REDUCTION OF NECK INJURIES BY IMPROVING THE OCCUPANT INTERACTION WITH THE SEAT BACK CUSHION

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ABSTRACT

THIS PAPER DESCRIBES IN DETAIL the importance of seat back properties in its influence on head injuries in a car crash. The dynamic pressure distribution on the seat back generated by a 50 %-tile H III dummy is analyzed during rear end impacts. Common injury criteria like the NIC, 3ms max, the accelerations and neck forces / moments of the dummy are investigated as well. The seats have been tested on an active sled facility with a fully reproducible acceleration pulse. The acceleration of the sled was used to simulate the real acceleration of a rear end crash.

The comparison of the dynamic pressure distribution shows that with a soft seat back cushion the pressure starts building up in the lower back and then during acceleration moves up to the upper back. With a stiffer seat back cushion the pressure is distributed more evenly over the whole back of the dummy. The body of the dummy dives into the seat back almost without any rotation and therefore the distance between head and head restraint is bigger than with soft cushions. To enlarge the effect of the torso rotation it is helpful to use a hard cushion on the lower part of the seat back and soft foams on the upper part.

The results of this study show that it is also important to have a look on the cushion of the seat back and not only on the stiffness of the construction and the development of active head restraint systems. There is still a big potential in decreasing the risk of neck injuries by selecting the appropriate material for the seat back cushion in connection with the seat back construction itself.

COMPARED TO OTHER INFLUENCES (car mass, physiognomy of the passenger, angle of collision, ...) the seat and the head restraint are the most important facts concerning neck injury prevention (Eichberger et al. 1996). Therefore actually a lot of money is spent to investigate the injury risks in rear end impacts and to develop mechanical systems for active head restraints (Bigi et al. 1998). It is believed that neck injuries in rear-end collisions are related to shear forces and then extension-flexion motion of the neck. This results from the rearward displacement of the head relative to the torso (Svensson et al. 1993). As investigated by Cullen et al. (1996) most vehicle occupants of front seats use poorly positioned head restraints. To reduce risks resulting from this carelessness this paper deals with an examination of the influence of the seat back cushion on neck injuries. It shows the importance and capacity of the cushion in decreasing neck injuries by reducing the distance between head and head restraint through a rotation of the torso-head line (no relative displacement) and a following minimized extension of the neck.

METHODOLOGY

TEST FACILITY

ALL THE TESTS were performed on an active sled test facility. The sled is generated by compressed air in a special cylinder. The energy is transmitted by a piston rod to the sled. It is possible to accelerate the sled following each given pulse. Therefore the rod – acceleration is controlled by a very fast hydraulic brake (Hofinger 1998).

A 50%-tile H III dummy equipped with the TRID-neck and with sensors for the neck force, the neck moment and tri-axial accelerometers in the head, chest and the pelvis were used to measure the load on car passengers during rear-end impacts. A high speed video (1000 frames per second) shows the movement of the dummy and a pressure foil at the seat back indicates the pressure distribution during the rear end impact. To analyze the movement of the dummy in detail the targets in the high speed video have been tracked.

Each single test configuration has been performed with an acceleration of 3g (delta v 9.6 km/h) as well as with an acceleration of 5g (delta v 14.2 km/h) as shown in Fig 1.

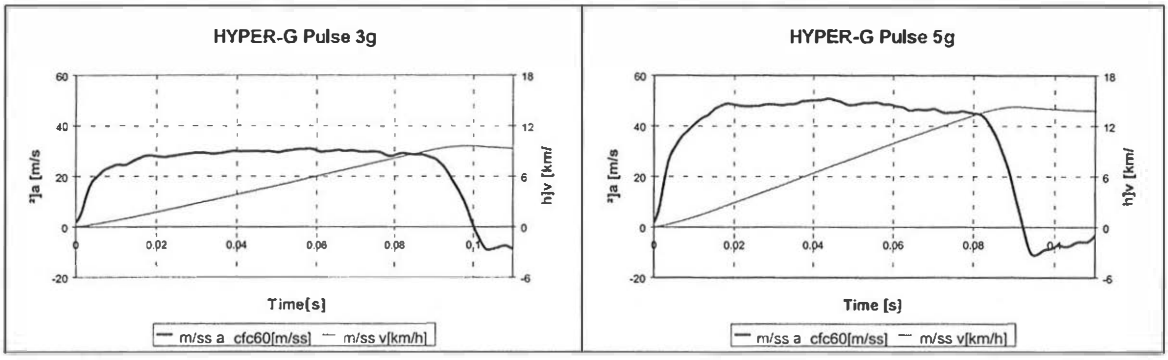


Figure 1: Shape of the 3g and 5g pulse

SEAT

TO EXCLUDE THE INFLUENCES OF THE SEAT ELASTICITY a special stiff construction was used [Fig. 2]. Considering different seating positions each test configuration has been performed with a seat back angle of 15° and 25°.

