

PERFORMANCE OF SEATING SYSTEMS IN A FMVSS NO. 301 REAR IMPACT CRASH TEST

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ABSTRACT

Seating systems are designed for occupant comfort as well as for affording occupant protection in various crash modes. FMVSS No. 207 specifies seat performance criteria, of which, one requires that a seat back withstand a minimum of 373 Nm moment measured about the seating reference point. The sufficiency of this requirement has been a source of significant debate. Some researchers believe that the potential hazards from a seat back collapsing in a rear impact include: the inability to control the vehicle in the event of a second impact, ejection of the occupant from the seat and injury to the rear seat occupant when struck by the front seat.

Molino (1998) reported that the average yield strength and average ultimate strength for all seats tested were 2.1 times and 3.4 times the current standard respectively. In spite of the greater strength of current production seats than FMVSS No. 207 requirements, there are still anecdotal cases of front and rear occupant injuries and fatalities due to seat back collapse (Saczalski, Cantor). NHTSA has in the past stated that improving seating system performance may be more complex than simply increasing the strength of the seat (57 FR 54958). Seat back force-deflection characteristics and energy management along with occupant interaction with the seat upholstery, head restraint and belt restraints may all play critical roles in mitigation of injuries in rear impacts.

This paper examines the performance of original equipment manufacturer (OEM) seat systems in a series of FMVSS No. 301 crash tests of 2002 model year vehicles by using the instrumented 50th percentile male Hybrid III dummy.

INTRODUCTION

FMVSS No. 207 came into effect in 1968 for cars and in 1972 for multipurpose passenger vehicles (MPVs), trucks, and buses. The current test procedure

for seat back strength evaluation involves applying a force at the upper cross-member of the seat back in a rearward longitudinal direction that produces a 373 Nm moment about the seating reference point (or H-point). The FMVSS No. 207 regulation requires that the seat back withstand this applied load.

Molino (1998) conducted static tests to evaluate the seat back strength of various production seats and found that the average ultimate strength of single and dual recliner seats was 3 and 4 times greater than FMVSS No. 207 specified strength of 373 Nm H-point moment.

Even though current production seats exceed the FMVSS No. 207 requirements, there are still anecdotal cases of front and rear occupant injuries and fatalities due to seat back collapse (Saczalski 1993 and Cantor 1989). These researchers believe that the potential hazards from a seat back that deforms too much in a rear impact include: the inability to control the vehicle in the event of a second impact, ejection of the occupant from the seat and injury to the rear seat occupant when struck by the front seat. Further, fatalities and injuries to rear child occupants due to seat back collapse of the front seat in rear impacts have also been reported. This is especially of concern since NHTSA recommends to the public that children of age 12 and under should be placed in the rear seat.

Other researchers contend that seats that deform are preferable. Studies by Strother and James (1987) and Warner, et al. (1991) indicated that there was an underlying design conflict between occupant retention by a "stiff" or "rigid" seat in severe, but relatively infrequent rear crashes, and the need for a "yielding" seat back to prevent whiplash injuries in the more frequent, minor rear impacts.

More recently, Viano, (2002, 2003) has demonstrated the efficacy of high retention seats in reducing injuries and fatalities associated with ramping out of the seat in high speed rear impacts as well as in

reducing whiplash injuries in low speed rear crashes. High retention seats have a strong frame structure with high recliner stiffness that yield by deformation of the seat trim. Further, a recent investigation of insurance claims of rear impact crashes (Farmer, 2002) indicated that the use of head restraints that are higher and closer to the occupant's head as well as active head restraints have reduced whiplash injury claims by as much as 30%.

Advances have also been made on assessing whiplash injuries in rear impacts (Viano, 2002) using the Hybrid III dummy. In light of the recent advances in seat design and rear impact injury evaluation criteria, NHTSA undertook examining the performance of current seat systems in moderate to high speed rear impact crashes (velocity change between 22 to 30 kph) using the current FMVSS No. 301 rear impact test procedure.

