EFFECTS OF SEAT BACK FORCE-DEFLECTION PROPERTIES ON INJURIES FOR BOTH FRONT AND REAR SEAT OCCUPANTS IN REAR IMPACTS

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ABSTRACT

The public debate over the most appropriate seat design to best protect occupants at all rear impact speeds is more than an decade old. There have been numerous publications in the technical literature discussing the relative merits of lower versus higher seat back strength. Proponents of lower seat back strength assert that the larger rearward deformation of seat backs allowed by most current seats is less injurious to the seats' occupants than seats with higher seat back strength. However, proponents of higher seat back strength assert that stiffer seat backs provide greater overall safety benefits to occupants of the seats and also protect passengers that may be seated behind them.

The current study used a modified version of a validated MADYMO computer model of a 1986-1994 GM Grand Am production seat, originally developed by the University of Virginia (UVA), to determine the effect of seat back strength on occupant injury in rear impacts. Both a single seat and tandem seat arrangement were modeled at a crash change of velocity (ΔV) approximately seventeen and thirty kilometers-per-hour. Seat occupants were 5th percentile female, 50th and 95th percentile male Hybrid III dummies. The maximum injury measure for each dummy, normalized by performance limits, were used to assess the results.

The single seat results for 30 kph ΔV rear impacts indicate that the least severe injury occurs at a seat strength three to five times the baseline seat for all dummy sizes, except the 95th percentile male. For the 95th percentile male a slightly lower injury value was obtained for a non-deforming or rigid seat. The 17 kph ΔV rear impacts results varied with occupant size and head restraint position. In the dual seat simulations with a baseline front seat, highly injurious contact occurred between the 95th percentile male front seat dummy and 5th percentile female rear seat dummy. Increasing the front seat strength by three times prevented this contact. For a single out-of-position 50th percentile male dummy, the injury measures for the baseline seat were similar to those for a seat with three times the baseline strength.

INTRODUCTION

Background

Federal Motor Vehicle Safety Standard (FMVSS No. 207) - Seating Systems, went into effect in 1968 for passenger cars. FMVSS No. 207 was extended to multi-purpose vehicles, trucks and buses in 1972. It specifies the minimum requirements for seat strength and strength of the interface between a seat and a vehicle. Section 4.2(d) of FMVSS No. 207 requires that a seat withstand a 373 Nm rearward moment. Since 1989 the National Highway Traffic Safety Administration (NHTSA) has granted five petitions for rulemaking related to seating system performance in the rear direction. Many of these petitions seek an increase in rearward seat back strength requirements. Since that time, the agency has opened public dockets seeking comment on the design of seats and their performance (54 FR 40897), NHTSA's plans for research (57 FR 54958), and research findings [1]. The agency has continued to perform research through funded projects by outside contractors. For instance, the University of Virginia (UVA) developed a model of a production seat to study the safety issues related to rear impacts. Three associated reports were placed in the Docket [1]. One UVA study by Sieveka, *et al.*, demonstrated the effects of changing certain seat parameters, such as seat back stiffness, seat back energy return, cushion stiffness, cushion energy return, and friction on occupant response [2]. Sieveka concluded that increasing the seat back rotational stiffness by about three times from the baseline seat reduced the seat back rotation and subsequent occupant ramping.

The study by Sieveka adds to the body of literature on this topic of seat strength from which two distinct schools of thought have appeared. Some people believe that deformation of the seat back in a rear impact is desirable because they believe that stiff seats are more likely to cause injury to the seats' occupants, especially if they are out of position. Others believe that more rigid seat backs provide greater overall safety benefits to all of a vehicle's occupants. They believe stronger seats will better protect both the seat occupant and any occupants who may be behind them. They also believe stronger seats keep occupants in a more favorable position in the event of a secondary frontal impact. One representative paper on each side of the debate are briefly described below.

Prasad, et al., reviewed 1980-94 National Automotive Sampling System (NASS) rear impacts cases to compare the injury severity of occupants in pickup trucks as compared to cars and found that pickup occupants were more severely injured [3]. The author concluded that rigid non-deforming seats may induce more injuries. However, most of the pickups in the crash data analyzed did not have head restraints because trucks were not required to have head restraints until model year (MY) 1993. Additionally, Prasad, et al. exposed a variety of OEM and modified OEM vehicle seats to sled tests at 9, 16, 24 and 40 kph ΔV rear crash pulses. From the differences in neck load cell readings of a 50th percentile male dummy it was concluded that stiffening of conventional seats without any other modification can result in an overall increase in whiplash injuries in the 8 to 24 kph ΔV range. It was also concluded that the stiffer seats tested showed no distinct advantage over the baseline OEM seats.