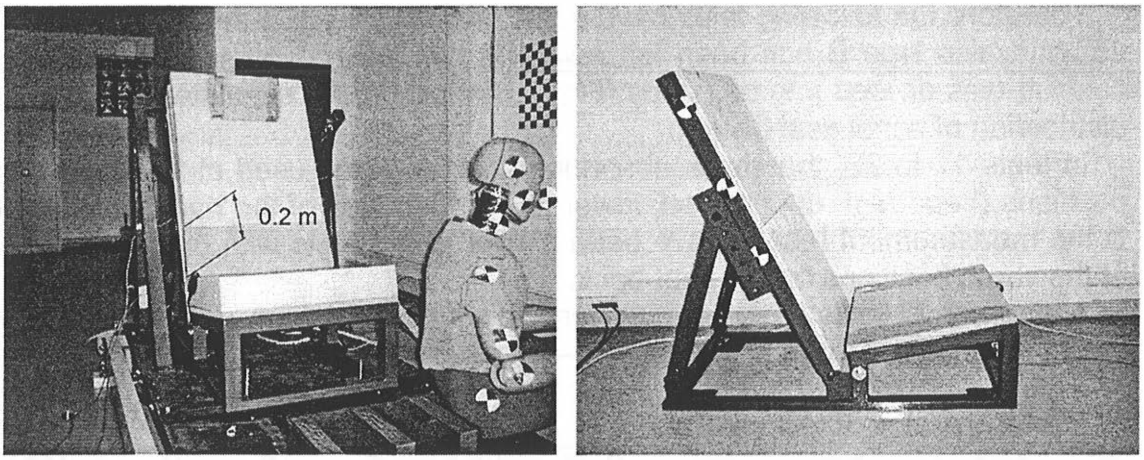


Figure 2: Test Seat (Cushioning, Construction)

FOAM

FOR THE PADDING OF THE SEAT BACK four different types of standard foams with a thickness of 100mm have been used. [Tab. 1]. The foams differ in hardness and density. The types A, B and C are elastic deformable and type D is a kind of shock absorbing foam. The amount of deformation of type D becomes smaller with an increasing velocity of the load. Therefore its behavior at high load velocities is similar to type C.

For the head restraint except for the tests 17 and 18 the hard type C was used. The combination in test 17 and 18 turned out to be too hard at high contact velocities of the head and did not deliver acceptable results.

The cushion of the seat was the same in all tests (type A).

To simulate the attributes of the real cover material of a seat a textile cover was put over the foam.

Table 1: List of used foams

A	B	C	D
density / hardness	density / hardness	density / hardness	density / hardness
kg/m^3 / kPa	kg/m^3 / kPa	kg/m^3 / kPa	kg/m^3 / kPa
N 35 / 43	H 50 / 78	H 100 / 170	SAF 60 / 120

TEST COURSE

IN THE FIRST 12 EXPERIMENTS a single part of a soft (A), a middle (B) and a hard (C) type of foam has been used as seat back cushion. Relating to an investigation of rear-end impacts in Germany (Eichberger 1995) about 70% of whiplash injuries occur at a Δv of 0 to 15 km/h. Therefore each padding has been tested at two different pulses (3g / 9,6km/h; 5g / 14,2km/h) and two different seat back angles (15°, 25°). The results of these tests show that there is not a big difference in the load between the three types when they are used as a single part on the whole seat back. Concerning the seat back angle the tendencies in the load results are the same with both positions.

Therefore the following tests have been performed with a seat back angle of 25° and also type B has been left away. In the tests 13 to 16 the seat back cushion was divided into two parts [Fig. 2, left picture] to simulate the damping distribution of serial seat backs.

In tests 17 to 22 the shock absorbing foam (D) was used at three different positions (head rest, upper torso, lower torso). Because of the hardness of type D the measurement results have been similar to the tests with the hard type C at the same positions on the seat back.

Altogether 22 tests have been performed which differ from each other by the combination of the foam, the seatback – angle and the pulse [Tab. 2].

Table 2: Matrix of test parameter

N°	Pulse		Cushion (seatback)	Cushion (head rest)	Seatback - Angle	$a_{x,\,max}$ Head	$F_{x,\,max}$ Neck	$F_{z,\,max}$ Neck	$M_{y,\,max}$ Neck	NIC 3ms
	g	km/h	low / high		°	g	N	N	Nm	
1	3	9.6	A	C	15	12.1	-133.6	-284.5	6.4	14.0
2	5	14.2	A	C	15	18.6	-167.8	-480.8	16.0	38.6
3	3	9.6	A	C	25	12.7	-101.5	-270.1	8.9	17.8
4	5	14.2	A	C	25	19.5	-136.1	-462.1	15.6	38.4
5	3	9.6	B	C	25	15.8	-110.0	-279.2	4.7	13.8
6	5	14.2	B	C	25	22.5	-108.4	-524.6	9.5	25.7
7	3	9.6	B	C	15	14.2	-124.9	-300.8	4.2	14.6
8	5	14.2	B	C	15	23.2	-136.1	-550.9	10.6	32.9
9	3	9.6	C	C	15	16.9	-158.3	-296.4	4.7	15.7
10	5	14.2	C	C	15	24.1	-204.4	-583.1	10.7	32.4
11	3	9.6	C	C	25	15.8	-121.6	-250.2	4.1	15.6
12	5	14.2	C	C	25	23.2	-155.5	-541.6	8.5	31.1
13	3	9.6	C / A	C	25	11.9	-57.8	-171.0	4.4	12.3
14	5	14.2	C / A	C	25	17.4	-67.1	-304.8	10.5	19.5
15	3	9.6	A / C	C	25	14.9	-139.3	-322.7	3.9	18.2
16	5	14.2	A / C	C	25	24.0	-166.8	-654.8	8.3	36.8
17	3	9.6	C / A	C + D	25	12.5	-84.3	-204.1	6.7	12.5
18	5	14.2	C / A	C + D	25	18.4	-62.3	-331.7	9.8	20.6
19	3	9.6	C / D	C	25	14.0	-136.7	-256.8	6.0	13.9
20	5	14.2	C / D	C	25	25.1	-140.6	-476.3	9.9	29.6
21	3	9.6	D / A	C	25	13.0	-75.0	-194.3	8.2	13.4
22	5	14.2	D / A	C	25	19.8	-101.6	-235.5	14.3	19.1