PROBLEM DEFINITION

The National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) data files for the years 1992-2001 were examined to determine the number of rear impacts compared to other crash modes and to determine the injury rate of outboard occupants in rear impacts. The data was divided into different crash types, which include rollover, frontal, side, rear, other and unknown. All data presented in the paper are weighted to represent the national estimates.

Rear impact crashes account for only 8 percent of all tow away crashes in the NASS/CDS database (Figure 1). In addition, the risk of moderate to severe injury (1990 Abbreviated Injury Scale, AIS 3+) injuries is lowest for rear impacts (0.5%) as compared to rollover (6%), frontal (2%) and side (2.5%) (Figure 2). In contrast Figure 3 shows that the risk of whiplash is greatest for rear impacts (20%) compared to other crash modes. Further, unlike the risk of AIS 3+ injuries, the risk of whiplash injury is approximately the same at high and low speeds (Figure 4). Cervical spine strain or sprain injuries without fracture or dislocation and of AIS 1 severity were considered as whiplash injury in this analysis. Previously NHTSA has reported NASS whiplash rates of greater than 30% (NHTSA 1999). The lower rate reported here is likely due to the fact that only occupants with a whiplash and no other injury greater than AIS 1 were included in the data analysis.

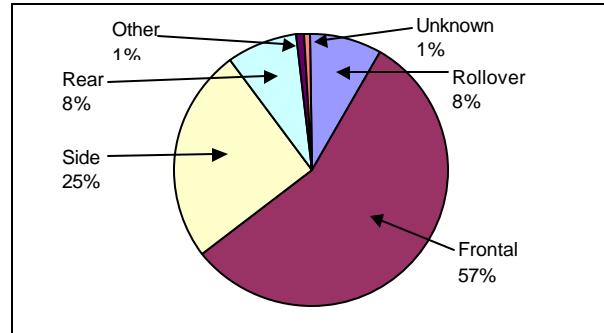


Figure 1. Distribution of types of crashes.

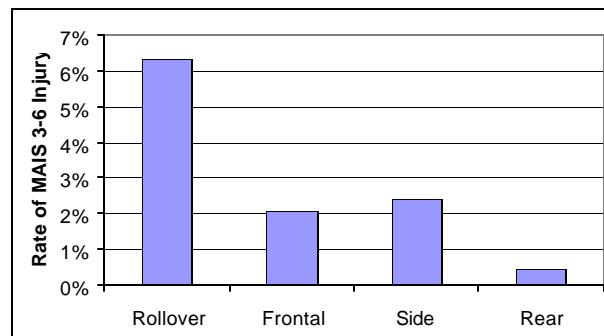


Figure 2. Rate of MAIS 3 -6 injuries by impact type.

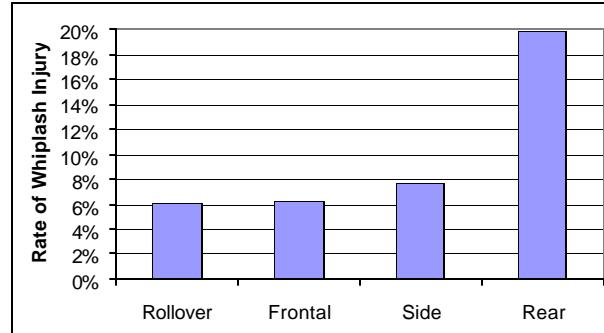


Figure 3. Rate of whiplash injuries by impact type.

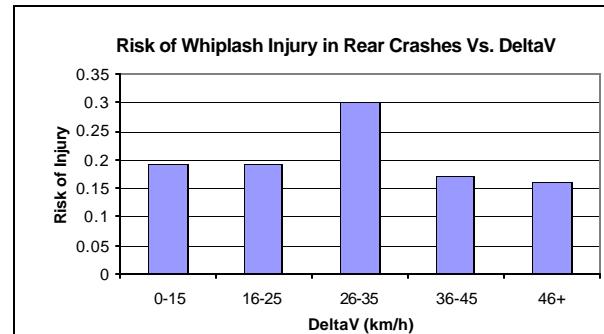


Figure 4. Average annual estimates of risk of whiplash injury for light vehicle occupants in tow away rear crashes at different deltaVs (NASS years: 1992-2001).