Nilson, et al., used sled test validation and MADYMO simulations to investigate the influence of seat back stiffness and energy absorption capacity on occupant kinematics and biomechnical responses [4]. The seat modeled was described by the author as having a high head restraint. The head restraint backset (see Figure 1.) was 155 mm. The moment rotation curves of the seat back about the H-point were linear in the loading phase with weak (43.5 Nm/deg), medium (87 Nm/deg), and stiff (174 Nm/deg) slopes. The unloading phase (energy return) was either completely elastic (no residual deformation), completely plastic (no rebound) or in between. This resulted in 9 potential seat back designs. The simulation dummy was a 50th percentile male. Up to an crash ΔV of 32 kph, dummy protection increased from the weak seat to the medium seat and then leveled off with the strong seat, regardless of plasticity. Beyond the threshold, the dummy response was not as sensitive to stiffness. A final variation on the analysis was done for the medium stiffness (87 Nm/deg) seat by introducing yield/ultimate strength value. Dummy protection was increased with increasing ultimate strength up to a value of about 1500 Nm. Beyond that threshold the dummy response was not as sensitive to ultimate strength.

Current Project

The study described in this paper utilized the validated mathematical model originally developed for NHTSA by UVA to determine the effect of seat back strength on occupant injury to properly positioned occupants for both a single seat and tandem seat arrangement at crash ΔV of approximately seventeen and thirty kilometers-per-hour and to an out-of-position occupant at an crash ΔV of thirty kilometers-per-hour. The tandem seat simulation represented a front seat occupant placed directly in front of rear seat occupant and was used to assess the interaction between the seats and occupants. Additional variables addressed in this evaluation were dummy size, head restraint position, and relative initial position of front and rear seat occupants.

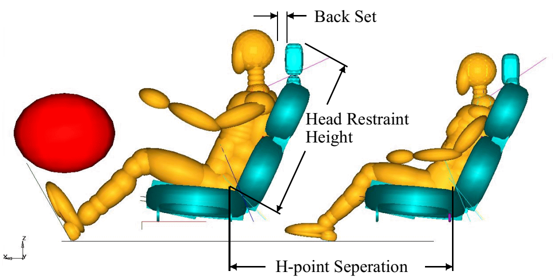

Figure 1. Dummy and Head Restraint Position.

MODEL DESCRIPTION

Model Modifications

The seat model represents a 1986-1994 GM Grand Am production seat with slight modifications [2]. Using the method for static strength described in [5], the ultimate strength of the seat is 1210 Nm about the H-point at 47 degrees of loading arm rotation. The stiffness is 35 Nm/deg and the yield point 843 Nm at 30 degrees of rotation. For the current study, the geometry of the seat was modified in several significant ways. First, the head restraint was positioned higher and closer to the occupant's head than typically found in the fleet today. In addition, the seat back was extended in order to eliminate a potential gap between the head restraint and seat back and the center of rotation for the head restraint rotates was positioned at the top of the seat back. Furthermore, the seat back angle was set to 25 degrees from vertical. Finally, the head restraint, extended seat back and head and neck complex of the dummy were modeled as facets to allow more realistic interaction between the dummy and these seat components.

The seat back and seat bottom force-deflection characteristics were modified by changing the characteristics of the point restraints that connect the seat back to the seat bottom and that connect the seat bottom to inertial space. The point restraints were defined by loading, unloading, and hysteresis curves, as shown in Figure 2.

The percentage energy return (ER) for the model is defined by,

$$ER = \left[\frac{A_1 + A_2}{A_1 + A_2 + A_3}\right]100 \qquad (1.)$$

where A_1 is the area under the unloading curve, A_2 is the area under the hysteresis curve and A_3 is the area under the loading curve minus A_1 and A_2. In order to simulate permanent deformation of the seat back, the slope of the unloading function was set to zero, resulting in zero area for A_1. For this case, the slopes of the loading (S_2) and hysteresis (S_1) curves are related to the energy return by the equation,

$$S_1 = \frac{S_2}{ER} \qquad (2.)$$

The slope of the hysteresis curve was chosen to achieve the desired percent energy return for all point restraints in the seat. The seat back stiffness point restraint was modeled as two point restraints applied to both sides of the seat to prevent twisting of the seat back.

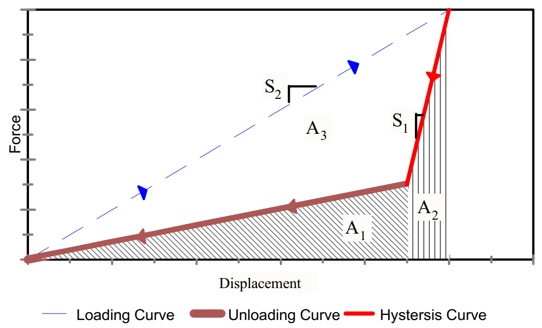

Figure 2. Point Restraint Definition.

Model Parametric Runs

Acceleration Pulses The model was run at two different crash ΔV's. The first acceleration pulse represents a moderate-to-high severity crash with a velocity change of 30 kph. The pulse used was from a FMVSS No. 301 test of an 1992 Toyota Tercel (Figure 3). The second acceleration pulse represents a low-to-moderate severity crash with a velocity change of 17.3 kph. The pulse used in the model was that specified in the FMVSS No. 202 dynamic option, which has a peak of 8.8 Gs and a duration of 88 ms.

Energy Return The model was run with a 50th percentile male dummy with the FMVSS No. 301 acceleration pulse applied to determine the seat back rotation in order to estimate an appropriate energy return. The seat back rotation for this scenario was determined to be 42 degrees.

