tested male volunteers. But even the males showed a wide variation in seating height, head mass and neck circumference (Kroonenberg, 1998).

RESULTS -The first visual impression was a significant variation between different volunteers under the same test conditions. Most male volunteers showed a different head flexion behavior (rebound, minor forward flexion) compared to female volunteers (clear forward flexion).

Figure 3: Kinematics of volunteers at delta v 9,5 km/h, 25° seat inclination, high head-restraint



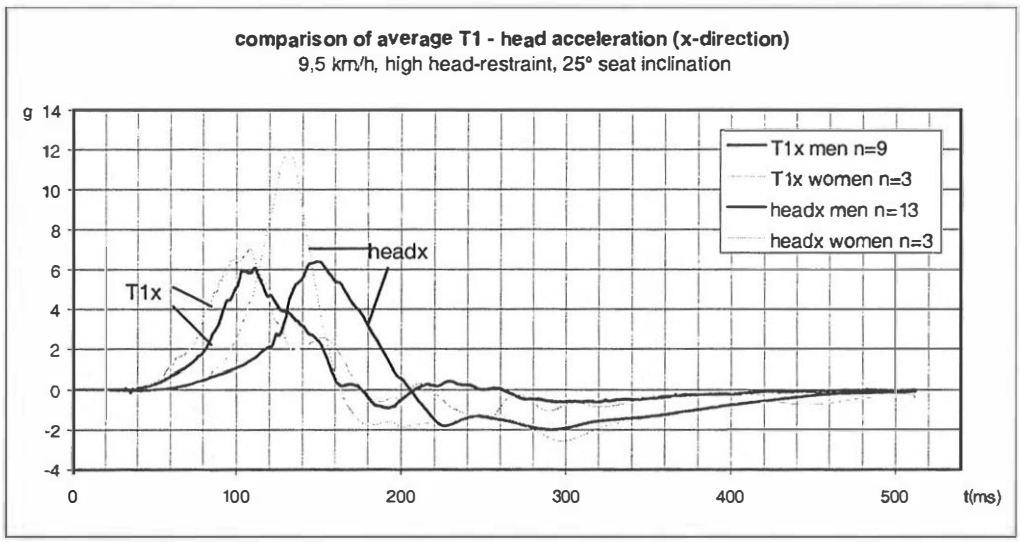
The visual differences (see Figure 3) produced a deeper analysis of individual subject related response factors which were able be compared because most tests were performed under the exactly same conditions, the only variable being the volunteer.

Although both volunteers (Fig. 3) show about the same seating height and age, the more fragile female tends to show a different kinematic, which appears to show a much larger forward flexion of the torso especially during the last phase at time-frame 190ms-280 ms. The initial horizontal gap between head and head restraint was closer for all three tested females, and the measured peak head acceleration (x-direction) values were much higher (see below). The complex analysis of the acceleration of different body parts showed differences

in which the deceleration of the T1 forward movement (T1 back) lasts only 10ms in the rebound phase (from 190 to 200 ms) for this female volunteer, whereas the male decelerates earlier and takes longer (from 170 to 210 ms) (the T1 sensor was fixed to the back, below the vertebral prominence). Hence, this female possibly continues to flex forward for a longer period of time.

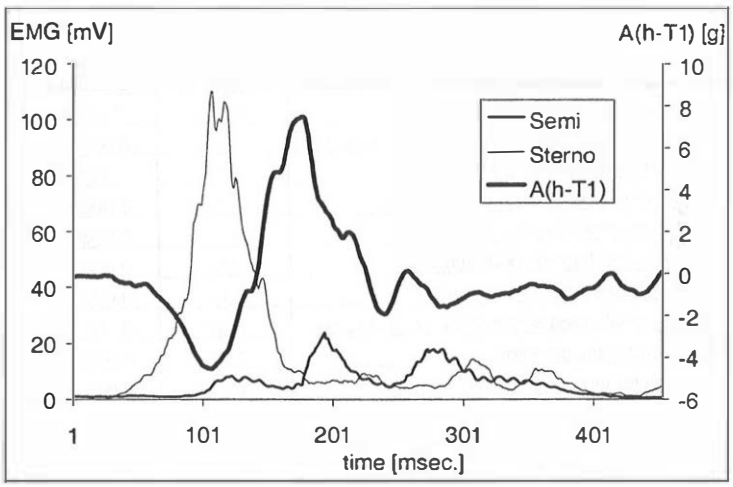
It is seen, however, that there is no obvious difference between male and female for all three tested females (Figure 4). In contrast to the different measures for head acceleration, the T1 peak acceleration between tested male and female volunteers was nearly similar. For both groups a time gap of about 20 and 30 ms, respectively, was detected between the occurrence of the peak T1 and the peak head acceleration (horizontal direction).