As the results of the forces, moments and accelerations correlate in the tests with 5g and 3g as well as for the seat back - angle of 15° and 25° [Tab. 2] only 4 significant tests shall be described in detail. Because of the higher injury risk only tests with 5g and 14,2 km/h have been chosen.

Shown in table2 the results of the tests with a seat back – angle of 25° are a little bit better than those with 15°. In general that should be different because the distance between head and head restraint decreases with steeper seat backs. But in this test series we used the same distance of 100mm for all tests which caused a steeper neck position combined with a different initial force direction relative to the neck in the 15° tests. So higher loads were indicated.

Concerning the tests with 3g acceleration the results show that the influence of the different cushion types is completely the same as with 5g.

EXPERIMENTAL RESULTS

THIS SECTION DESCRIBES THE FOUR MOST SIGNIFICANT TESTS which had the most different conditions regarding the padding behavior.

Table 3: Selected test configuration for the in depth study

N°	Acceleration [g]	Velocity [km/h]	Lower Seat Back	Upper Seat Back	Seat	Head Restraint
4	5	14.2	soft (A)	soft (A)	soft (A)	hard (C)
12	5	14.2	hard (C)	hard (C)	soft (A)	hard (C)
14	5	14.2	hard (C)	soft (A)	soft (A)	hard (C)
16	5	14.2	soft (A)	hard (C)	soft (A)	hard (C)

The initial gap between head and head restraint was 100 mm and was used for all tests.

Test N° 4:

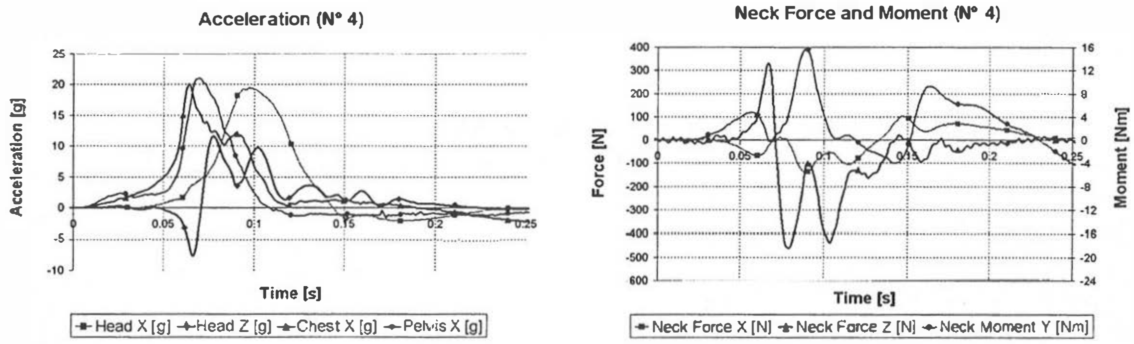


Figure 3: Accelerations and neck loading diagrams

The soft cushion of the whole seat back caused a deep penetration of the dummy which resulted in a delayed torso acceleration and a steep and high increase of the pelvis and chest acceleration. Due to these heavy peaks a strong head acceleration in z minus combined with a big neck force in z plus occurred. The high neck M_y peak resulted from the ramping effect of the torso while the head is held in its position by the friction between head and head restraint.

