EVOLUTION OF A DYNAMIC SEAT TEST STANDARD PROPOSAL FOR A BETTER PROTECTION AFTER REAR-END IMPACT

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ABSTRACT

Current car seats are designed with respect to ergonomics, production and cost efficiency, but in many cases not for protection in a low speed rear-end impact. The Institute of Vehicle Safety therefore funded different seat test series, where a dynamic seat test standard proposal has been worked out. This standard has been already discussed at ISO and should be implemented in future regulations to improve the protection of the occupant. Currently the ISO/TC22/SC10/WG1 is in the process of developing criteria for a dynamic test standard.

At the moment, one test procedure should test the performance of the seat at delta v 15 km/h and a mean acceleration of 6g, with an additional test at delta v 10 km/h. Two test series with a total number of 24 tests mainly conducted at 15 km/h were carried out in which it clearly turned out that many seats show significant safety deficiencies.

Keywords: Whiplash, Sled Tests, Seats, Head-restraints, Neck

CERVICAL SPINE DISTORTION injuries represent a major impact on modern society with a high incidence and high socio-economic costs (Hell, 1999, Langwieder, 1996, 1999, Minton, 1997). CSD is one of the most common injuries in car accidents (about 80% of all car/car accidents with injuries, predominantly in the car struck in low velocity rear-end impacts (GDV)). Most head-restraints in current cars are able to protect the passenger from severe neck injuries such as fractures, luxations, ligamental damage, but the number of so-called minor soft tissue injuries of an AIS1 injury severity score even continues to increase in many countries. One problem is the difficulty in diagnosing CSD, another one the lack of understanding of the injury mechanism in its full complexity. Activities for improving seat design and reducing injury rates have been going on for a long time. Nevertheless, measurements of head-restraint geometry revealed that the majority of current cars exhibit only "acceptable" or even "poor" head-restraint design. Some prototypes and even production models, however, have shown that a significant reduction of neck loads in dynamic rear-end impacts is possible. Many organisations interested in seat design, such as manufacturers of cars or seats, universities, accident investigators, have declared that due to the absence of a test standard neither a comparison between the safety potentials of different seats nor an improvement in the situation is possible.

To find a practicable test procedure suitable for comparing seat/head-restraint constructions, a synthesis from proposals of different research groups was developed and tested. The results of those test series led to continuously improved working drafts for a test standard which was finally presented and discussed at ISO.

Below, the results of the test series as well as the dynamic seat test standard proposal are presented.

SEAT TEST SERIES

In an initial series 11 tests were performed. A proposal was developed afterwards which was validated in a second test series comprising 12 tests. Altogether 17 models from 12 manufacturers had been used, some of which were tested repeatedly under different conditions.

MATERIALS AND METHODS, SEAT TESTS – At first Seat A was tested at different sled pulses (4g, 6g and 8g, mean value), each at a delta v of 15 km/h being in the range of the most frequent changes in velocity leading to a CSD injury (Hell, 1998). To also represent newer car constructions with stiff front- and rear-ends, a compromise pulse of 6g was selected for the following tests. Although the real car pulse is influenced significantly by the car construction philosophy (stiff or soft) of both vehicles involved, it will only be possible to evaluate an exact comparison of the protection potential of a seat using tests which take place at the same crash pulse. Seats A-T were therefore all tested using a 6g pulse (mean value). Seats B, J, K and N were equipped with an Neck Protection System (NPS). Seat O describes the testing of Seat J with a blocked head-restraint and Seat S the Seat O situation and an additional head-restraint padding. Seat G also describes a situation with head-restraint padding of Seat F afterwards.

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 report
- Measurement of torque and forces at the neck level, and of head acceleration
- Calculation of NIC_{max} (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); no seat tested produced biomechanical loadings in that range. It appears more difficult to focus on cervical spine distortion injuries (AIS 1) only. Values given in the literature that were scaled and values discussed in expert groups have been used, but it has to 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 cervical spine distortion injuries (AIS 1) is the Neck Injury Criterion (NIC) (Boström, 1996, Eichberger, 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_{max} value (Boström 2000) within the first 150ms represents only the first crash phase (i.e. rearward movement against the seatback and impact against the head-restraint). To consider the influence of the forces acting on the head joints, moments and shear forces are calculated. For the rebound phase the velocity of the head during the re-entry of its initial position (zero-phase) is selected as well as the elasticity of the head-restraint..

The following measurement values were finally judged as being representative and selective to describe and value the protection potential of car seats.

- NIC_{max} 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 occurring 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. In addition moments of torque and shear forces had been combined, represented by the parameter N_{km}. Extension and flexion (k) are crossed with anterior and posterior directed shear forces (m). The only occurring combinations are N_{ep} and N_{fa}.(For calculation see Muser, IRCOBI 2000)
- Head velocity at zero-phase used as a measure of the risk of additional injury during the rebound phase (v_{head} rebound[m/s])
- Elasticity of the head-restraint as a parameter influencing the kinematics of the rebound phase
- Seatback deflection during impact and the remaining inclination difference
- Head-head-restraint distance horizontal and vertical

The distance between head and head-restraint is added to document the initial position and connected a priori advantages or disadvantages. The seatback deflection performance was measured to get an insight into the construction characteristics of the seat.

Values resulting from the seat comparison tests can be seen in Appendix A.

In the next step the results mentioned above are used to assess the safety potential of a seat using a scheme for classifying the individual values.

NIC_{max} $[m^2/s^2]$:	[0,10]	good	(+)	]10,15[	medium	(o)	[15, ∞)	problematic	(-)
N_{ep}:	[0,0.25]	good,	(+)	]0.25,0.5[	medium,	(o)	[0.5, ∞)	problematic	(-)
N_{fa}:	[0,0.25]	good,	(+)	]0.25,0.4[	medium,	(o)	[0.4, ∞)	problematic	(-)
V_{head}rebound [m/s]	[0,2]	good,	(+)	]2,4[	medium	(o)	[4, ∞)	problematic	(-)
Elasticity HR	[0-0.3]	good	(+)	]0.3,0.7[	medium,	(o)	[0.7-∞)	problematic	(-)

At the moment it is still being discussed which and how many parameters to take into account, how they are to be weighted, how to set the limits and how to calculate the overall value, that means whether to use a ramping system or a linear calculation system. The scheme presented in the following uses 3 parameters and a linear calculation system. Corresponding values to the results of the 5 parameters mentioned above are calculated linearly. The N_{km} values are combined to one criterion „neck loads“ and v_{head}rebound and elasticity HR are combined to a rebound criterion. The three remaining values are summarised for the overall rating. For comparison the values according to other calculation schemes are listed later.