TEST SETUP

The vehicle setup was according to the rear impact test procedure defined by FMVSS No. 301. In this procedure, the moving barrier, with flat rigid plate, impacts the rear of the vehicle at 48 kph (30 mph) (see Figure 5) and fully engages the rear of the vehicle. The head restraint was placed in the highest position and the seat back angle was set according to the manufacturers' specifications. The list of vehicles tested are presented in Table 1. The table also shows an abbreviation of each vehicle used throughout the paper.

Table 1. Test Matrix

Vehicle	Abbreviation
Kia Spectra	SPEC
Hyundai Accent	ACC
Chevrolet Trailblazer	TRAIL
Acura RSX	RSX
Chevrolet Venture	VENT
Suzuki Aerio	AERIO
Dodge Intrepid	INTR
Toyota Camry	CAMRY
Nissan Altima	ALT

The Hybrid III 50th percentile male dummy was positioned in the driver's seat according to the procedure defined in FMVSS No. 208. The dummy was instrumented with 3-axis accelerometers in the head and chest and 6-axis upper and lower neck load cells. To measure head-to-torso rotation, the dummy was instrumented with Magnetohydrodynamic (MHD) angular rate sensors (ATA model ARS-02) in the head and upper spine. For three of the tests the head-to-torso rotation was also measured using goniometers (Figure 6). One goniometer link measured the upper neck rotation relative to the upper torso and the second link measured head rotation relative to the upper neck.

The seat back rotation was calculated using the following two methods: The first method used single axis accelerometers placed perpendicular to the seat back. The first accelerometer was placed at the height of the H-point (Figure 7). The second accelerometer was placed 262 mm above the first accelerometer along the seat back. Equation 1 was used to calculate the seat back angle. The second method was to place an MHD angular rate sensor just above the upper accelerometer and then integrate the output to get angular displacement. Note that both the left and right side of the seat were instrumented.

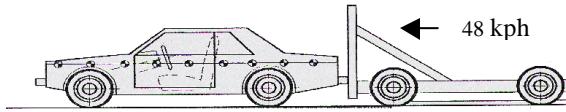


Figure 5. Test setup.



Figure 6. Goniometer setup.

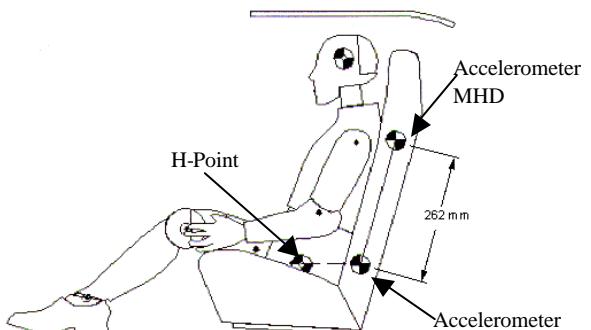


Figure 7. Seat setup.

$$SeatBackRotation = \int \int \frac{(SB_t - SB_b)}{L} \quad (1)$$

Where: SB_t: Acceleration of the upper accelerometer

SB_b: Acceleration of the lower accelerometer

L : Distance between the two accelerometers

INJURY ASSESSMENT

To assess severe injuries in moderate to high speed rear impacts the current FMVSS No. 208 (CFR 2001) injury criteria were monitored. Several neck injury criteria to assess whiplash injury have been

proposed in recent years such as NIC (Svensson et al., 1993, 2000), Nkm (Schmitt et al. 2001), IV-NIC (Panjabi, et al., 1999), NDC (head-to-torso rotation) (Viano, 2002) and lower neck moment (Prasad et al., 1997).