Table 4: Dummy loading and evaluated values

a_{max} Head	19.5 g	98 ms
a_{max} Chest	20.3 g	63 ms
a_{max} Pelvis	21.1 g	70 ms
F_x posterior	-136.1 N	91 ms
F_z posterior	-437.5 N	104 ms
M_y posterior	15.6 Nm	89 ms
NIC $_{3ms}$	38.4	61 – 64 ms
φ_{rel} max	-27.6 °	116 ms

1st Contact Head – Head Restraint	61 ms
a Head	1.8 g
a Chest	17.5 g
a Pelvis	6.6 g
F_x	-67.6 N
F_z	149.3 N
M_y	4.0 Nm
φ_{rel}	0.8 °

TEST N° 12:

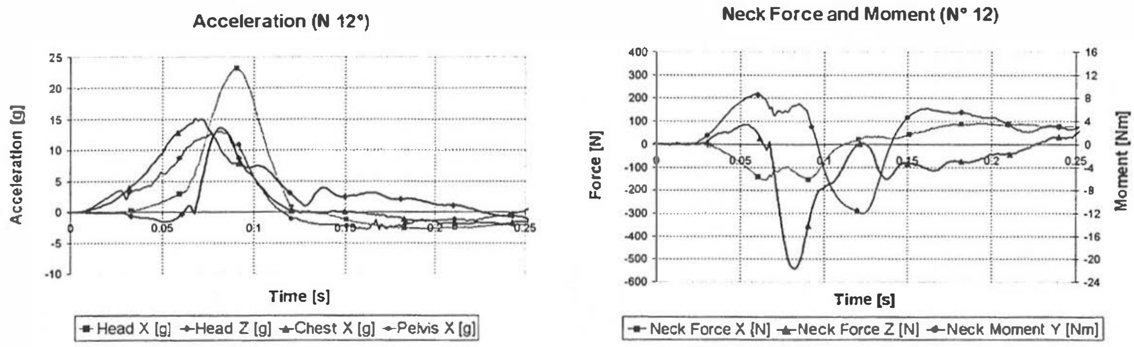


Figure 4: Accelerations and neck loading diagrams

Due to the stiffer foam the torso acceleration started earlier and resulted in smaller chest and pelvis loads. The little penetration caused a bigger gap between head and head restraint and a stronger head extension. This leaded further to a stronger g peak for the head acceleration. The strong neck force in z-direction caused the ramping effect while the head had contact with the head restraint.

Table 5: Dummy loading and evaluated values

a_{max} Head	23.2 g	90 ms
a_{max} Chest	15.1 g	68 ms
a_{max} Pelvis	13.1 g	80 ms
F_x posterior	-155.5 N	90 ms
F_z posterior	-541.6 N	83 ms
M_y posterior	7.0 Nm	85 ms
NIC $_{3ms}$	31.1	62 – 65 ms
φ_{rel} max	-33.7 °	104 ms

1st Contact Head – Head Restraint	63 ms
a Head	3.6 g
a Chest	14.0 g
a Pelvis	10.5 g
F_x	-151.8 N
F_z	-0.9 N
M_y	8.2 Nm
φ_{rel}	-4.0 °

TEST 14:

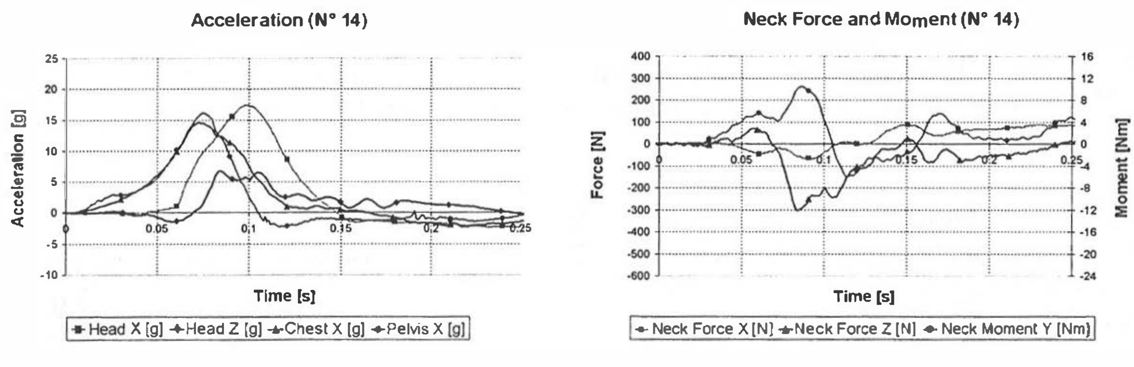


Figure 5: Accelerations and neck loading diagrams

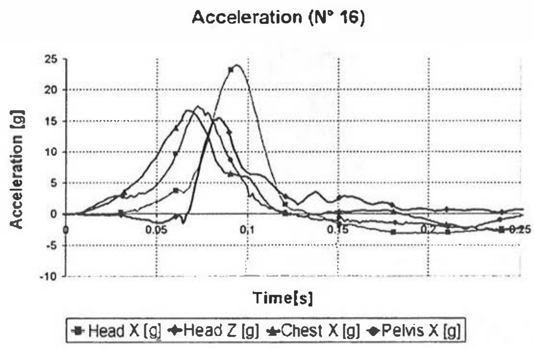
By using a stiffer pelvis and a softer back cushion an earlier rotation of the torso around the pelvis was initiated. This movement with less relative displacement in the pre-contact phase decreased the gap between head and head restraint and resulted in a smaller head extension and the best acceleration and loading values in comparison to the other tests.