Figure 4: Average acceleration of T1 and head in x-direction, comparison male–female



The EMG of one volunteer is shown by way of example (see Figure 5): The activity of the sternocleidomastoid muscle begins right when the relative head-thoracic acceleration A(h-T1) begins to increase. At the moment of minimal A(h-T1) (head reaches head-restraint) the maximum electric activity of the m.st. is reached. Then the activity of the semispinalis capitis muscle starts as well. While the activity of the m.st. then very promptly decreases afterwards, the activity of the m.se. increases and reaches its maximum shortly after maximum A(h-T1) is attained. The muscle stays active until the upright head position is reached again.

Figure 5: Temporal progression of head acceleration relative to thorax acceleration and the average EMG amplitudes of both sternocleidomastoid muscles and of both semispinalis capitis muscles of one volunteer



The high electric amplitude of the m.st. during head translational movement and extension is understandable.

The only modest amplitude of the m.se. is somewhat more difficult to explain. An antagonistic inhibition due to the activity of the m.st. may possibly be the cause. Another explanation might be the following: head flexion in relation to the thorax may possibly occur only very late in the rebound phase. Thus the muscle stays relaxed during head extension, most probably until the resistance of the safety belt is reached.

Influencing variables -About 35 different anthropometric parameters of the volunteers with respect to length, circumference and weight dimensions of the head, neck and trunk were investigated as to their influence on the kinematic response. Accelerations of the head, T1 and thorax, angular acceleration of the head, maximum flexion and extension degree and the force acting on the head due to the head-restraint as well as the point of time at which peak values occurred have been evaluated. A statistical investigation was also performed with respect to linear regression between anthropometric data and measurement values. Since peak acceleration values depend on the test velocity, and the head-restraint position and seat inclination were also expected to be a factor, two main groups were established: both with a seat inclination of 25° and a high head-restraint position, one group with a lower sled pulse having a delta v of about 6,5 km/h, the other group having a higher delta v of about 9,5 km/h. The statistical investigation was performed on both groups separately. A statistic correlation was accepted for both groups showing minimum $r^2>0,5$ and p-value<0,05. Parameters with significant influence on the kinematic response were neck circumference, height of the head, body height and weight, and the distance between cervical vertebra 7 and sitting level. Another important individual parameter with a major impact on the kinematic response was the distance between the head and the head-restraint. The measured data that were influenced were the positive peak head acceleration in the x-direction, the

positive angular acceleration of the head and the head restraint force (see Table 1).

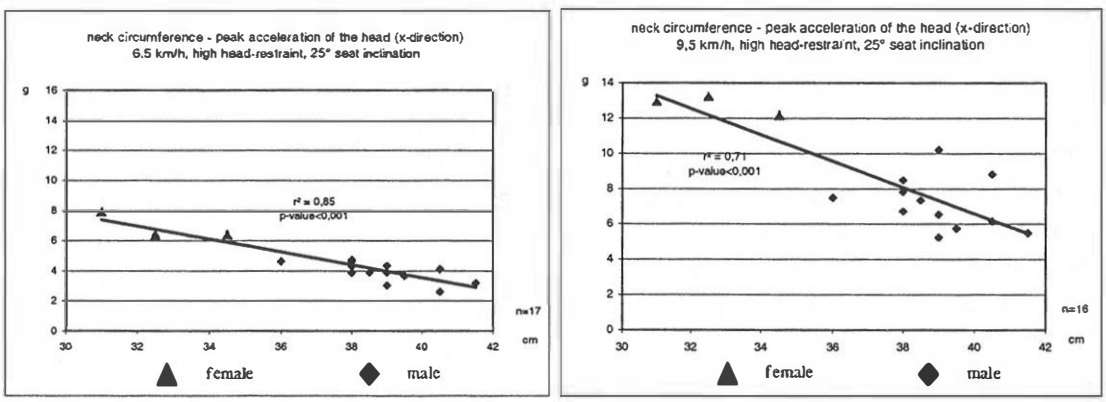
Table 1: Correlation coefficients between variables