Prasad, et al. (1997) conducted rear impact tests with the Hybrid III dummy in production seats and found that among all dummy responses, the extension moment computed at the base of the neck was most sensitive to seat design changes and crash severity. Prasad recommended a corrected lower neck moment threshold level on the Hybrid III dummy of 154-186 Nm to mitigate ligamentous neck injury. While Prasad et al. (1997) noted that the Hybrid III dummy responses in rear impact crashes correlated well with cadaveric head/neck responses, other researchers (Svensson, et al. 1993, Schmitt, et al. 2001) found Hybrid III dummy neck responses in rear impacts were not biofidelic and suggested that application of NIC and Nkm on Hybrid III dummy neck responses to assess whiplash injury risk may not be appropriate.

While there remains a lack of consensus on the underlying whiplash injury mechanism, there is a consensus that limiting the relative head to torso motion would reduce the incidence of whiplash injuries (Viano, 2002, Yoganandan, 2000, Langweider, 2000). Viano and Davidsson (2002) demonstrated that the relative head to torso rotation versus relative head to torso longitudinal displacements trajectories of the Hybrid III dummy in rear impacts were similar to those of volunteers. Therefore, injury criteria based on relative head to torso motion of the Hybrid III dummy may be adequate in assessing whiplash injury risk.

RESULTS

Figure 8 shows the left seat back rotation (SBR) calculated from the accelerometers with zero being the starting seat back position. Many of these curves indicate rotation values that pass through zero and continue with a negative slope. However, these results are in question since video analysis showed that no seat back returned to its initial position. This discrepancy in measured and observed seat rotation could be attributed to the error in calculating angle from double integrating the accelerometers or due to the axis of the accelerometers not remaining parallel to each other during the event due to seat deformation. Note that Table 1 in Appendix 1 summarizes all results from these rear impact tests. This same trend was found on the right side of the seat.

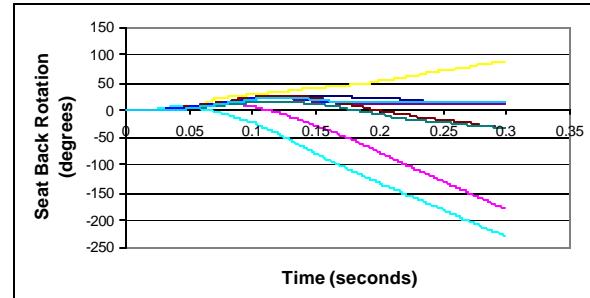


Figure 8. Left seat back rotation calculated from accelerometers.

Figure 9 shows the left side of the seat back rotation calculated from the MHD and the Delta V for each vehicle. The seat back rotation ranged from 11 to 52 degrees of rotation and the Delta V ranged from 22 to 30 kph. Figure 10 and Figure 11 show the dummy position at maximum seat rotation for the Trailblazer and the Accent which had rotations of 11 and 52 degrees, respectively. The Accent seat back completely collapsed and was found in contact with the rear seat post-test. The recliner mechanism was inspected after the tests to determine the cause of the collapse. The teeth of the recliner were not sheared off and there were no noticeable scratches on the sides of the recliner mechanism. In addition, the recliner worked properly after the test. Therefore, the exact cause of the large seat back rotation could not be determined.

Although not shown, the rotations of the right side of each seat back was also measured using a MHD, but the data from that MHD was questionable for most of the tests. The reason for this could be because the MHD was old and may not have been working properly.

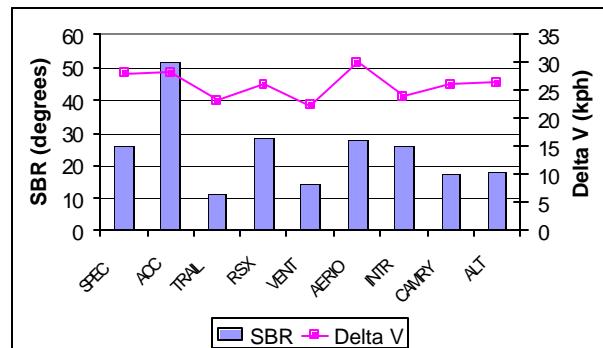


Figure 9. Left seat back rotation calculated from MHD.



Figure 10. Max Seat rotation of a 2002 Chevrolet Trailblazer (11 degrees).



Figure 11. Max Seat rotation of a 2002 Hyundai Accent (52 degrees).