Table 6: Dummy loading and evaluated values

a_{max} Head	17.4 g	99 ms
a_{max} Chest	14.6 g	73 ms
a_{max} Pelvis	16.1 g	76 ms
F_x posterior	-67.1 N	93 ms
F_z posterior	-304.8 N	84 ms
M_y posterior	10.5 Nm	87 ms
NIC $_{3ms}$	19.5	63 – 66 ms
φ_{rel} max	-24.5 °	114 ms

1st Contact Head – Head Restraint	60 ms
a Head	1.0 g
a Chest	9.9 g
a Pelvis	10.1 g
F_x	-46.6 N
F_z	66.2 N
M_y	5.6 Nm
φ_{rel}	4.5 °

TEST 16:



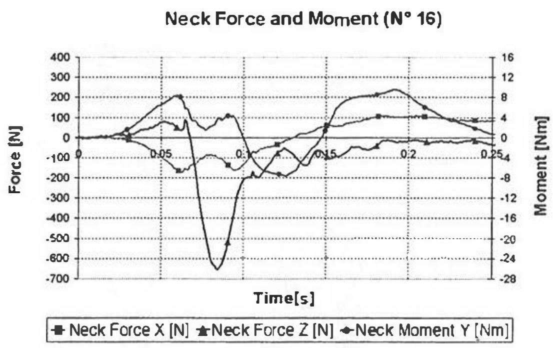


Figure 6: Accelerations and neck loading diagrams

The usage of a soft cushion in the lower and a stiffer one in the upper area caused a deeper penetration of the pelvis. Thereby the dummy occupied a steeper position as the seat back angle. This resulted in a bigger gap between head and head restraint following a stronger head Extension, a higher head acceleration combined with a strong neck force in z-direction.

Table 7: Dummy loading and evaluated values

a_{max} Head	24.0 g	94 ms
a_{max} Chest	16.6 g	68 ms
a_{max} Pelvis	17.4 g	73 ms
F_x posterior	-160.5 N	95 ms
F_z posterior	-654.8 N	85 ms
M_y posterior	4.3 Nm	91 ms
NIC $_{3ms}$	36.8	69 – 72 ms
φ_{rel} max	-31.9 °	103 ms

1st Contact Head – Head Restraint	64 ms
a Head	3.4 g
a Chest	15.8 g
a Pelvis	12.3 g
F_x	-151.6 N
F_z	91.0 N
M_y	5.8 Nm
φ_{rel}	24.5 °

DISCUSSION

TEST 14 SHOWED THE BEST RESULTS IN GENERAL. In this test a soft cushion was used on the upper part of the seat back and a hard one on the lower part.

Croft, (1998) confirmed the risk of cervical injuries at the moment of the first contact between head and head restraint [Fig. 7]. Such injuries can occur even if the restraint is properly positioned. Immediately following head contact the upper cervical spine will be forced into acute flexion as the inertia of the neck continues to draw it rearward, since there is no contact with either seat back or head restraint (Geigl, 1997).

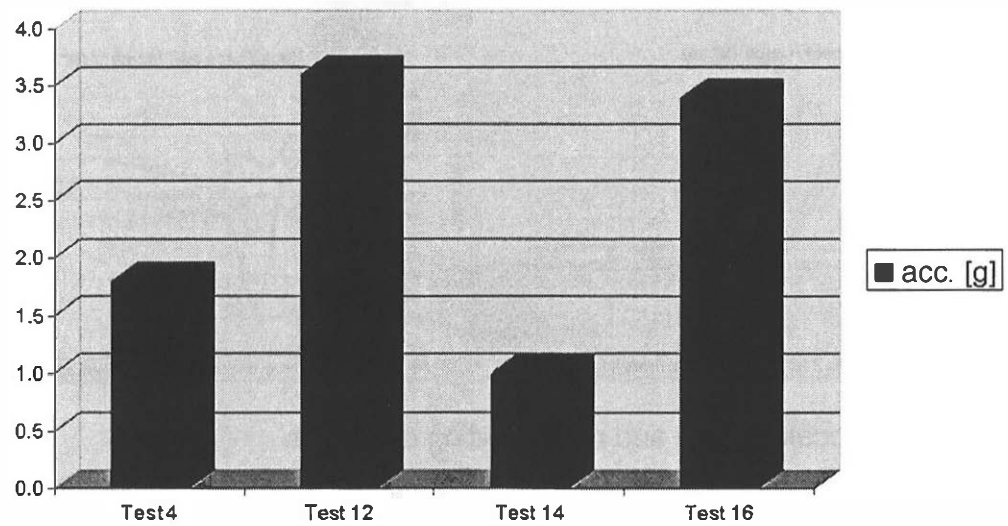


Figure 7: Comparison of the Head Acceleration immediately before the 1st Contact

The low acceleration in test 14 resulted from a diving of the torso into the seat back combined with a rotation. Therefore the distance between head and restraint was very small when the extension of the head started and the acceleration values stayed low. In test 4 the soft cushion was used for the whole seat back. In this case the torso dived into the seat back, too, but with less rotation. So there was a bigger gap between head and head restraint at the beginning and more rotation was indicated in the head until it hit the head restraint. This lead to higher loads at the head as described before. Test 12 and 16 were even worse because there was, due to the hard padding only little penetration of the torso into the foam. The results of the bigger distance between head and head restraint were later starting and higher accelerations. Looking at the series of frames in figure 8 which show the period of the first contact between head and head restraint there is an obvious higher rebound of the head in test 12 and 16 caused by the high accelerations.