25 ° seat inclination, high head-restraint	r^2 9,5 km/h	p-value	r^2 6,5 km/h	p-value
distance head/head-restraint x - peak head rest force	0,89	0,001436	0,92	0,0005467
distance head/head-restraint x - peak positive angular acceleration	0,85	0,000409	0,75	0,0025904
t(head rest force max) - peak head acceleration (x-direction)	0,77	0,0091	0,69	0,0214
distance head/head-restraint x - peak head acceleration (x-direction)	0,76	0,000991	0,77	0,0001738
distance head/head-restraint x - t(peak head rest force)	0,73	0,014	0,80	0,0065
neck circumference - peak head acceleration (x-direction)	0,71	0,000043	0,85	0,0000002
body weight - peak head acceleration (x-direction)	0,71	0,000042	0,66	0,0000731
head/neck index - peak head acceleration (x-direction)	0,65	0,000148	0,83	0,000000426
C7-sitting-level - peak head acceleration (x-direction)	0,62	0,036674	0,67	0,006923342
chin-occiput circumference - peak head acceleration (x-direction)	0,57	0,001782	0,63	0,000747565
head height - peak T1 downward acceleration	0,57	0,002960	0,63	0,0021152
body height - peak head acceleration (x-direction)	0,53	0,001457	0,51	0,00132728

No correlation was detectable for any other dimensions like flexion and extension degree or NIC, but in most cases only because the data material was limited. So there might still be other influencing parameters that have not been taken into consideration until now or there might be a correlation between investigated parameters which was not able to be proven in that test series.

Although the case number for female tests (N=6) is relatively low and the females were young and less corpulent, the initial trend for this collective was a significantly higher peak acceleration of the head in the x-direction compared to all volunteers with a higher neck circumference at both test velocities: lower delta v 6.5 km/h (more than 6g average value for females versus 3g male average) and higher delta v 9.5 km/h (12g versus 6g) at the same seatback inclination (25 degrees).

Figure 6: The correlation between neck circumference and peak acceleration of the head (positive x-direction)