The distance between head and head-restraint was excluded for the overall evaluation, as we wanted to evaluate performance rather than design criteria. In this way a neck protection system reducing the initial distance during impact is not put at a disadvantage. Also, the seatback deflection characteristics are not included for the time being, but for the visual impression in this paper a rating scale is added.

Seatback deflection dynamic (°)		Seatback deflection remaining (°)		d horizontal [mm]:	
5-10] degrees:	low	±1,5] degrees:	low	[0,50]:	low
10 to 15] degrees:	medium	±1,5 to ±3] degrees:	medium	]50,100]:	medium
over 15 degrees:	high	over ±3 degrees:	high	]100, ∞):	high

To make the following table readable for the non biomechanically skilled person we also decided to produce a simplified version with +/- and even a (subjective) star rating, which is only valid for the 15 km/h test. Although the evaluation process is not finished, this first evaluation shows that many of the seats will need major optimisation. Most seats have to be improved in some or many parameters.

In the following table 1 all the results can be seen:

Table 1: Results from 15km/htest series

3 criteria for overall valuation		3/3	1/3	1/3		1/3				
Seat	Index	overall valuation	NIC_{max}	NkmExt-x	NkmFlex+x	V_{head}rebound [m/s]	Elasticity HR	Seat deflection dynamic	Seat deflection remaining	d HR[mm]
B*	Neck Protection System	**52,4**	10.3	**0.06**	0.22	2.6	0.4	-12.3	-3	45
N*	Neck Protection System	51.4	**10.2**	0.07	**0.17**	2.5	0.6	-13.1	**0**	75
K*	Neck Protection System	22.5	12.5	0.3	0.43	1.8	0.7	-16.3	-6.4	60
J*	Neck Protection System	5.8	17.1	0.25	0.47	2.5	0.6	-10.9	-1	115
J*/O	NPS, blocked HR	-26.9	23.1	0.56	0.4	2.5	0.9	-10	-1	100
J*/S	NPS, blocked HR, add. HR padding	9.4	16.6	0.38	0.26	2.3	0.9	-8.3	**0**	55
H	low seatback strength	34.0	13.5	0.38	0.28	1.6	**0.3**	-18.2	-9.3	45
M	very low seatback strength	15.7	16.7	0.35	0.21	3.6	0.5	-11.6	-5.7	110
L	very low seatback strength	7.4	18.2	0.65	0.27	**1.2**	0.5	-15.2	-6.2	90
R	high seatback strength	-5.8	18.1	0.36	0.35	2.7	1.1	-13.2	-2	95
D	high seatback strength	-7.6	19.9	0.41	0.38	2.9	0.7	-12	-1	85
E	high seatback strength	-56.8	16.2	1.26	1.03	2.7	0.6	-11	-2	50
Q	high seatback strength	-29.1	22.3	0.55	0.35	2.9	1.2	-9.5	1	65
I	high seatback strength	-43.5	24.2	0.61	0.61	2.9	0.8	-6.3	**0**	58
A	high seatback strength	-43.8	23.4	0.79	0.42	4.2	0.9	-9.3	1	95
F	high seatback strength	-17.5	22.7	0.31	0.45	2.9	0.7	-14	-4	120
F/G	high seatback strength, add. HR padding	-2.2	15.5	0.37	0.39	3.8	1	-14	-3	50
C	older construction	-13.4	20.9	0.48	0.45	3	0.5	-20	-7.2	55
P	balanced	-5.6	17.3	0.72	0.32	2.3	0.8	-7.5	**0**	65
T	balanced	16.8	11.5	0.41	0.25	3.5	1.1	-11.8	2	**30**

The range of values is shown in the next table, the valuation on the following page.

Table 2: Range of values

	overall valuation	NIC_{max}	NkmExt-x	NkmFlex+x	V_{head}rebound [m/s]	Elasticity HR	Seat deflection dynamic	Seat deflection remaining	d HR[mm]
maximum value	52.4	24.2	1.26	1.03	4.20	1.2	-6.3	2.0	120
median	-3.9	17.2	0.40	0.37	2.70	0.7	-11.9	-1.5	65
average	-1.8	17.5	0.46	0.39	2.72	0.7	-12.2	-2.4	73
minimum value	-56.8	10.2	0.06	0.17	1.20	0.3	-20.0	-9.3	30

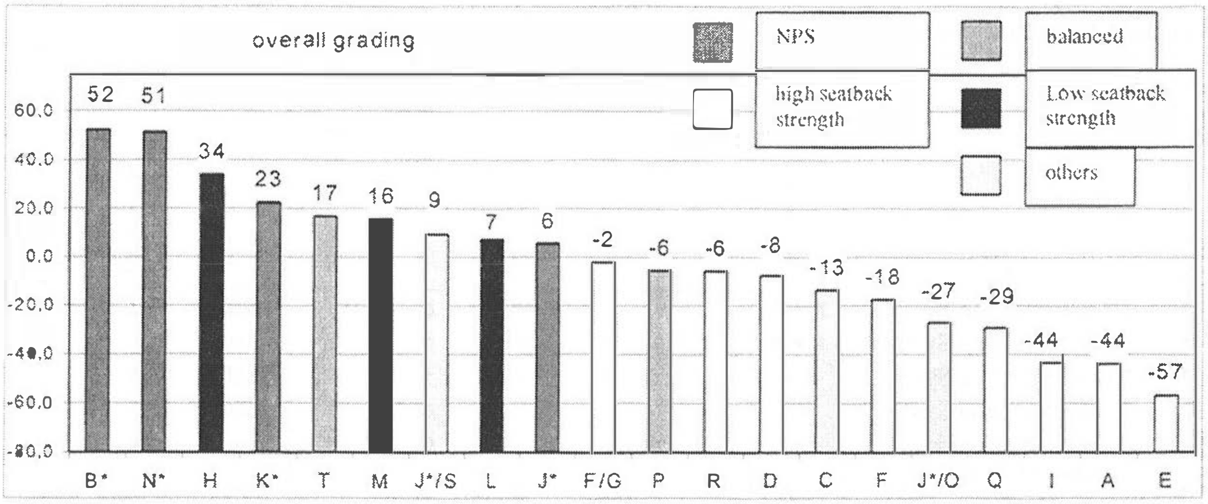
Table 3: Simplified classification of the results from 15km/h test series