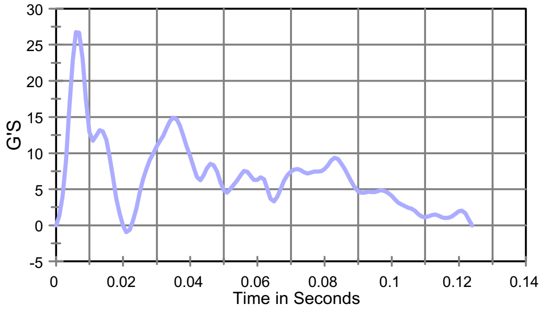

Figure 3. 1992 Tercel, Floorpan Average Acceleration (CFC 60).

Table 1.
Energy Absorbed (Work Input) as a Function of Loading Arm Rotation

Angle (degrees)	Energy Absorbed (Nm)
10	32
20	136
30	297
40	472
50	638

In 1998, NHTSA evaluated the static seat back strength of different seat designs and determined that the average energy absorbed was a function of loading arm rotation for single recliner seats (Table 1) [5]. Consequently, the average energy absorbed for a single recliner seat tested at 42 degrees of rotation was estimated to be 505 Nm. NHTSA also developed an equation for percent energy return (ER) as a function of work input, namely,

$$ER = \left[\frac{0.224WI + 23.0}{WI}\right]100 \qquad (3.)$$

where WI is the work input. Using Equation 3, the percent energy return of the model yields 27 percent. Volvo also reported a similar energy return equation. However, for the Volvo data, the 505 Nm work input level is beyond the range of the reported data [6]. If the Volvo data are extrapolated using the 505 Nm work input level, the percent of energy return is about 27 percent. Therefore, a 25 percent energy return was selected for all simulations at the FMVSS No. 301 ΔV. Using the same method for FMVSS No. 202 ΔV, a 30 percent energy return was chosen for the FMVSS No. 202 rear impacts.

Single Seat The effect of increasing the seat strength on dummy injury measures was evaluated for a range of dummy sizes, head restraint heights, and seat back strengths (Table 2). The head restraint was positioned at a height above the H-point of 750 mm or 800 mm and a 50 mm backset assuming a 50th percentile male occupant at both height positions (Figure 3), which is consistent with the newly proposed upgrade to FMVSS No. 202 - Head Restraints [7]. The 95th percentile male and the 5th percentile female dummies were also modeled at the same head restraint heights. The 50th percentile male with the head restraint height equal to 800 mm was also placed with the torso parallel to the vertical, which is termed out-of-position (OOP). This increased the backset to 338 mm.

The seat back strength was varied by increasing the stiffness of the point restraints connecting the base of the seat to the seat back. In addition, the point restraints connecting the base of the seat to inertial space were increased to prevent large, unrealistic deformations of the seat base with respect to inertial space. The "rigid" model simply locked all seat members in place with respect to the inertial frame, except the head restraint.

Table 2
Model Runs Assessing the Effects of Increase Seat Back Strength at FMVSS No. 301 ΔV

Seat Back Strength Factor	Head Restraint Height (mm)	Test Dummy
100%	750	5th and 50th
100%	800	50th, 50th OOP* and 95th
150%	750	5th and 50th
150%	800	50th, 50th OOP* and 95th
200%	750	5th and 50th
200%	800	50th, 50th OOP* and 95th
300%	750	5th and 50th
300%	800	50th, 50th OOP* and 95th
500%	750	5th and 50th
500%	800	50th, 50th OOP* and 95th
1,000%	750	5th and 50th
1,000%	800	50th, 50th OOP* and 95th
Rigid	750	5th and 50th
Rigid	800	50th, 50th OOP* and 95th

* OOP - Out-of-position dummy

Tandem Seats Table 3 shows the matrix of simulations when one occupant is directly behind the other. The two front seats were modeled with a seat back strengths of 100 and 300%. The front seat head restraint was 800 mm high. The rear seat was modeled as rigid with a 750 mm high head restraint. The backset selected for both front and rear head restraints was 50 mm, relative to the head position of the 50th percentile male. The simulations utilized 50th and 95th percentile male front seat dummies and 50th male and 5th percentile female rear seat dummies.

The front and rear dummy separations was determined using NHTSA's electronic data base of a variety of vehicle interior and exterior dimensions measured as defined in SAE J1100 [8] (Figure 1). One of the available dimensions is the horizontal distance between the front and rear Seating Reference Points (SRP). The SRP is the theoretical H-point location with the seat in the rearmost manufacturers' recommended driving position. It was assumed that the H-point separation for the mid-track position is half the seat track length plus the SRP in the database for a given vehicle. The average track length of 24 1997- 2000 MY NCAP vehicles, including all light vehicle types, was 215 mm. The average front-to-rear SRP separation determined from more than 1130 1995 - 2000 MY vehicles was 783 mm, with a standard deviation of 91 mm. The H-point separation with the front seat at mid-track was estimated to be 890 mm.

Using the above estimates, the target dummy separations modeled were the average and ± two standard deviations. If it is was not possible to position the rear occupant at minus two standard deviations, the closest distance was used. It also should be noted that the closest distance for the 95th percentile male in the front and the 50th percentile male in the rear seat is approximately the mean value, therefore the mid-point between the closest possible seat separation and the +2σ separation was used as a simulation configuration.