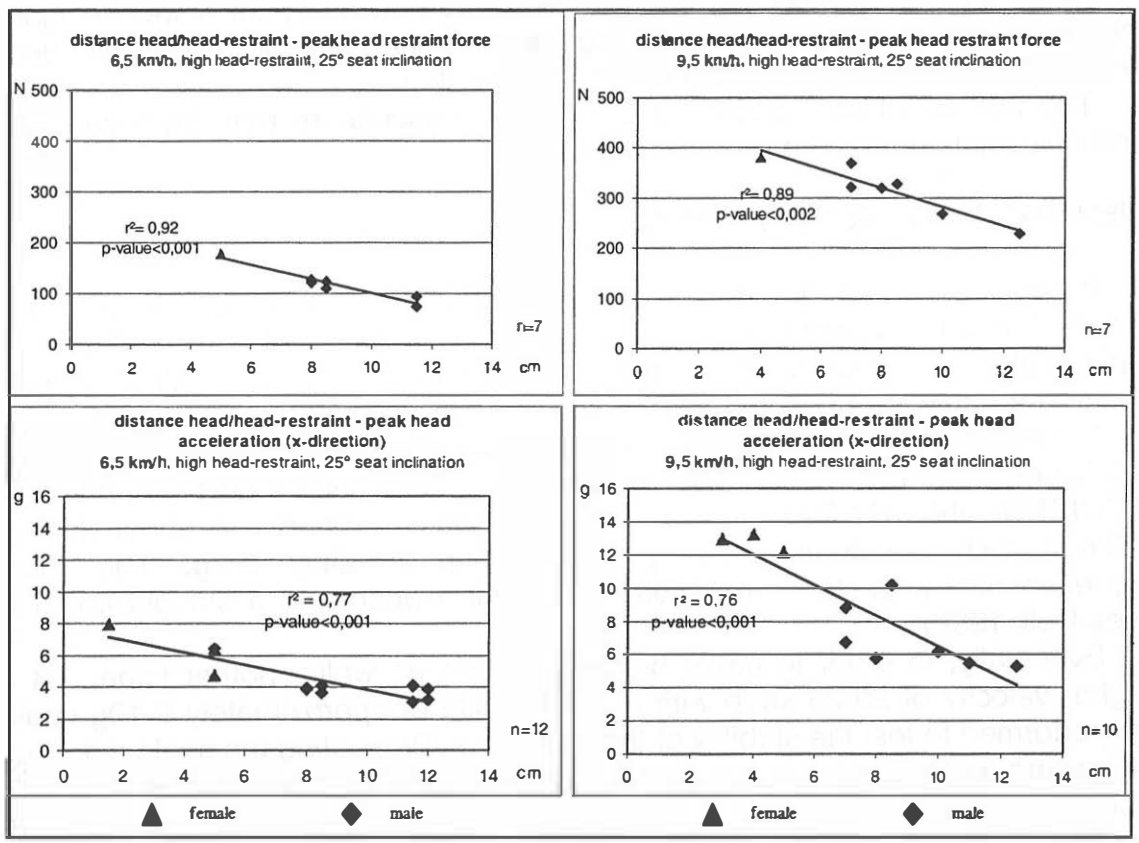


When we focussed on gender differences of the tested volunteers, the 3 tested females often showed a different trend compared to the males. But generally speaking, volunteers (male and female) with a smaller neck circumference showed higher peak acceleration values of the head (x-direction)

in the test series, whereas "bull necks" (male gender in test series) showed significantly lower head x values (see Figure 6).

The distance between the head and head-restraint turned out to be the main factor on the impact force acting on the head (r^2=0,92 and 0,89, p-values<0,001 and 0,002, respectively, for higher and lower test velocity). As the head mass is obviously of minor significance, although it does still exist, the distance and the peak horizontal acceleration of the head correlate in the same way. A correlation of r^2=0,77 and 0,76, respectively (6,5 and 9,5 km/h), with p-values<0,001 was found between those two parameters. The values of the parameters head-restraint force and peak horizontal head acceleration declined with increasing distance (see Figure 7).

Figure 7: Influence of the distance between head and head-restraint on head-restraint force and peak horizontal acceleration of the head



The peak angular acceleration of the head increased as distances increased. Here the tested females showed low values due to a relatively small head/head-restraint distance. As the head/head-restraint distance increases, peak angular acceleration for the flexion phase increases based on a correlation of r^2 0.75 and r^2 0.85 (low and higher test velocity). But the distribution of peak values was widely different for the prior extension phase and no significant statistical correlation could be found.

In recent test series (Eichberger, 1996) long horizontal distance also turned out to be a risk factor for minor neck pain, but more experiments and analyses should be carried out.

DISCUSSION OF THE VOLUNTEER SLED TEST SERIES -Because females show a 1,4 to 2 times greater risk of a CSD injury (Hell, 1998, Temming, 1998) in real accident analyses, a smaller value for neck circumference could be expected to be a risk factor in rear-end accidents (a fragile neck has a greater risk than a "bull neck") although this study did not include enough tests with females. Hence, more tests will be necessary in the future, but the results of the accident study confirm that women are at higher risk. The fact that woman generally have smaller values for neck circumference suggest that this may be the actual risk factor. It is possible that, due to a smaller neck with less resistance, the impact velocities of the female heads against the head restraints are higher, resulting in higher head accelerations. Therefore, head acceleration should also be analyzed further as a general qualitative indicator of CSD injury.