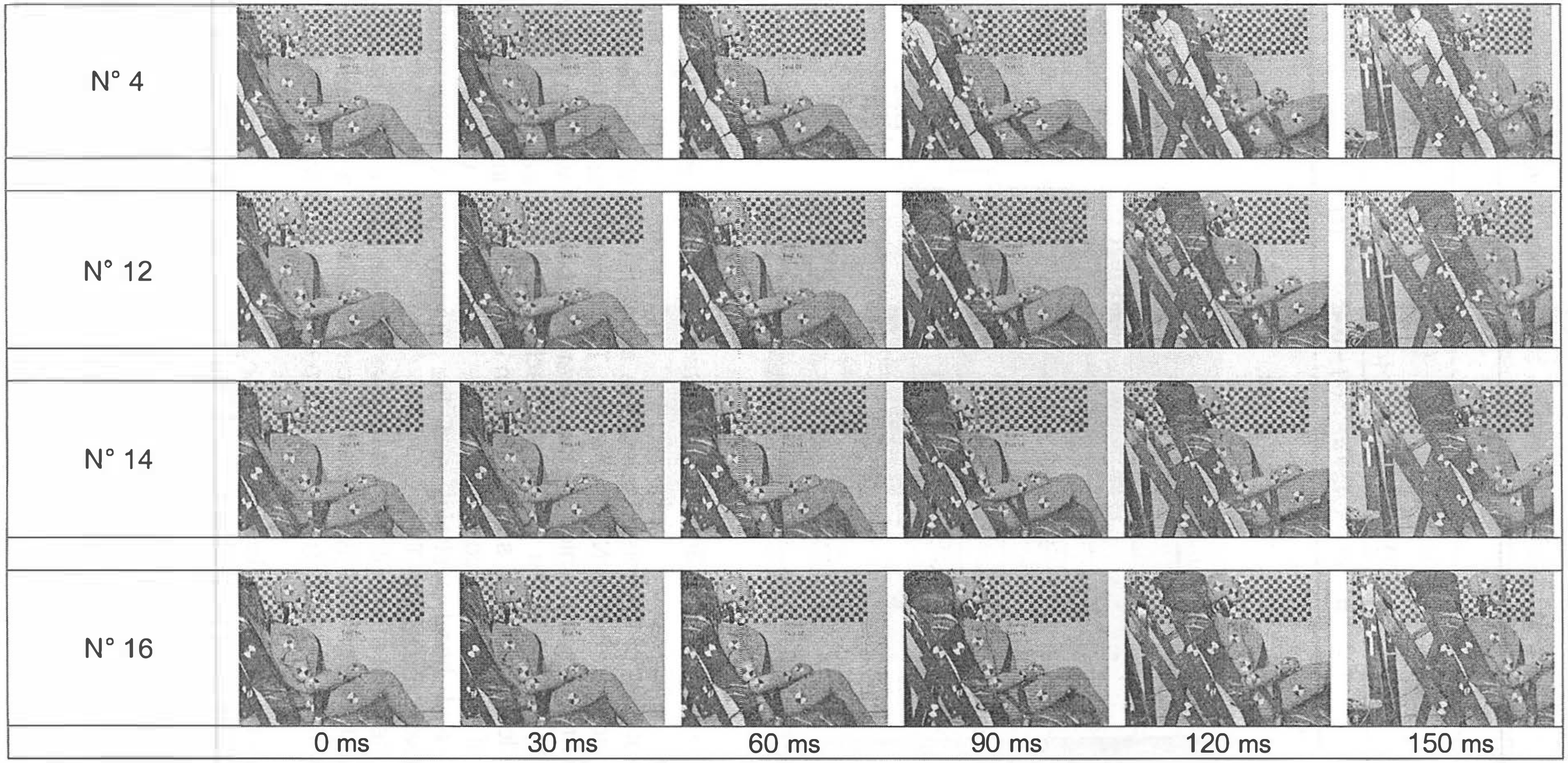


Figure 8: High Speed Video Sequences of the 4 chosen tests

The course of the videos shows clearly the earlier head rotation when using a stiff torso cushion and moreover the stronger rebound effect for these cases.

Concerning the NIC [Figure 9] better results occur when there is a rotation in the torso combined with a penetration into the seat back.