Table 3
Horizontal Separation (mm) of Front and Rear H-points for Tandem Configuration

Front	Rear	H-Point Separation (mm)
50th Male	5th Female	709 (-2σ), 890 (mean), 1071 (+2σ)
50th Male	50th Male	762 (closest possible), 890 (mean), 1071 (+2σ)
95th Male	5th Female	649 (closest possible), 783 (mean), 964 (+2σ)
95th Male	50th Male	744 (closest possible), 854 (mid-point), 964 (+2σ)

INJURY CRITERIA

The injury criteria and performance limits selected to evaluate the potential for head, neck, chest, and femur injury to the 5th percentile female and the 50th percentile male dummies are the same as that specified in the Interim Final Rule recently adopted for FMVSS No. 208. The performance limits for the 95th percentile male were scaled from the 50th percentile male. In addition, the potential for lower neck injury was evaluated using the lower neck load cell, as specified in SAE J1733 (December 1994). Prasad suggested a threshold for ligamentous damage to the lower cervical spine for the mid-male that is about three times higher than that of the upper cervical spine [9]. By contrast, preliminary biomechanical data suggests that the upper ligamentous cervical spine is stronger than the lower in both bending and tension [10][11]. Since the tolerance of the lower cervical spine is currently under investigation, the Nij value for the lower neck in this study was calculated using the upper neck critical Nij values established for in-position testing.

A useful means of comparing the potential benefit for the various body regions is to normalize each of the injury measures by the Injury Criteria Performance Limits (ICPLs) shown in Table 4.

Table 4
Injury Criteria Performance Limits (ICPLs)

Dummy	N_{ij}	Chest G	HIC_{15}	Femur	Chest Deflection
95th Male	1	55	700	12,700	70
50th Male	1	60	700	10,000	63
5th Female	1	60	700	6,800	52

RESULTS

Single Seat

FMVSS No. 301 Pulse For the 30 kph ΔV case, the peak seat back rotation decreased as the seat strength was increased for different size dummies (Figure 4).

Four injury measures were evaluated for each run. These were HIC (15 ms), chest acceleration, upper neck Nij and lower neck Nij (Figures 5 - 8). The chest accelerations for all the dummies did not change appreciably until the seat was modeled as rigid. For the 50th percentile dummy at both the 750 and 800 mm head restraint positions, the HIC increased with seat back strength. For the 95th percentile dummy, the HIC decreased from its baseline seat value and then increased with subsequent increases in seat strength until dropping to its lowest value for the rigid case. For the 5th percentile female dummy, HIC decreased with increasing seat strength, except for the rigid seat case where HIC was a maximum. At all levels of seat strength except 1,000%, the 5th percentile female had the highest value of HIC.

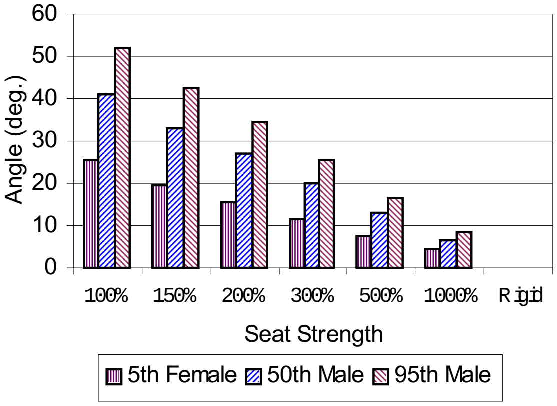

Figure 4. Change in Seat Back Rotation vs. Seat Strength.

For the 50th percentile dummy with the 800 mm head restraint there was a strong downward trend for upper neck Nij with increasing seat back strength. At all levels of seat strength the highest upper neck Nij value was for the 50th percentile dummy with the 750 mm head restraint.

The lower neck Nij values generally decreased as seat back stiffness increased. The 95th percentile dummy obtained the highest lower neck Nij values for all seat back strengths, except for the rigid seat case.

For each combination of dummy size and seat strength, the maximum normalized injury measure (MNIM) and the corresponding body region are shown (Figure 9 and Table 5). In general, the MNIM reached a minimum near 300% seat back strength. The 95th percentile obtained the highest normalized injury measures at each seat back strengths except for the rigid case. For the runs where the dummy heads had the greatest relative height with respect to the head restraint (50th percentile male with 750 mm head restraint and 95th percentile male with 800 mm head restraint), the largest normalized injury measures were for the 100% baseline seat case. For these two simulation configurations, the largest normalized injury measure was the lower neck Nij in the tension-extension mode. For the test dummies where the dummy heads had the least relative height with respect to the head restraint (50th percentile male with 800 mm head restraint and 5th percentile female with 750 mm head restraint), the largest normalized injury measures were for the rigid seat case. For these two simulation configurations, the largest normalized injury measures was the chest acceleration.