3 criteria for overall valuation		3/3	1/3	1/3		1/3				
Seat	Index	overall valuation	NIC_{max}	NkmExt-x	NkmFlex+x	V_{head}rebound [m/s]	Elasticity HR	Seat deflection, dynamic	Seat deflection, remaining	d HR[mm]
B*	Neck Protection System	★★★	o	+	+	o	o	med	med	/
N*	Neck Protection System	★★★	o	+	+	o	o	med	low	/
K*	Neck Protection System	★★	o	o	-	+	-	high	high	/
J*	Neck Protection System	★★	-	+	-	o	o	med	low	/
J*/O	NPS, blocked HR	★	-	-	-	o	-	low	low	med
J*/S	NPS, blocked HR, additional HR padding	★★	-	o	o	o	-	low	low	med
H	low seatback strength	★★★	o	o	o	+	+	high	high	low
M	very low seatback strength	★★	-	o	+	o	o	med	high	high
L	very low seatback strength	★★	-	-	o	+	o	high	high	med
R	high seatback strength	★	-	o	o	o	-	med	med	med
D	high seatback strength	★	-	o	o	o	-	med	low	med
E	high seatback strength	☆	-	-	-	o	o	med	med	low
Q	high seatback strength	★	-	-	o	o	-	low	low	med
I	high seatback strength	☆	-	-	-	o	-	low	low	med
A	high seatback strength	☆	-	-	-	-	-	low	low	med
F	high seatback strength	★	-	o	-	o	-	med	high	high
F/G	high seatback strength, additional padding	★	-	o	o	o	-	med	med	low
C	older construction	★	-	o	-	o	o	very high	high	med
P	balanced	★	-	-	o	o	-	low	low	med
T	balanced	★★	o	o	+	o	-	med	med	low

★★★	advanced protection	+	good
★★	medium protection	o	medium
★	low protection	-	problematic
☆	very low protection		

The overall valuation is presented in figure 1, which gives a first impression of the differences between seats.

figure 1: results of seat classification



Other calculation systems partly lead to differing ranking positions. The tendency among the seats remains the same more or less. When using 5 criteria, the N_{km} values, vrebound and elasticity HR each contribute 20% to the overall rating and gain similar importance to the $NIC_{max.}$ The NIC_{max} value is given less importance this way. Using the ramp system the limits mentioned on page 3 are used. Every "good" value reaches 10 points, every "problematic" value reaches 0 points. Points for the values in the medium range are linearly interpolated. A maximum of 50 points can be achieved as an overall rating for both the 3 and 5 parameter proposal. On the contrary to the 3 stages of the ramp system the linear calculation system punishes very bad results in single columns and rewards very good results. The resulting values and ranking lists for the four combinations between linear and ramping system and 3 or 5 criteria can be seen in Appendix B.

For the sake of clarity a division into different groups has been made and some descriptive facts are given.

Table 4: Comments on seats with Neck Protection System

Seat		Points	Comment
B*	NPS	**52,4**	high rearward displacement, less elastic, head at HR contact not in extension
N*	NPS	51.4	little rearward displacement, elastic, hard HR
K*	NPS	22.5	medium rearward displacement, less elastic
J*	NPS	5.8	medium rearward displacement, CS S-shape at HR contact, high flexion moment
J*/O	NPS, blocked HR	-26.9	medium rearward displacement, very elastic, extension at HR contact
J*/S	NPS, blocked HR, additional HR padding	9.4	medium rearward displacement, elastic, elasticity at head-restraint

Promising results were found for the seats with an NPS to protect against cervical spine distortion in rear-end collisions.

Seat J (pre-series prototype) should be evaluated more carefully, as the contact between head and head-restraint took place during the vulnerable S-shape phase of the cervical spine. When testing with a blocked neck protection system, the biomechanical loading values were significantly worse. By adding an after-market head-restraint pillow for the decrease of the horizontal head-head-restraint distance, the parameters show significantly better results for the seat with blocked head-restraint and in this case even better results than under original conditions.

Table 4 shows a generally positive overall evaluation for the delta v 15 km/h test for modern NPS.

Table 5: Comments on seats with low seatback strength

Seat		Points	Comment
H	low seatback strength	34.0	high rearward displacement, less elastic, less extension at HR contact
M	very low seatback strength	15.7	high rearward displacement, less elastic, high horizontal distance
L	very low seatback strength	7.4	Very high rearward displacement (structure near collapse), less elastic HR contact , but extreme strong extension after HR contact, very elastic seatback

These seats were classified as "low seatback strength" and showed positive results at the 15 km/h test due to their values elasticity, head velocity during rebound and flexion momentum. It has to be remarked that in situations with higher velocities the seatback strength might not be able to sustain higher loads. Another criterion for seatback strength should be worked out in the future. Nevertheless real accident data (Hell 1998, Temming 1998) show that the majority of rear-end impacts happened at lower velocity. The 15 km/h test procedure therefore appears to be the most relevant test.

The following results are from seats built in respect to "high seatback strength" to avoid the seatback breaking (mainly cars exported to the US market). The seats are therefore relatively stiff and the delta v 15 km/h test showed poor performance values. This philosophy may lead to an overall increased incidence of CSD injuries, because the majority of rear end accidents with a loading to the cervical spine is in the lower velocity region. This fact should be also cleared up in the future in the analysis of real-life accidents.