Used equation:	$NIC(t) = a_{rel}(t) * 0.2 + (v_{rel}(t))^2$
with:	$a_{rel}(t) = a_x^{T1}(t) - a_x^{Head}(t)$
	$a_x^{T1}(t) = 1.45 * a_x^{chest}(t) - 0.45 a_x^{pelvis}(t)$

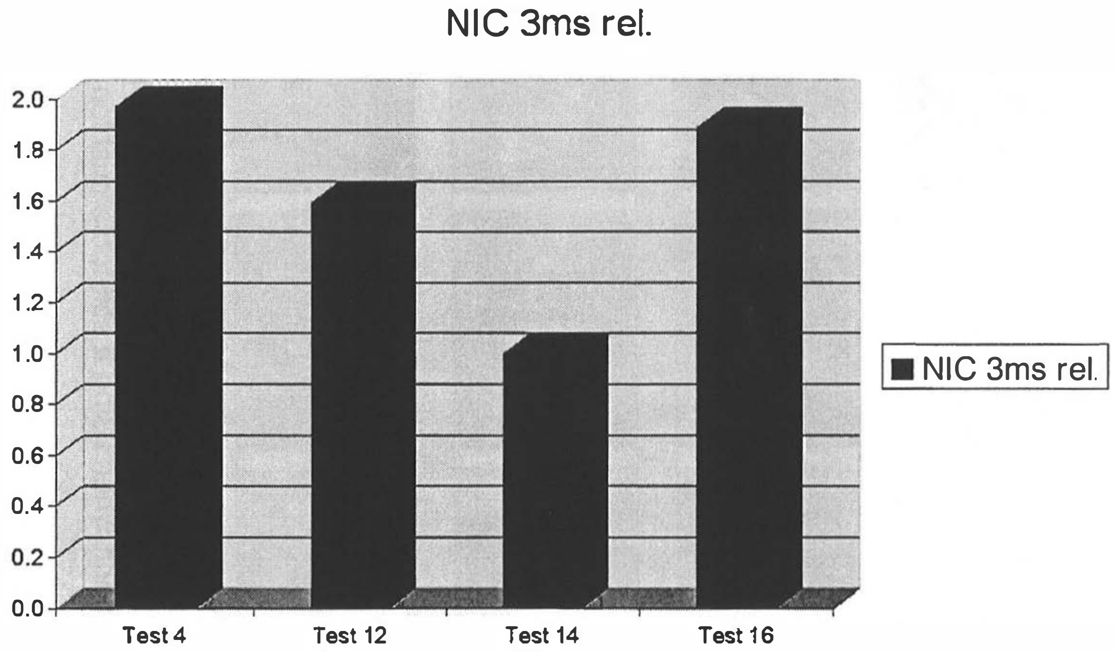


Figure 9: Standardized NIC 3ms values to the best NIC value (N° 14)

Because of rotation of the torso the relative acceleration between head and T1 is very low and therefor the NIC is low, too. The similar results of test 4 and test 16 come from the soft cushion on the lower seat back. It was too soft and the dummy even hit the frame of the seatback. For there was little rotation indicated by the lower torso the seating position was too erect immediately after the beginning of the torso acceleration. The consequence was a big gap between head and head restraint and the dummy got a high relative acceleration between head and T1.

Considering the neck moment and the relative rotation between the head and the torso the head rotation energy shows the positive effect of a hard padding in the lower part and a soft padding in the upper part of the seat back, too [Figure 10].

Assuming that there is little risk for severe neck injuries with a big amount of head rotation at low neck moments (Ono et al., 1993), test 14 also shows the best results because there is almost no relative head rotation and so the neck moment alone cannot cause severe neck injuries. However considering experimental results of Dr. A. C. Croft, (1998) it is important not to isolate single physical loads. But if we have a look at the neck shear forces, they also, caused by an even load of the torso and the head, prove to be low in test 14.