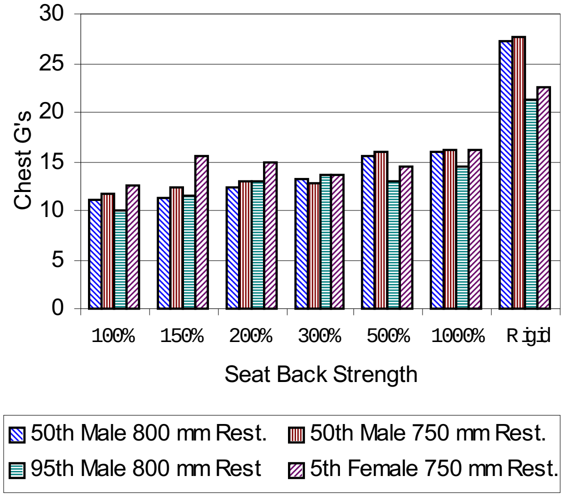

Figure 5. Chest G's.

Table 5
Body Region with MNIM for Single Seat Simulations

Seat Strength	5th Female - 750 mm	50th Male - 800 mm	50th Male - 750 mm	95th Male - 800 mm
100%	LN/cf	UN/te	LN/te	LN/te
150%	LN/cf	UN/te	UN/te	LN/te
200%	LN/cf	UN/te	UN/te	LN/te
300%	LN/cf	Chest	UN/te	LN/te
500%	Chest	Chest	UN/te	LN/te
1,000%	Chest	Chest	UN/te	LN/te
Rigid	Chest	Chest	Chest	Chest

LN = Lower Neck, UP = Upper Neck, c = compression, t = tension, f = flexion, e = extension

For the simulations with the 5th percentile female with a seat strength ranging from 100% to 300%, the lower neck Nij in compression-flexion mode produced the MNIM. For these simulations, the maximum Nij values occurred in the rebound phase of dummy motion. Consequently, these cases may benefit from additional reductions in energy return to reduce seat rebound.

<u>FMVSS No. 202 Pulse</u> Assuming a 25% energy return and a rear impact in the 30 kph ΔV range, the modeling of FMVSS No. 301acceleration pulse indicates an overall benefit to the single occupant case when the seat back is strengthened. However, it is not known whether there is an overall disbenefit to strengthened

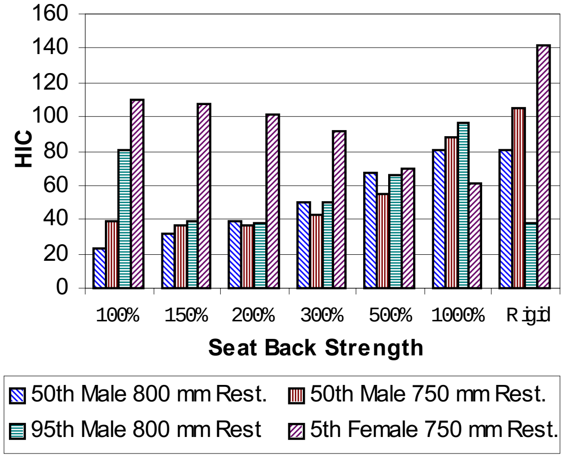

Figure 6. HIC (15 ms).

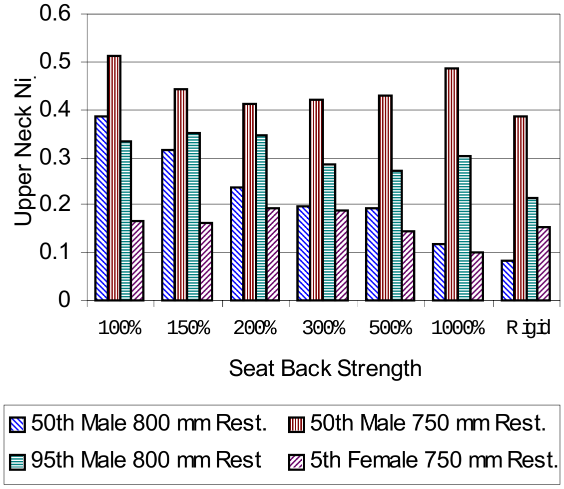

Figure 7. Upper Neck Nij.

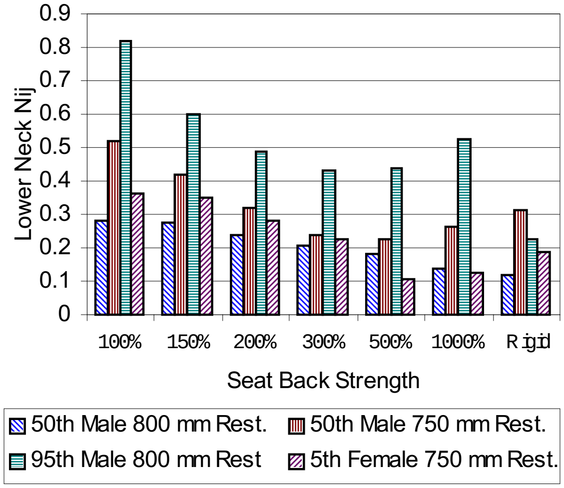

Figure 8. Lower Neck Nij.

seat backs for lower speed impacts. To investigate this possibility, the simulations listed in Table 1 were repeated using the FMVSS No. 202 half sine acceleration pulse. The MNIM and corresponding body region were determined as a function of seat strength (Figure 10, Table 6).