Figure 12 shows the comparison of measuring head-to-torso rotation using MHD's or goniometers. From this figure it is seen that both measurement techniques give approximately the same result. The percent difference between the peaks of the two measurement techniques are 5.8 and 5.3 percent for the Altima and RSX respectively.

The head-to-torso rotation (H2T) ranged from 7.8 to 30.2 degrees (see Figure 13) for the seats tested. Since the Camry MHD data was bad, the goniometer data was plotted for this vehicle. The Kia Spectra had the highest head-to-torso rotation at 30.2 degrees.

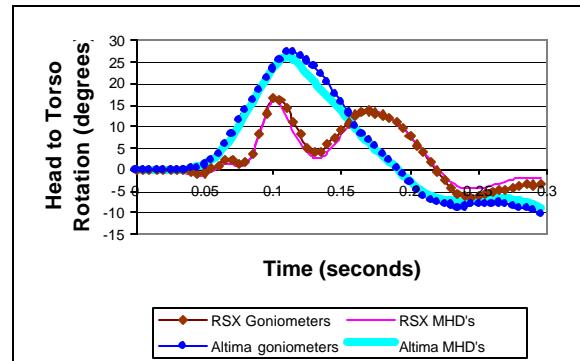


Figure 12. Comparison of techniques of measuring head-to-torso rotation.

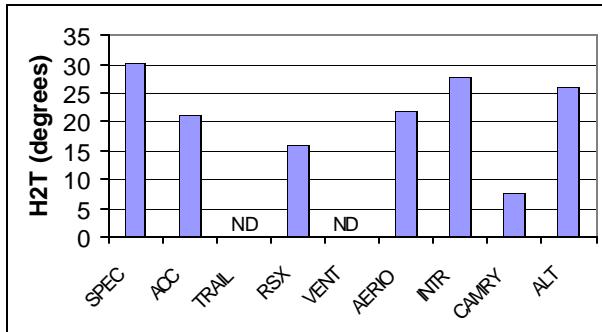


Figure 13. Head-to-Torso Rotation.

Figure 14 and Figure 15 show the HIC 15 and chest g's for each vehicle, respectively. The vehicles with the maximum HIC 15 (147) and chest g's (20 g's) were the Acura RSX and Chevrolet, respectively.

Figure 16 and Figure 17 show the maximum upper neck Nij and the maximum upper neck Nkm for each vehicle. Nij was computed as specified in FMVSS 208. Though Nkm was developed for the Hybrid III dummy with the TRID neck, it was applied to the Hybrid III neck measurements as done by Yoganandan, et al (2002). The peak values for the Nij and Nkm were 0.31 and 0.82, respectively. Figure 18 shows the corrected maximum lower neck moment for each vehicle. The vehicle with the maximum corrected lower neck moment was the Trailblazer at 148 Nm.

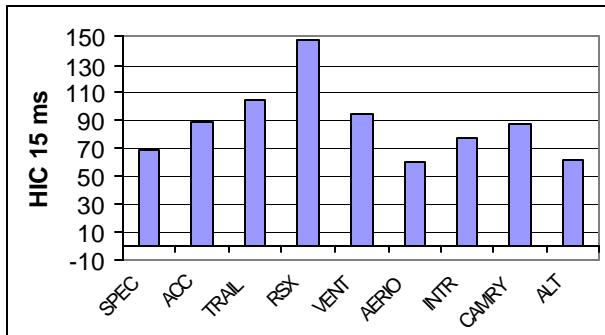


Figure 14. 15 ms HIC.

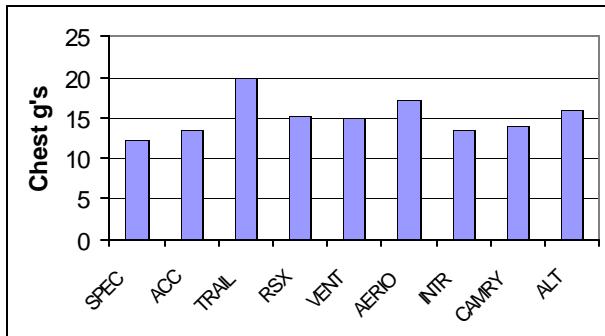


Figure 15. Chest g's.