Table 6: Comments on seats with high seatback strength

Seat		Points	Comment
R	high seatback strength	-5.8	High rearward displacement, very elastic, strong extension before HR contact
D	high seatback strength	-7.6	Medium rearward displacement, elastic, head at HR contact in extension
E	high seatback strength	-56.8	Medium rearward displacement, elastic, HR too low (!), head at HR contact in extension
Q	high seatback strength	-29.1	medium rearward displacement, very elastic at shoulderpart, extension after HR contact
I	high seatback strength	-43.5	Little rearward displacement, very elastic, very hard HR
A	high seatback strength	-43.8	high rearward displacement, strong elastic seatback, head at HR contact in extension
F	high seatback strength	-17.5	medium rearward displacement, HR with high horizontal distance, less elastic
F/G	high seatback strength, additional HR padding	-2.2	medium rearward displacement, HR with aftermarket pillow, less elastic seatback

The next seats were constructed according to a "balanced" philosophy due to optimisation either to seatback strength and to better performance at lower velocity without neck protection devices. It seems necessary to follow this philosophy in developing future seat generations, although in the case of these tested seats the head-restraint design and the elasticity of the seat/head-restraint construction could be optimised.

Table 7: Comments to seats with a balanced performance

Seat		Points	Comment
P	balanced	-5.6	medium rearward displacement, HR not stable pushed downward
T	balanced	16.8	medium rearward displacement, HR stable

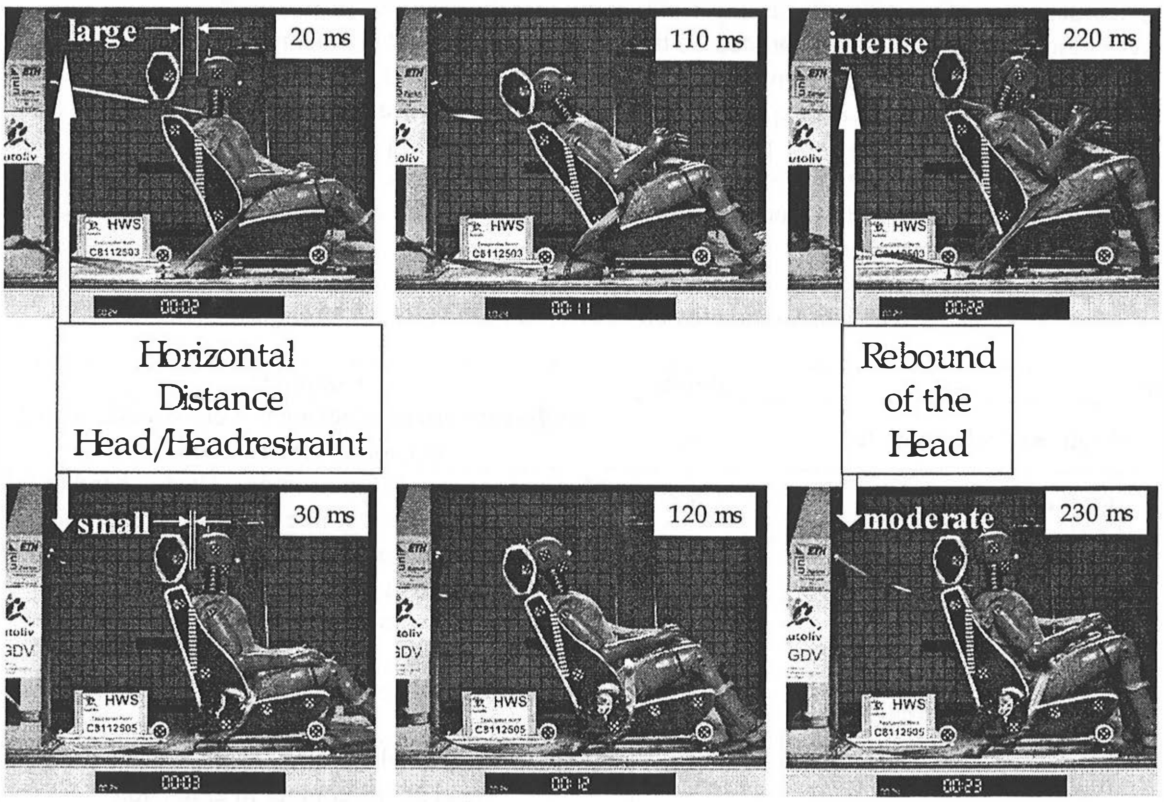
Table 8: Comments on a seat from a 1987car model

Seat		Points	Comment
C	older construction	-13.4	High rearward displacement, elastic, head at HR contact in extension, HR elastic and shifted downward

This seat is from a 1987 car model with a frame head-restraint and was tested for comparison with an older seat generation.

The following figure shows two examples of seat behaviour. Here it is seen that even a yielding seatback (upper row) does not equal "energy absorbing" in general. Especially in the case of a very elastic head-restraint the relative motion of the head to thorax may increase. It appears obvious that seatback construction is very important with regard to the kinematic behaviour of the occupant.

Figure 2: Horizontal distance and head rebound for two different seat types at a 6g pulse (Δv 15 km/h)



The overall comparison of different seats during a delta v 15 km/h test shows that modern seat designs with NPS perform partly well at this test condition. It has to be emphasised that elastic (not energy absorbing) seatbacks showed inferior results compared to plastically deforming seats. This appears at least as important as a low horizontal distance of the head versus the head-restraint. High head rebound velocity shows, that there is possible optimisation potential in terms of foam or other energy absorbing devices.

The measurement of the deep cervical spine musculature during the rear end impact (Kramer 1999) indicates that also the rebound phase could be injury associated.

One aftermarket head restraint pillows shows at tests with two different seats, that reducing the horizontal head head-restraint distance is an effective countermeasure in a low velocity rear- end impact.