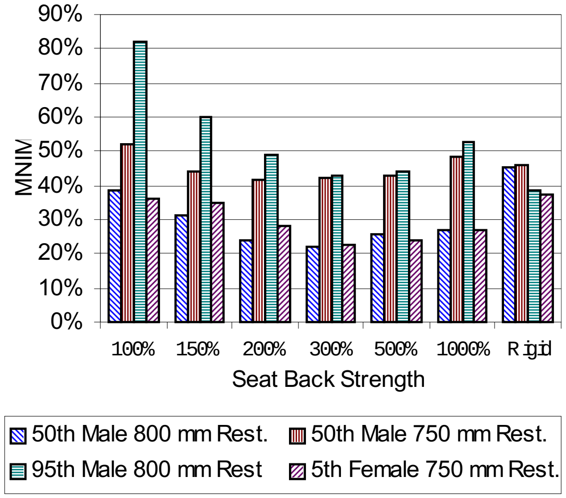

Figure 9. MNIM - FMVSS No. 301 Pulse.

For the test dummies with the least relative head to head restraint height (50th percentile male with 800 mm head restraint and 5th percentile female with 750 mm head restraint), the MNIM was largest for chest acceleration and occurred with the rigid seat back. For the test dummies with the greatest relative head to head restraint height (95th percentile male with 800 mm head restraint height and 50th percentile male with 750 mm head restraint) the MNIM was largest in the lower and upper neck, respectively, with the 300% seat strength.

For the 5th percentile female and 50th percentile male with 750 mm head restraints, the smallest MNIM occurred for the 1000% seat in the chest and upper neck, respectively. For the 50th percentile male and 800 mm head restraint, the smallest injury measure occurred in the lower neck with the 300% seat strength. For 95th percentile male, the smallest injury measure was for the lower neck in the baseline seat.

For the test dummies with the least relative head to head restraint height (5th percentile female and 50th percentile male with 800 mm head restraint) the MNIM was Nij which was in compression/flexion mode. This was true for 50th percentile male simulations with 800 mm head restraint with seats strengths at 200% and 300% and all of the 5th percentile female simulations at 500% or below. All other simulations where the Nij was the MNIM for the dummy had a mode of tension/extension. The cases of maximum compression/flexion may indicate the seat design could benefit from additional reductions in energy return to reduce seat rebound.

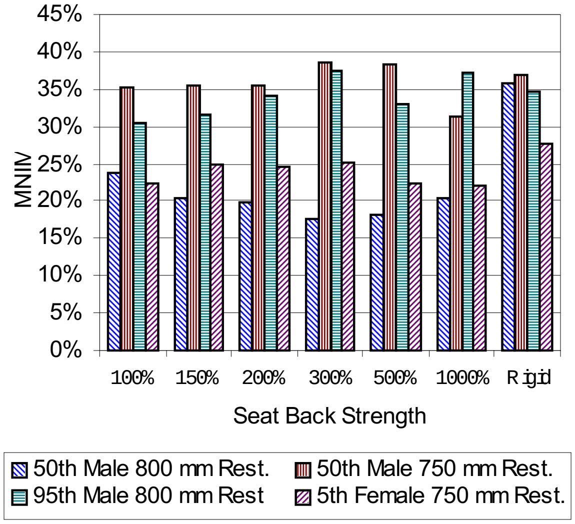

Figure 10. MNIM - FMVSS No. 202 Pulse.

Table 6
Body Region with MNIM in FMVSS No. 202 Impact

Seat Strength	5th Female - 750 mm	50th Male - 800 mm	50th Male - 750 mm	95th Male - 800 mm
100%	LN/cf	UN/te	UN/te	LN/te
150%	LN/cf	UN/te	UN/te	LN/te
200%	LN/cf	LN/cf	UN/te	LN/te
300%	LN/cf	LN/cf	UN/te	LN/te
500%	LN/cf	Chest	UN/te	LN/te
1,000%	Chest	Chest	UN/te	LN/te
Rigid	Chest	Chest	Chest	Chest

LN = Lower Neck, UP = Upper Neck, c = compression, t = tension, f = flexion, e = extension

<u>In-Position vs Out-of-Position Dummy</u> The FMVSS No. 301 pulse was applied to the 50th percentile male OOP runs that are described in Table 2. Figure 11 shows the MNIM for the dummy in each seat. For all seat back strengths the MNIM increased when the dummy was not properly positioned. The baseline seat OOP normalized injury was 2.4 times larger than that for the in-position simulations. The MNIM for the OOP baseline and 300% seat was the same. At all other seat strengths there was an increase in normalized injury from the baseline. The lower neck injury was the area of maximum injury for the dummy in all seats. Based on the in-position simulations, the out-of-position results are expected to vary with dummy size and head restraint height.

Tandem Seats

For the analysis of the tandem or dual seat simulations, the MNIM measure was used to compare the injury potential for each simulation. The injury criteria and ICPL's used were the same as previously described, with the addition of femur compression and chest deflection.