Peak angular acceleration increases with the distance from the head to head restraint. It therefore appears to be an absolute necessary for a well-designed head restraint to minimize the distance between head and head-restraint during rear impact for as many size occupants as possible.

The modest electric activity of the dorsal musculature may be a cause of possible injury during the rebound phase.

NEW DYNAMIC TEST STANDARDS

It could be concluded from the results of collision analysis and sled test series that car seat and head restraints have to be improved. This could be not only evaluated on the basis of static measurements, but also using dynamic tests where the seatback and head restraint performance were measured.

It appears to be beneficial at first to examine the most common impact configuration (due to collision analysis, see chapter "NEW DATA ANALYSIS ACCIDENT INVESTIGATION" of the paper) which amounts to about delta v 15km/h with a mean crash pulse of approximately 6-7g. The most representative impact configuration covers full overlap and a straight collision (see Hell, 1998).

Eventually, in order to cover higher delta v's as well, another impact at a higher velocity of 20-25 km/h with a crash pulse of approximately 9-10g could be performed to test the stability of the seat back. Preventing the seat back from collapsing totally might be beneficial in the rare collision scenario with a high delta v rear impact.

If this test were integrated into FMVSS 301 (48 km/h 1800 kg barrier impact for fuel tank integrity) against the car rear-end, an average delta v of 30 km/h would be reached for a car weighing 1100 kg. This accident scenario is relatively rare and it represents the most catastrophic case in which the load limits of seat back are reached. A design for such high energies would probably decrease CSD protection at lower velocities.

The ECE R 34 European test standard covers an impact velocity of 35-38 km/h with a barrier mass being 1000 kg. This results in a delta v of 20-25 km/h for a 1100 kg car. Nevertheless, this standard is rarely performed due to the higher US specifications.

This underlines the strong need for improved rear-end impact standard requirements, where at least one delta v 15 km/h test should be performed initially, which could then be followed by a test at a higher velocity for seat stability optimisation.

DYNAMIC TEST STANDARD PROPOSAL AND TEST SERIES 15 km/h

For the further improvement of current seat/head-restraint designs, there is currently no uniform dynamic test standard which allows the protection potential to be compared. Therefore, a dynamic standard test proposal was developed that is a synthesis from different research groups. Seats from 6 manufacturers have been tested in 11 tests, some of which used different sled pulses.

MATERIAL AND METHODS, SEAT TESTS -Different sled pulses (4, 6, and 8g) were tested at a delta v of 15 km/h. To also represent newer car constructions with stiff front- and rear-ends, a compromise pulse of 6g was selected for the additional delta v 15 tests. Although the real accidental car pulse is influenced significantly by the car construction philosophy (stiff or soft), it will only be possible to evaluate an exact comparison of the protection capability of a seat using tests which take place at the same crash pulse. Seats A-F were therefore all tested using a 6g pulse (mean value).

Test Set-up:

- 50 Percentile Hybrid III Dummy with TRID-neck (TNO-Delft)
- delta v 15 km/h, mean average acceleration 6 g
- detailed geometrical installation and positioning instructions and protocol
- Measurement of torque and forces at the neck level, and of head acceleration
- Calculation of NIC (Neck Injury Criterion) as an evaluation criterion for the first crash phase (rearward movement of dummy relative to sled)
- Calculation/measurement of additional geometrical parameters (angular acceleration and velocity of the head relative to the thorax) for evaluation of the second crash phase (rebound)

RESULTS AND DISCUSSION, SEAT TESTS -Most of the known injury criteria are relevant for AIS 2+ cervical spine injuries (ligamentous or bony damage [17]); no tested seat revealed such high values. It appears more difficult to focus on isolated cervical spine distortion injury (AIS 1) only. Literature values that were scaled and values discussed in expertise groups have been used, but it be noted that they have not been validated (Muser, 1994, Walz, 1995, Dippel, 1997).