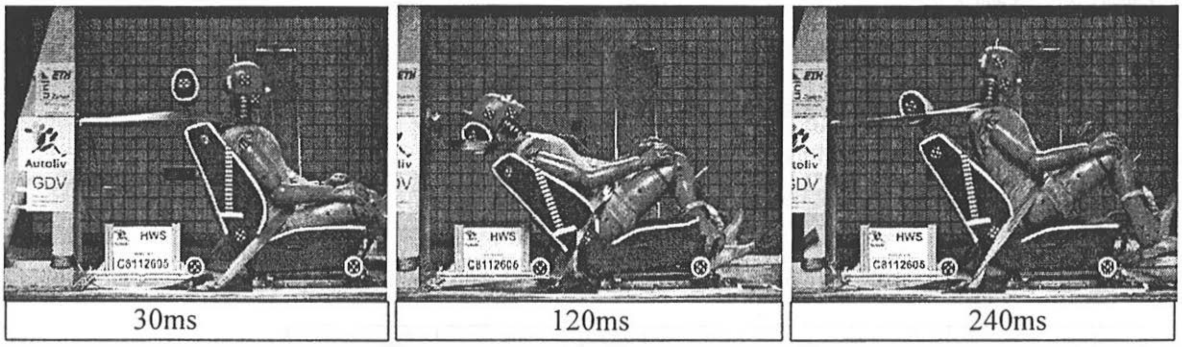
Although the evaluation criteria have to be refined in the future the best valuation criteria appears to be the linear 3 criteria model (see APPENDIX B) because NICmax and the other combined criteria (forces and moments, Rebound parameters see top of table 1 + 3) are equally weighted in a linear mode. Nevertheless other compared evaluation models (stairs 3-5 criteria, linear 5 criteria) end up generally with the same ranking between most of the tested seats.

Low cost seat constructions with a low seatback strength show a reasonable outcome in the delta v 15 km/h test resulting in low biomechanical loads due to significant seatback deflection which reduces the relative movement between head and torso. Future constructions should focus on a well-balanced behaviour in low velocity as well as high velocity rear-end impacts.

First experiments with prototypes showed up a significantly better performance without using an NPS, but there is still room for optimisation, especially in the NIC (first phase) as well in the rebound (second phase). In a delta v 15 km/h collision it appears to be more dangerous to sit on a seat with a stiff seatback compared to a low seatback strength model. More evaluation criteria with a rating for high speed seatback performance are to be included in the seat evaluation and more tests including seatback deflection should be performed. In a later stage this has to be clearly integrated into the overall evaluation of the seat performance.

To demonstrate seatback behaviour one seat with a "high strength" philosophy was tested with an acceleration pulse of 10 g (delta v 25 km/h). The pictures show that a high displacement and a large seatback deflection occurred and the measured loads were high. Is has to be remarked that many other current seat constructions will not withstand such a test and will break down completely.

Figure 3: Test with delta v of 25km/h and 10g mean acceleration pulse



DESCRIPTION OF THE PROPOSED TEST STANDARD

SCOPE: The test procedure simulates a low speed rear-end impact resulting in a delta-v of the struck car of 15 km/h. Its main purpose is the comparison of different front seat systems under standard conditions with respect to their protection potential and the associated risk for soft tissue neck injuries.

The test procedure is designed for the fiftieth percentile male person/dummy. It is assumed that positive features of seats observed for this group of persons will also yield benefits for other (e.g. fifth percentile female) groups.

The injury protection potential of front seat systems in other collision situations (e.g. higher delta-v/car accelerations possibly resulting in a collapse of the seat back) is not covered by this procedure.

Definitions: The neck injury criterion (NIC) is calculated as follows:

$NIC(t) = a_{rel}(t) \cdot 0.2 + (v_{rel}(t))^2$, where

$a_{rel}(t) = a_x^{T1}(t) - a_x^{Head}(t)$, $\quad v_{rel}(t) = \int a_{rel}(t) \quad dt$, and

$a_x^{T1}(t)$ = acceleration versus time measured in the antero - posterior (x) direction at the height of the first thoracic vertebra (lower neck accelerometer)

$a_x^{Head}(t)$ = the acceleration versus time measured in the antero - posterior (x) direction at the height of the c.o.g. of the head (head accelerometer), i.e. near the first cervical vertebra

The acceleration signals are to be filtered according to CFC180. The maximum value of NIC(t) within an interval of 150 ms after the beginning of the sled acceleration is determined and documented as the NIC_{max} value. If the head, after contacting the head-restraint, reverses its direction of relative movement at a point in time before 150 ms, the upper end of the interval of NIC(t) for the determination of NIC_{max} will be limited by this point in time.

HIC36, a(3ms)-values: The head injury criterion and the 3 millisecond exceedence values should be calculated according to SAE J1727.

TESTING EQUIPMENT Test track: The test should be performed on a sled decelerated using an adequate braking system or on a hydraulically accelerated sled (HyGe system).

Anthropomorphic Test Device (ATD): A Part 572 subpart E (Hybrid III) fiftieth percentile male dummy equipped with a TRID-Neck shall be used.

Test objects: Front seats of passenger vehicles in standard positions

REQUIREMENTS: Anthropomorphic test device: The ATD is to be instrumented as described in tables 9 and 10. The head of the ATD is equipped with a device suitable for electronic detection of the time T_k of the first contact of the head and the head-restraint.

The rotational acceleration may be measured using a second uni-axial accelerometer mounted on the head of the ATD. This accelerometer should be mounted with its sensitive axis parallel to the x-axis of the standard head accelerometer, and in a position on top of the head on the z-axis of the standard head accelerometer. In this case, the rotational acceleration of the head around the y-axis can be calculated as:

$$\dot{\omega} = \frac{\left(a_{x,head\ c.g.} - a_{x,add.}\right)}{d}$$

where:

$a_{x,head\ c.g.}$ = the x component of the standard head accelerometer

$a_{x,add.}$ = the signal from the additional accelerometer

d = the distance along the z-axis of the two accelerometers (in meters)

For this purpose, the acceleration signals should be filtered according to CFC 1000.

Position	Measurement	Axes	Filter
Head	Acceleration	x/y/z	CFC 1000
Upper neck (C1)	Force	x/z	CFC 1000
	Moment of torque	y	CFC 600
Lower neck	Acceleration	x	CFC 180
Chest	Acceleration	x/y/z	CFC 180
Pelvis	Acceleration	x/y/z	CFC 1000

Table 9: Standard Instrumentation

For NIC calculation the x-axis signal of the head acceleration needs to be filtered using CFC 180 as well.