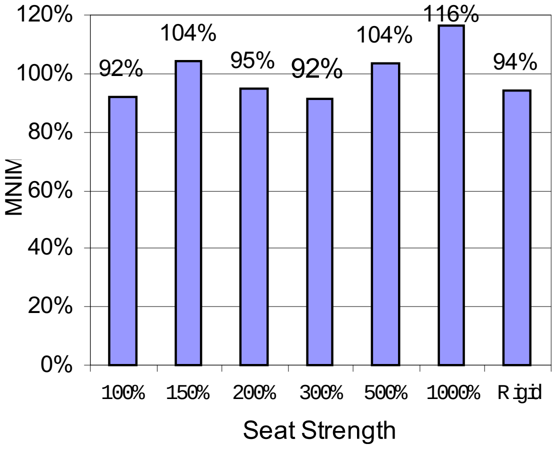

Figure 11. MNIM for Out-of-Position 50th Percentile Male with 800 mm head Restraint with FMVSS No. 301 pulse.

A total of 24 unique simulations were performed using combinations of front and rear seat adult dummies, three seat separations, and front seat strengths of 100% and 300% (Table 3). Of these 24 simulations, contact between the front and rear dummy occurred in only two cases. Both of these cases occurred with the 95th percentile dummy in the front and the 5th percentile female in the rear and the baseline seat back strength. In the first case, there was clear head-to-head contact between the dummies when the seats were as close as possible (649 mm between H-points). The second case of dummy-to-dummy contact occurred with an H-point separation of 783 mm, which represents the mean for all vehicles with the front seat at the mid-track. In this case, the head of the front seat dummy appears to make contact with the chest of the rear seat dummy

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Figures 12 through 15 show the MNIM for both front and rear dummies for each simulation. Table 8 lists the body region of the MNIM and Table 9 lists the percentage reduction in the MNIM between the 100% and 300% seat strength. All front seat dummies showed a benefit to increasing the seat back strength by three times. This is consistent with the results of the single seat simulations where a benefit was seen by increasing the seat strength from 100% to 300%.

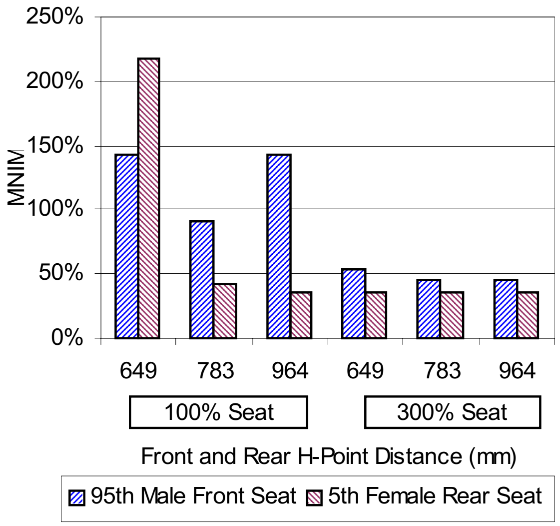

Figure 12. MNIM 95th Male Front Seat - 5th Female Rear Seat.

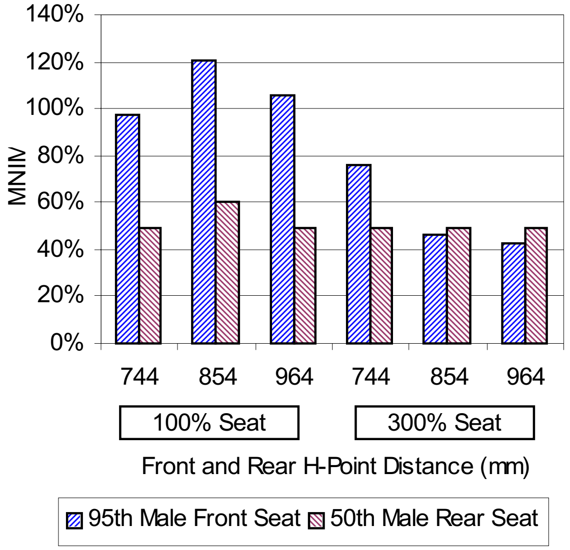

Figure 13. MNIM 95th Male Front Seat - 50th Male Rear Seat.

All rear seat dummies either had a decrease in MNIM or no change. Figure 12 shows that for the 95th percentile male front seat dummy and 5th percentile female rear seat dummy, there is a marked decline in the normalized injury measures for both front (62.3% decrease) and rear (83.6% decrease) dummies between the 100% and 300% seat back at an H-point separation of 649 mm. For the front seat dummy, the normalized HIC of 1.42 is the MNIM. For the rear seat dummy the lower neck Nij of 2.18 is the MNIM. By increasing the seat strength to 300%, the MNIM for the front seat dummy was reduced to 0.54 for the lower neck Nij and 0.36 for the chest acceleration of the rear seat dummy, because the stronger seat back prevents head-to-head contact. Similarly, for the simulation with the same combination of dummies and an H-point separation of 783 mm, the decrease in the MNIM is 49.5% for the front seat dummy and 13.8% for the rear seat dummy.