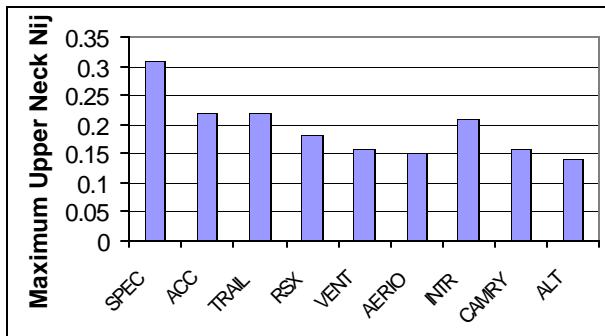


Figure 16. Maximum upper neck Nij.

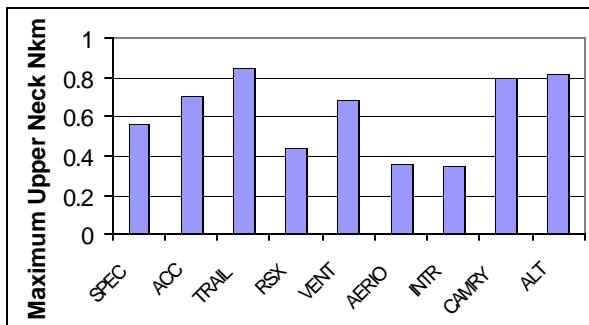


Figure 17. Maximum upper neck Nkm.

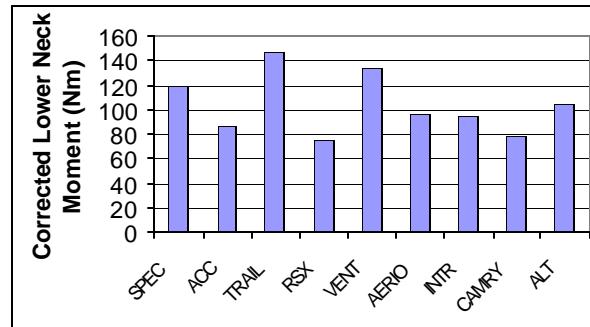


Figure 18. Corrected maximum lower neck moment.

DISCUSSION

The NASS analysis showed that only 8 percent of tow away crashes are rear impacts and the risk of AIS 3+ injuries in rear crashes is only 0.5 percent.

Even though current OEM seats are on average approximately 2-3 times stiffer and stronger than the current FMVSS No. 207 standard requirement, the test of the Hyundai Accent resulted in a seat back rotation of 52 degrees with the dummy's head contacting the rear seat back. In spite of the head contact, the dummy performance criteria monitored were not able to distinguish between the Hyundai Accent seat that collapsed from other seats that stayed upright. From Figure 11 it can be seen that if an occupant was present in the rear seat of the Accent, the front seat and /or the front seat occupant would have contacted the rear occupant and may have caused injury to that occupant. Video observation of dummy kinematics showed no noticeable translation of the dummy up the seat back (ramping) for the vehicles tested, even for the seat that collapsed. This is contrary to reports from real world crash investigations (Saczalski, 1993). However, no quantitative assessment of this relative motion was possible.

The seat rotation computed from accelerometer data did not appear to match the qualitative assessment of seat back rotation that was made from the video. This may have been due in part to the probable rotation of accelerometers caused by localized deformation of the seat back, as well as the computational error discussed previously. The seat rotations computed from the MHD data were similar to the assessment of seat back rotation made from video. A more thorough evaluation of the MHD sensors for use in determining seat back rotation should be conducted. The head-to-torso rotations computed using MHD sensors located in the head and upper spine and those computed using the goniometers were nearly identical. This indicates

that both of the measurement techniques employed for determining head-to-torso rotation are reasonably accurate. The MHD sensors are relatively unobtrusive and do not interfere with interaction of the dummy head and upper body with the seat back and head restraint. Since the goniometer links are externally placed on the dummy head and neck, they may alter dummy and seat back interaction in some instances. This should be further investigated.