Position	Measurement	Axes	Filter
Head	Rotational acceleration	y	CFC 1000
Upper neck (C1)	Force	y	CFC 1000
	Moment of torque	x/z	CFC 600
Lower neck	Force	x/y/z	CFC 1000
	Moment of torque	x/y/z	CFC 600

Table 10: Optional Instrumentation

Film Targets: A film target (T1) should be mounted on the side of the head at the location of the head C.G. At least three other film targets are to be mounted on the seat as depicted in figure 4.

Neck Bracket Adjustment: The neck bracket of the ATD are to be adjusted so that, in the final seated position, the x-axis of the head accelerometer is horizontal ± 1°. When a lower neck transducer is used, an appropriately shaped wedge should be mounted between the transducer and the thoracic mounting flange in order to achieve the correct orientation of the head accelerometer.

Figure 4: Measurements on the seat and positioning of the ATD

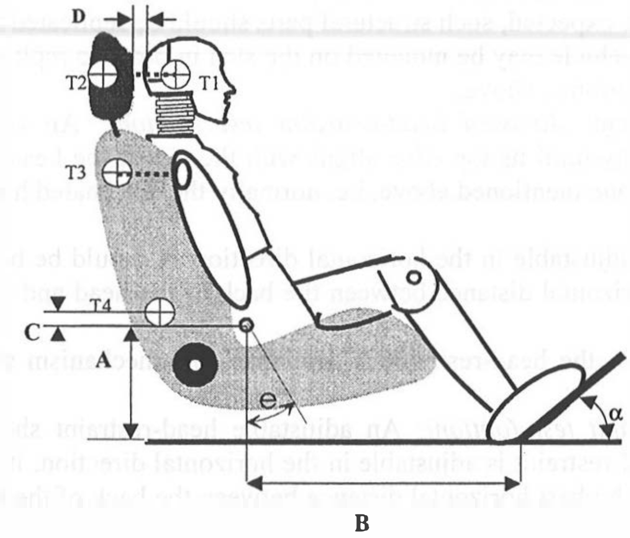


Table 11: Measurements on the test set-up

Designation	Description	Test device	Dimension
A	Vertical distance floor-H-point	H-Punkt-Machine	(275 + 15) mm
B	Horizontal distance toepan-H-point	H-Punkt-Machine	(850 ± 100) mm
C	Vertical distance H-point / target T4	ATD	(100 ± 5) mm
α	Angle footrest-floor		40° - 45°
e	Pelvis angle	ATD	25° + 2°

Designation A may be replaced by target vehicle reference seating position values as described in the following.

TEST PREPARATIONS <u>Mounting of the seat on the sled</u>: The mounting supports on the sled and the adjustment mechanisms of the seat are to be adapted so that the designated reference seating position for the 50th percentile male occupant is replicated as specified by the manufacturer.

In cases where such specifications are not available, the seat should be mounted on the sled and adjusted so that:

- the dimensions A and B in figure 4 are maintained. The angle of the seat ramp should be 12° ± 1°.
- the torso line reads 25° against the vertical.
- the seat height adjustment is in its lowest position
- the seat angle adjustment is in the lowest position
- the lordosis support at maximum retraction

The dimensions A and B as well as the torso line and seat ramp angle should be documented in the protocol. Documentation provided by the manufacturer specifying the reference seating position should be an integral part of the protocol.

The H-point machine should be used to adjust and verify the specified dimensions.

<u>Positioning of the ATD on the seat</u>: The ATD is positioned according to the procedures used in frontal impact tests (cf. ECE R-94). The feet should be positioned on the foot rest, the heels touching the floor plate.

The measured H-point of the ATD shall not differ horizontally and vertically more than 20 mm from the H-point location previously determined by the H-point machine.

The neck bracket angle should be adjusted as mentioned above.

The ATD may be secured using a loosely fitting 3-point belt system.

Additional considerations: In cases where, due to the reclining movement of the seat during the test, a contact between the seat back and structural parts of the target vehicle (e.g. the rear wall in a two-seat sports car) is to be expected, such structural parts should be replicated on the sled.

The body of the target vehicle may be mounted on the sled in order to replicate the seating position and the structural parts mentioned above.

Head-restraint adjustment: *Adjusted head-restraint test (option):* An adjustable head-restraint should be adjusted vertically until its top edge aligns with the top of the head. If this is not possible, the position nearest to the one mentioned above, i.e. normally the designated highest possible position, should be selected.

If the head-restraint is adjustable in the horizontal direction, it should be brought into the position that yields the smallest horizontal distance between the back of the head and the surface of the head-restraint.

If a locking mechanism for the head-restraint is available, this mechanism should be engaged (i.e. locked).

Worst case head-restraint test (option): An adjustable head-restraint should be adjusted to its lowest position. If the head-restraint is adjustable in the horizontal direction, it should be brought into the position that yields the highest horizontal distance between the back of the head and the surface of the head-restraint.

If a locking mechanism for the head-restraint is available, this mechanism should be engaged (i.e. locked).

Film targets on the seat: For a subsequent film analysis, the following film targets should be applied to the seat:

T2: on the side face of the head-restraint, at the same height as the head c.g.

T3: on the back rest, at the same height as the shoulder joint.

T4: on the back rest, according to figure 4 relative to the H-point.

Test report: The measured coordinates / angles of H-point, pelvis and thorax angle, and all film target locations should be documented in a report. The distance D (back of the head >> head-restraint) is measured and included in the protocol.

Camera positions: First camera: stationary, side view showing the seat and ATD during the deceleration/acceleration phase of the test.

Second camera: mounted on the sled, side view showing the torso, head, and head-restraint.

It should be ascertained that the seat back, the head-restraint, and the upper body parts of the ATD are visible on the film/video during a time interval equal or longer than 400 ms after the onset of the sled deceleration/acceleration (t0).

The camera frame rate should be equal or greater than 500 frames/sec. The use of a setting of 1000 frames/sec is recommended.