The only value known up to now, that is explicitly used for isolated cervical spine distortion injury (AIS 1) is the Neck Injury Criterion (NIC) (Boström, 1997, Eichberger, 1998, Wheeler, 1998). This value is based on the calculation of the relative acceleration and the consecutively integrated relative velocity between the centre of gravity of the head and the 1st thoracic vertebra.

For physical reasons and based on the definition of the NIC calculation, the NIC value represents only the first crash phase (i.e. rearward movement against the seatback and impact against the head restraint). The elasticity of the seat construction, which leads to a rebound movement cannot be evaluated on the basis of the NIC value.

Rebound movement was assessed by measuring the head velocity and the relative angular velocity of the head relative to the thorax at the head/thorax position corresponding to the original head/thorax position before impact ("zero-phase").

In order to simplify the comparison of a large number of tests, the number of parameters should be greatly reduced. We propose the following measurements:

- Head-head restraint distance horizontal and vertical
- NIC as measure of AIS 1 cervical spine distortion injuries which occur in the first phase of the crash
- Maximum flexion/extension momentum between the neck endplate and head occur along the y axis, as a measure of the flexion/extension injury risk.
- Data analysis only from time interval t=0 up to contact with the belt system
- Head velocity at zero-phase used as measure of the risk of additional injury during the rebound phase (v_{head} [m/s])

Results from seat comparison tests:

Seat	A	B	C	D	E	F	G
d hor [mm]	95	45	55	85	50	120	50
NIC [m^2/s^2]	22.2	9.9	19.8	19.4	15.0	21.5	15.0
My Flex/Ext [Nm]	18.4/13.8	6.6/6.7	15.8/23.3	10.7/20.1	8.8/5.3	17.9/15.3	11.8/17.9
V_{head} [m/s]	4.5	1.3	4.7	3.7	3.7	4.6	4.4

D hor = horizontal distance between head-restraint and head. In a next step the results mentioned above can be used to assess the safety potential of a seat:

d horizontal [mm]:	[0,50] good,	(50,100] medium,	(100, ∞) problematic
NIC [m^2/s^2]:	[0,10] good,	(10,15] medium,	(15, ∞) problematic
My Extension:	[0,12] good,	(12,24] medium,	(24, ∞) problematic
My Flexion:	[0,17] good,	(17,35] medium,	(35, ∞) problematic
V_{head} [m/s]	[0,2] good,	(2,4] medium,	(4, ∞) problematic

Following classification could be discussed:

Seat	A	B	C	D	E	F	G
d hor [mm]	o	+	o	o	+	-	+
NIC [m^2/s^2]	-	+	-	-	o	-	o
My Flex/Ext [Nm]	o/o	+/+	o/o	+/o	+/+	o/o	o/o
V_{head} [m/s]	-	+	-	o	o	-	-

+: good, o: medium, -: problematic

At the WAD congress in Vancouver (2/99), an ad hoc group consisting of experts from Europe, Canada and the USA arrived at the same conclusion, i.e. that a dynamic test standard with 15 km/h should be established in order to quantify the protection capability of seat-head restraints. Currently the ISO/TC22/SC10/WG1 is in the process of building up criteria for a dynamic test standard.

OVERALL DISCUSSION

The new accident analysis data showed that the area with the highest epidemiological frequency is in a rear-end collision with delta v 15 km/h, because over 50% of the reconstructed rear end accidents occurred under this velocity. In the current material no increase in terms of QTF injury severity could be found.

Females showed a higher incidence of QTF 3 injury grade (neurological damage) with approximately the same distribution for the driver and front passenger seating positions. No male showed QTF 3 injury severity in the compared accident sample. Generally speaking, these aspects should be examined in future studies.

Identical sled tests with the volunteer as a variable show different kinematic behaviour, where some statistically significant relationships could be found including neck circumference, head and body height, body weight, head restraint distance and C7-sitting level distance. A correlation of measured values was observed with positive peak head x acceleration, head restraint force and angular acceleration.

It is interesting that the degree of flexion and extension as well as the NIC value did not achieve a statistical correlation.