The Insurance Institute for Highway Safety (IIHS) publishes head restraint rating for different vehicles (www.highwaysafety.org). The rating is determined by the height of the head restraint relative to the top of a test device representing the head position of a 50th percentile male and the distance from the back of the test device to the head restraint (backset) (see Figure 19). Note that a vehicle can have more than one rating since each vehicle may have different seats for different body styles and IIHS does not separate the vehicles in their rating system. That is, a vehicle can have a rating GA, which stands for Good or Acceptable. Table 2 shows the abbreviations of the IIHS ratings used for this paper. Figure 20, Figure 21 and Figure 22 show the head-to-torso rotation, Nkm and corrected lower neck moment grouped with the IIHS head restraint rating, respectively, for each vehicle. From these figures it can be seen that within a IIHS head restraint rating the three whiplash injury risk assessments varied greatly in the vehicle crash tests. For example for the vehicles that were rated GA by IIHS the head-to-torso rotation ranged from 8 to 28 degrees and the maximum upper neck Nkm ranged from 0.35 and 0.79. Also, the lower neck moment ranged from 86 Nm to 134 Nm for vehicles rated A by IIHS. This indicates that the IIHS static head restraint measurements ratings did not correlate well with the dynamic tests using the Hybrid III dummy along with the various whiplash injury measures for the tests under study. However, one may expect that in a higher speed dynamic test such as performed here, the seat back design characteristics may have just as much effect on the whiplash injury risk assessment as they have on the static head restraint position.

Table 2. IIHS Ratings Used

Abbreviation	IIHS Rating*
G	Good
GA	Good or Acceptable
A	Acceptable
AM	Acceptable or Marginal
M	Marginal

*Rating depends on seat style

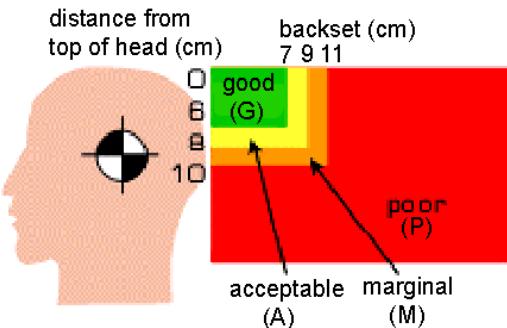


Figure 19. IIHS Head restraint rating scale

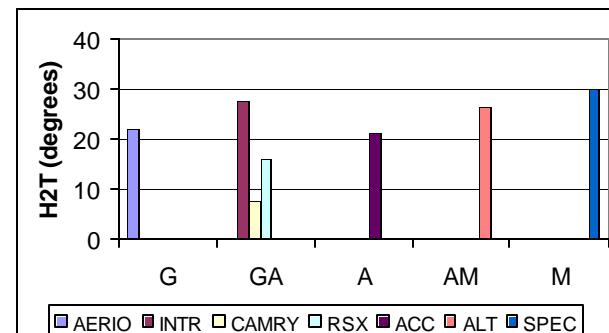


Figure 20. Head-to-torso rotation grouped by IIHS head restraint rating.

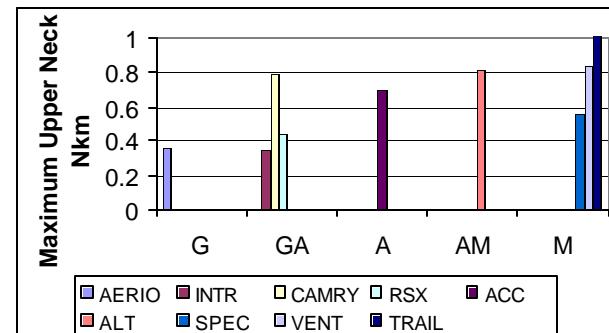


Figure 21. Maximum Nkm grouped by IIHS head restraint rating.