TEST CONDITIONS: Test velocity - The test velocity should be 15 ± 1 km/h. If a decelerated sled is used, the test velocity should be measured immediately before the impact using a suitable measuring device. In the case of an accelerated (HyGe principle) sled, the test velocity should be measured immediately after the acceleration phase has been completed.

Deceleration/acceleration pulse:

figure 5: Corridor for the deceleration/acceleration pulse

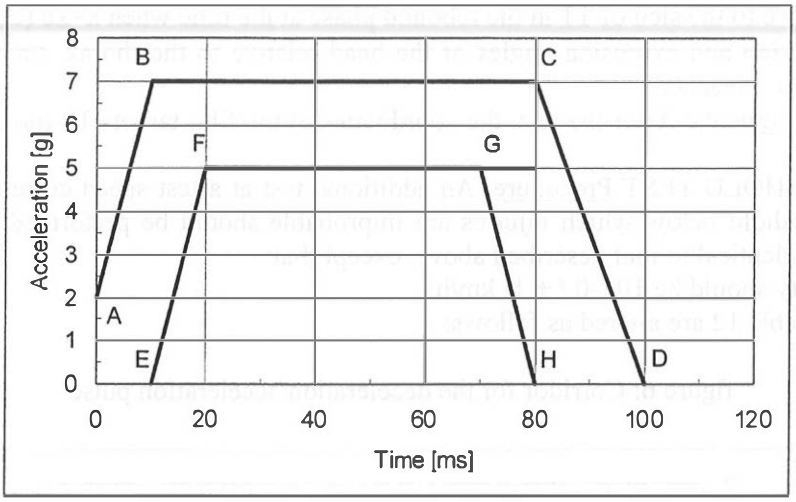


Table 12: Corridor for the deceleration/acceleration pulse

Point	Time[ms]	a [g]	Point	Time [ms]	a [g]
A	0	2	E	10	0
B	10	7	F	20	5
C	80	7	G	70	5
D	100	0	H	80	0

Neck Protection Systems: Protection devices that require a trigger signal in order to deploy during the collision should be installed so that deployment occurs under the same conditions as in the target vehicle.

If such devices are triggered electronically, the trigger unit may be mounted on the sled. As an alternative, the trigger point can be specified as a time delay with respect to t0. In this case, the manufacturer should prove that the trigger time corresponds to the trigger time that would be measured in the target vehicle under collision circumstances equal to those simulated by the sled test described here. This can be demonstrated, for example, by a sled test with a narrower tolerance corridor for the acceleration/time history, in which the g-levels for B and C in figure 5 are set to 6.5 g and for F and G to 5.5 g respectively

If such devices are triggered mechanically, it should be ascertained that the triggering mechanics are mounted in a position corresponding to the mounting arrangement in the target vehicle.

The triggering configuration and the status of the device after the test (deployed/not deployed, time of deployment, remarks) should be documented in the test protocol.

DATA RECORDING: The measurement data should be recorded according to SAE J211/1. Measurement data should be considered for evaluation until the point in time at which the head, c.g. film target, (T1) reaches the position x0 during the rebound phase, i.e. its position shows the same horizontal (x-)coordinate as at the beginning of the deceleration/acceleration phase.

ATD data: The measurement channels as described in tables 9 and 10 and the sled deceleration/acceleration should be recorded electronically as a function of time. Data should be recorded during a minimum of 400 ms after the onset of the sled deceleration/acceleration (t0).

Where multiaxial accelerations are measured, the resulting accelerations should be calculated, and the 3-ms-exceedence, HIC, and NIC values should be calculated. The moments of torque measured at the neck should be documented without any corrections applied.

The point in time T_k where the ATD head touches the head-restraint for the first time should be determined.

Film analysis should be used to determine the following values:

- Maximum extent of the rearward motion of the film targets T1 through T4 (horizontal and vertical coordinates).
- Velocity relative to the sled of T1 in the rebound phase at the time when x=x0 (cf. above).
- Maximum flexion and extension angles of the head relative to the thorax, time points at which these maxima are reached.

Post-test measurements: After the test, the coordinates of the film targets T2 through T4 should be determined.

LOWEST THRESHOLD TEST Procedure: An additional test at a test speed currently considered to designate the threshold below which injuries are improbable should be performed. This test should follow a protocol identical to that described above, except that:

The test velocity should be 10 (-0 / + 1) km/h.

Figure 5 and Table 12 are altered as follows:

figure 6: Corridor for the deceleration/acceleration pulse

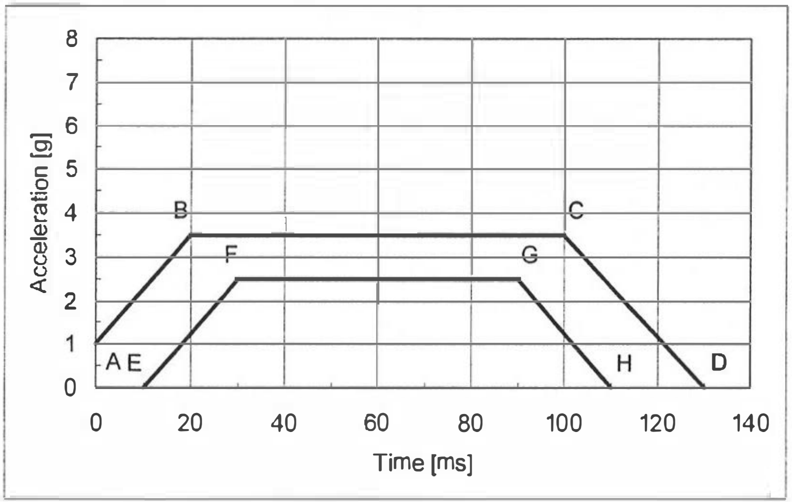


Table 13: Deceleration/acceleration pulse for the lowest threshold test

Point	Time[ms]	a [g]	Point	Time [ms]	a [g]
A	0	1	E	10	0
B	10	3.5	F	30	2.5
C	80	3.5	G	70	2.5
D	120	0	H	90	0

Small female ATD: If an ATD is available that represents the fifth percentile female and is suitable for rear-end impact testing, this ATD should be used in place of the fiftieth percentile male ATD specified above.