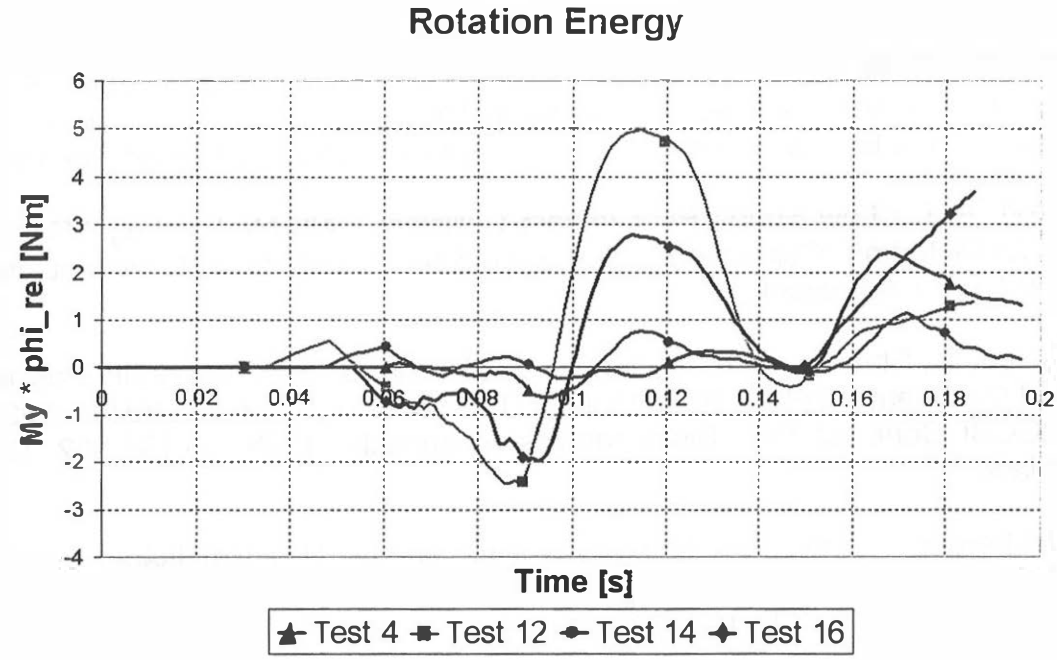


Figure 10: Head Rotation Energy

CONCLUSION

THE KNOWLEDGE OF THESE TESTS SHOWED THE IMPORTANCE OF THE CUSHION PROPERTIES due to their behavior in reduction of severe neck injuries in rear end impacts. Both the kind of cushion and its shape and position have a big influence to the seat characteristic. Basically the intention in designing seats must guarantee an early and nearly simultaneous support of torso and head which requires a defined diving into the seat back cushion to prevent or minimize a relative linear and angular displacement between head and torso. Due to different criterions in the interaction between seat and occupant like seating position or seat back angle it is important to reduce the distance between shoulder area and seat as soon as possible. However, this must not lead to a push away of the seat back which would increase the gap between head and head restraint (Geigl et al., 1994) and also the time of first contact. This process can easily be done by an early initiated rotation of the torso – head line around the pelvis. To get this movement the pelvis must take part at the seat movement to an early time which is realized by a stiff cushion in the pelvis area. This motion reduces both the shearing forces and the early angular displacement between head and torso.

The possibility of realization of this demand into standard car seats was investigated with several low speed volunteer tests by Watanabe et al. (1999). The use of such defined seats in future car fleets may result in correct working of the seats referring to the big range of weight classes of occupants. This challenge will be examined in further studies.

REFERENCES:

Bigi, D.; Heilig, A.; Steffan, H.; Eichberger, A.: A Comparison Study of Active Head Restraints for Neck Protection in Rear – End Coll. 16th Int. Technical Conf. on the Enh. Safety of Veh., Vol.2, 1998, pp. 1103-1125, Windsor, Canada

Croft, A. C.: Low Speed Rear Impact Collision; 1998 Medico-Legal-Congress, HWS-Distortion (Schleudertrauma) & Leichte Traumatische Hirnverletzungen., 1998, pp. 1-53, Basel

Cullen, E.; Stabler, K. M.; Mackay, G. M.; Parkin, S.: Head Restraint Positioning and Occupant Safety in Rear Impacts: The Case for Smart Restraints. 1996 Int. IRCOBI Conf. on the Biomechanics of Impacts, 1996, pp.137-152, Dublin, Ireland

Eichberger, A.: Beschleunigungsverletzungen der Halswirbelsäule bei Pkw / Pkw - Heckkollisionen im realen Unfallgeschehen. Diplomarbeit an der Techn. Universität Graz, 1995, Graz, Austria

Eichberger, A.; Geigl, B. C.; Moser, A.; Fachbach, B.; Steffan, H.: Comparison of Different Car Seats Regarding Head – Neck Kinematics of Volunteers during Rear End Impact. 1996 Int. IRCOBI Conf. on the Biomechanics of Impacts, 1996, pp.153 -164, Dublin, Ireland

Geigl, B. C.: "Whiplash" Bewegung der Halswirbelsäule beim Heckaufprall. Dissertation an der Techn. Universität Graz, 1997, Graz, Austria

Geigl, B. C.; Steffan, H.; Leinzinger, P.; Roll, P.; Mühlbauer, M.; Bauer, G.: The Movement of Head and Cervical Spine During Rear End Impact. 1994 Int. IRCOBI Conf. on the Biomechanics of Impacts, 1994, pp.127-137, Lyon, France

Hofinger, M.: Entwicklung einer aktiven Crash – Schlitten – Anlage. Diplomarbeit an der Techn. Universität Graz, 1998, Graz, Austria

Ono, K., Kanno, M.: Influences of the Physical Parameters on the Risk to Neck Injuries in Low Impact Speed Rear End Collisions. 1993 Int. IRCOBI Conf. on the Biomechanics of Impacts, 1993, pp. 201 – 212, Eindhoven, The Netherl.

Svensson, M. Y.; Aldman, B.; Lövsund, P.; Hansson, H. A.; Seeman, T.; Suneson, A.; Örtengren, T.: Pressure Effects in the Spinal Canal during Whiplash Extension Motion – A Possible Cause of Injury to the Cervical Spinal Ganglia. SAE paper no. 1993-13-0013, Proc. 1993 Int. IRCOBI Conf. on the Biomechanics of Impacts, 1993, pp.189-200, Eindhoven, The Netherlands

Watanabe, Y., Ichikawa, H., Kayama, O., Ono, K., Kaneoka, K., Inami, S.: Relationship between Occupant Motion and Seat Characteristics in Low-Speed Rear Impacts. SAE paper no. 1999-01-0635, Occupant Protection, SP-1432, 1999, pp. 303 – 318, Detroit, Michigan