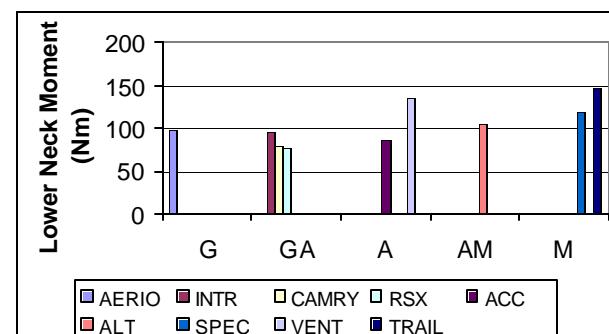


Figure 22. Corrected lower neck moment grouped by IIHS head restraint rating.

CONCLUSIONS

The performance of seatback systems in moderate to high speed rear impact vehicle crash tests was examined using the 50th percentile male Hybrid III dummy. The current FMVSS 208 injury criteria as well as various whiplash injury criteria were used to assess injury outcome. The seat back rotation during the impact event was also monitored.

Based on the results of vehicles tested and reported in this paper, the following conclusions can be drawn:

1. Though current OEM seats are on an average 2-3 times stiffer and stronger than the current FMVSS 207 standard requirement, they may collapse in moderate to high speed rear impact crashes (25-30 kph DeltaV). The front seat and / or the front seat occupant in a collapsing seat is likely to intrude into the rear occupant space. There are anecdotal cases of rear seat occupant injuries and fatalities due to such seat back collapse in real world rear crashes.
2. The seat back rotation computed from the MHD angular rate sensors were more accurate than those computed using accelerometers attached to the seat back.
3. The head and torso rotations measured using the MHD angular rate sensors and the goniometers are reasonably accurate.
4. The IIHS static head restraint measurement ratings did not correlate with the dynamic performance of the seat and head restraint system in moderate to high speed rear impacts as assessed using currently available whiplash injury criteria such as Nkm, lower neck moments, and head to torso rotation for the vehicles tested in this study.

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APPENDIX 1

Table 1. Summary of Test Results

Vehicle	Year	Delta V (kph)	Left Seat Back Rotation MHD's (degrees)	Head-to-Torso Rotation MHD's (degrees)	Time (ms)	Head-to-Torso Rotation Goniometer (degrees)	Time (ms)	15 ms HIC	Chest g's	Max Upper Neck Nij	Time (ms)	Nij Comp.	Correct Lower Neck Moment (Nm)	Time (ms)	Max Upper Neck Nkm	Time (ms)	Nkm Comp.	IIHS Head Restraint Rating *
Kia Spectra	2002	28	25.6	30.2	144	ND	ND	69.6	12.3	0.31	137	Nte	119.1	144	0.56	168	Nep	M
Hyundai Accent	2002	28.2	51.8	21.4	223	ND	ND	88.3	13.7	0.22	142	Nte	86.0	149	0.71	179	Nep	A
Chevrolet Trailblazer	2002	23.1	11.3	ND	ND	ND	ND	104.1	19.9	0.22	103	Ntf	147.5	104	0.84	128	Nep	M
Acura RSX	2002	26.1	28.4	16.1	102	16.9	103	147.4	15.3	0.18	97	Ntf	75.9	98	0.44	86	Nfa	GA
Chevrolet Venture	2002	22.4	14.2	ND	ND	ND	ND	95.3	15.0	0.16	116	Ntf	133.7	118	0.69	129	Nfa	A
Suzuki Aerio	2002	30	28.0	21.9	114	ND	ND	59.7	17.4	0.15	98	Ntf	96.3	105	0.36	93	Nfa	G
Dodge Intrepid	2002	23.9	25.9	27.7	137	ND	ND	77.5	13.7	0.21	130	Nte	95.0	137	0.35	161	Nep	GA
Toyota Camry	2002	26	17.4	ND	ND	7.8	111	87.3	14.1	0.16	113	Ntf	77.8	112	0.79	178	Nfa	GA
Nissan Altima	2002	26.4	18.0	26.3	111	27.8	113	61.5	16.1	0.14	119	Ntf	104.5	114	0.82	184	Nfa	AM

* Rating depends on seat style