DISCUSSION AND OUTLOOK

The test standard proposal has been harmonised with the outcoming proposal from the EU-project whiplash consortium (TNO; TU Graz) to avoid different proposals.

Initial discussions with representatives from the European car industry have also taken place, at which the 15 km/h test was generally accepted with some modifications i.e.: the seating position could be required from the car manufacturer's instruction manual, which allows a more realistic (i.e. MPV) test environment. At the present time we propose to test with optimally positioned head-restraint, but some misuse evaluations, or a downward head-restraint test could be added.

The evaluation criteria are currently not finished and more work has to be done to validate NIC and load limits for the cervical spine for distortion injuries, but nevertheless a comparison and a true optimisation of seats is possible now, because some measured values demonstrate that NIC, forces and moments as well as head rebound velocity could be significantly reduced.

For the optimisation of a single system (seat) in our opinion it does not appear necessary to perform an expensive full-size crash test, because many manufacturers can use the same basic seat construction in different car weight classes and body shapes.

In the next step the performance of the seatback under higher acceleration loads that occur in collisions with a higher change of velocity should be tested with a simple seatback deflection test, because the possible injury risk in the event of collapsing seatbacks should also not be neglected.

To avoid optimisation to one point (especially for an NPS) a second test with a delta v of 10 km/h is proposed, because the trigger mechanism of the NPS should also help at lower velocities.

It should be demonstrated that the seat should protect at least at:

- delta v 10 km/h
- delta v 15 km/h
- delta v 30 km/h (seatback deflection, possibly higher)

The dynamic test procedure turned out to be a good possibility for comparing different seats, even with a simple Hybrid III TRID-neck dummy.

It should be implemented in a harmonised test procedure in the near future.

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Appendix A

Results from Seat comparison tests:

Seat	NIC_{max}	d HR[mm]	My	My	Vhead[m/s] rebound	Elasticity HR	Seat deflection dynamic	Seat deflection remaining	NkmExt-x	NkmFlex+x
			Flexion	Extension						
A	23.4	95	18.4	13.8	4,2	0,9	-9,3	1	0,79	0,42
B*	10.3	45	6.6	6.7	2,6	0,4	-12,3	-3	0,06	0,22
C	20.9	55	15.8	23.3	3,0	0,5	-20	-7,2	0,48	0,45
D	19.9	85	10.7	20.1	2,9	0,7	-12	-1	0,41	0,38
E	16.2	50	8.8	5.3	2,7	0,6	-11	-2	1,26	1,03
F	22.7	120	17.9	15.3	2,9	0,7	-14	-4	0,31	0,45
G[1]	15.5	50	11.8	17.9	3,8	1,0	-14	-3	0,37	0,39
H	13.5	45	8.7	16.6	1,6	0,3	-18,2	-9,3	0,38	0,28
I	24.2	58	28.3	21.8	2,90	0,8	-6,3	0	0,61	0,61
J*	17.1	115	22.4	9.3	2,50	0,6	-10,9	-1	0,25	0,47
K*	12.5	60	20.5	10.6	1,80	0,7	-16,3	-6,4	0,3	0,43
L	18.2	90	7.7	30.3	1,20	0,5	-15,2	-6,2	0,65	0,27
M	16.7	110	6.0	5.8	3,60	0,5	-11,6	-5,7	0,35	0,21
N*	10.2	75	9.2	2.4	2,50	0,6	-13,1	0	0,07	0,17
O[2]	23.1	100	13.9	24.5	2,50	0,9	-10	-1	0,56	0,4
P	17.3	65	28.3	14.8	2,30	0,8	-7,5	0	0,72	0,32
Q	22.3	65	23.4	17.8	2,90	1,2	-9,5	1	0,55	0,35
R	18.1	95	19.8	12.2	2,70	1,1	-13,2	-2	0,36	0,35
S[3]	16.6	55	9.8	14.3	2,30	0,9	-8,3	0	0,38	0,26
T	11.5	30	10.7	6.9	3,5	1,1	-11,8	2	0,41	0,25

d HR = horizontal distance between head-restraint and head.
* Seat with NPS
[1] Seat F with additional aftermarket head-restraint pillow
[2] blocked head-restraint (Seat J)
[3] Seat O with additional aftermarket head-restraint pillow

Appendix B

Valuation systems: linear/ramp; 3criteria/5criteria
Differences of 4 ranks or more are marked

	linear, 3		ramp, 3		linear, 5		ramp, 5	
	overall value	rank	overall value	rank	overall value	rank	overall value	rank
B*	52,4	1	44,4	1	53,5	1	43,9	1
N*	51,4	2	41,0	2	52,1	2	39,6	2
H	34,0	3	32,3	3	37,8	3	35,8	3
K*	22,5	4	23,3	5	22,0	5	23,0	6
T	16,8	5	25,1	4	13,1	8	23,1	5
M	15,7	6	19,2	7	22,3	4	23,0	7
J*/S	9,4	7	18,9	8	14,4	7	22,6	8
L	7,4	8	19,7	6	15,3	6	23,7	4
J*	5,8	9	16,7	9	11,1	9	20,0	9
F/G	-2,2	10	5,7	18	-1,6	12	6,9	18
P	-5,6	11	11,5	11	-2,1	13	13,8	11
R	-5,8	12	12,9	10	-0,8	11	15,4	10
D	-7,6	13	8,7	14	0,6	10	10,4	14
C	-13,4	14	9,0	13	-4,3	14	10,8	13
F/G	-17,5	15	10,9	12	-5,6	15	13,1	12
J*/O	-26,9	16	6,3	17	-16,1	16	7,5	17
Q	-29,1	17	7,4	16	-20,3	17	8,8	16
I	-43,5	18	4,6	19	-33,8	18	5,5	19
A	-43,8	19	0,0	20	-35,7	19	0,0	20
E	-56,8	20	7,5	15	-65,8	20	9,0	15

can be seen that only 4 seats show very differing results depending on the used system