Although only limited tests have been performed with young and fragile females, visual differences were observed (high rebound torso movement) as well as highest positive head x accelerations statistically corresponding to smaller neck circumferences. Because females show a higher incidence in accident analysis and because women generally have a smaller neck circumference, this might lead one to the conclusion that this may be one actual risk factor.

Angular acceleration correlates with head restraint distance during the flexion phase and other studies have also confirmed that horizontal distance is a risk factor.

First results of muscular electrode measurement of the sled test with volunteers reveal a short reaction time for the superficial frontal sternocleidomastoid muscle but a late and modest response from the deep posterior semispinalis capitis muscle which might be a cause of injury during the rebound phase.

Currently, only statical measurement and evaluation of seat/head restraints is taking place. Manufactures as well as consumer tests need a dynamic seat test standard to quantify seat/head restraint protection performance. For this purpose collision analysis results were transformed into a representative test standard proposal at delta v 15 km/h and 6g average crash pulse as a compromise between stiff and soft car structures. Seats from different manufacturers have been tested. NIC, flexion/extension momentum, and head velocity were used as evaluation criteria for comparison purposes. With the exception of one newer seat construction, current seats would not attain the proposed protection limits. Most current seat designs must be modified to enhance potential protection from cervical spine distortion injury at 15 km/h. It should be a future objective to protect the occupant predominantly at this velocity and pulse as well. The elasticity of the seat back should be reduced for this purpose, the seat back should absorb energy and its frame stiffness and upholstery characteristics should be adapted to the corresponding parameters of the head restraint. It appears that the construction of the seatback is just as important as that of the head restraint, both should fulfil dynamic requirements at delta v 15 km/h and possibly even at 25 km/h, because a seat back that breaks could increase the risk of injury in severe accidents, where even the ejection of the belted occupant is possible in rare cases.

The NIC-value has to be validated further, head velocity seems appropriate for measuring the rebound phase.

Current tests using a Hybrid III dummy and a TRID neck seems appropriate to differentiate between the dynamic seat qualities, but more biofidelic spine dummies such as the BioRID should be used later (see Davidsson, 1998). It is important not to test and optimise only using a 50th percentile male dummy, but also one representing the highest risk population (5th percentile female).

REQUIREMENTS FOR BETTER CAR SEAT DESIGN

- Fulfil dynamic test standard requirements
- Low horizontal distance and adequate height adjustment of the head-restraint
- Seatback construction seems to be very important for the relative movement of the head/torso complex
- Height and horizontal head restraint adjustment should be optimised for every occupant (automatic or fixed static position); the design should also prevent low positioning even during the crash phase
- Head restraints with frame design should be avoided because of the higher functional distance head/head-restraint
- NIC, angular velocity and acceleration, extension/flexion momentum, head velocity, horizontal distance should be reduced
- Suitable for 5th –95th percentile occupants

NEW RESEARCH TOOLS

More research is strongly needed for:

- Injury tolerance levels at AIS 1, validation of current parameters
- Differences in the kinematic behaviour and the injury outcome between males and females
- Influence of muscular response and reflexes
- Risk factors for different populations for long-term cervical spine AIS 1 injuries
- Improvement of the accuracy of collision reconstruction in low Delta v range
- Improvement of vehicle crash absorbing structures (Vehicle Factor)

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APPENDIX

THE QUEBEC CLASSIFICATION OF WHIPLASH-ASSOCIATED DISORDERS	
Grade	Clinical Presentation
0	No complaint about the neck - No physical signs
1	Neck complaint of pain, stiffness or tenderness only - No physical signs
2	Neck complaint AND Musculoskeletal signs
3	Neck complaint AND Neurological signs
4	Neck complaint AND Fracture or dislocation

Table 1: QTF Injury Degrees

Grade	**ESTIMATED PATHOLOGY OF DIFFERENT QTF DEGREES**
1	Microscopic or multi-microscopic lesion Lesion is too small to cause muscular spasm
2	Distortion and soft tissue bleeding (joint capsules, ligaments, tendons and muscles). Secondary muscle spasm after soft tissue injury
3	Injuries of the neurologic system caused by mechanical damage or secondary irritation caused by bleeding or inflammation

Table 2: Pathology of CSD