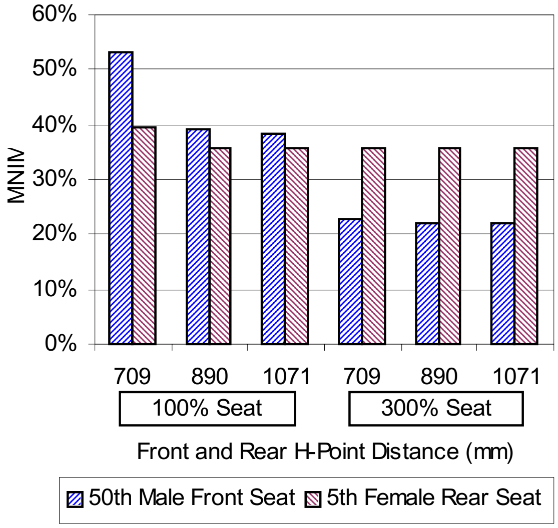

Figure 14. MNIM 50th Male Front Seat - 5th Female Rear Seat.

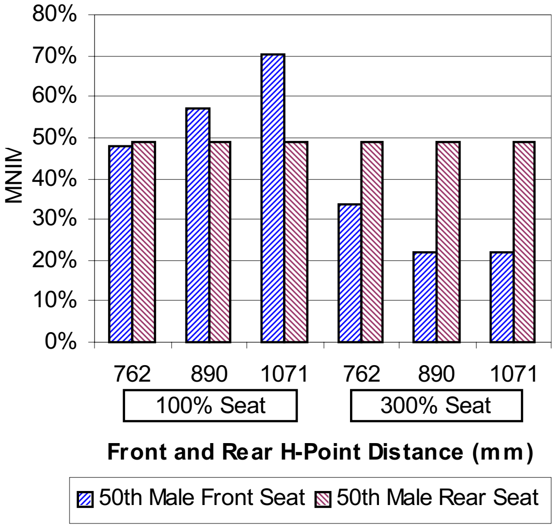

Figure 15. MNIM 50th Male Front Seat - 50th Male Rear Seat.

No simulations other than the two baseline seat simulations mentioned above showed contact between the front and rear seat dummies. Chest acceleration was the MNIM for the rear seat occupants in eight out of ten of the remaining baseline seat simulations (Table 8). Similarly, chest acceleration was the MNIM with the 300% seat strength cases (Table 9). There was virtually no change in the normalized chest acceleration value when the seat strength was increased from 100% to 300%.

There were two baseline seat simulations where no contact occurred between the front and rear seat dummy and a measurable reduction in the MNIM for rear seat dummy occurred. These occurred with a 95th percentile male front seat dummy and a 50th percentile male rear seat dummy having a 854 mm H-point separation and with a 50th percentile male front seat dummy and a 5th percentile female rear seat dummy having a 709 mm H-point separation. For both these simulations, the femur loading resulted in the largest normalized injury value. When the seat was strengthened to 300%, the femur loading was reduced for the rear seat dummies so that the MNIM became the chest acceleration.

Table 8
Body Region with MNIM for each Tandem Simulation.

Front Occ.	Body Region		Rear Occ.	Body Region		Seat Sep. (mm)
	100%	300%		100%	300%	
95th	HIC	LNij	5th	LNij	Chest	649
95th	LNij	LNij	5th	Femur	Chest	783
95th	LNij	LNij	5th	Chest	Chest	964
95th	LNij	LNij	50th	Chest	Chest	744
95th	LNij	LNij	50th	Femur*	Chest	854
95th	LNij	LNij	50th	Chest	Chest	964
50th	LNij	Chest	5th	Femur	Chest	709
50th	LNij	Chest	5th	Chest	Chest	890
50th	UNij	Chest	5th	Chest	Chest	1071
50th	LNij	Chest	50th	Chest	Chest	709
50th	LNij	Chest	50th	Chest	Chest	890
50th	UNij	Chest	50th	Chest	Chest	1071

* Left femur load was used due to an anomalus spike in the right leg.

Table 9
Percent Decrease in MNIM for each Tandem Simulation.

Front Occ.	Percent Decrease	Rear Occ.	Percent Decrease	Seat Sep. (mm)
95th	62.3	5th	83.6	649
95th	49.5	5th	13.8	783
95th	67.9	5th	0.0	964
95th	22.0	50th	0.1	744
95th	61.8	50th	19.0	854
95th	59.2	50th	0.0	964
50th	57.2	5th	9.2	709
50th	43.6	5th	0.0	890
50th	42.5	5th	0.0	1071
50th	29.5	50th	0.0	709
50th	61.5	50th	0.0	890
50th	68.7	50th	0.0	1071

CONCLUSIONS

For Madymo simulations of a single seat and occupant using a 30 kph ΔV rear impact pulse, the smallest MNIM occurred at a seat strength which is three times the baseline strength for a 5th percentile female dummy (750 mm high and 50 mm backset head restraint position) and 50th percentile male dummy (750 and 800 mm high and 50 mm backset head restraint position). The smallest MNIM occurred for the 95th percentile male dummy for the rigid seat (800 mm high and 50 mm backset head restraint position). The baseline seat and a seat with three times the strength had the same normalized injury measure for simulations where a 50th percentile male dummy was leaning forward prior to impact. For a 17 kph ΔV rear impact pulse, the trends in MNIM versus seat strength depend on the dummy size and relative head restraint position. For tandem seat simulations with a baseline strength front seat and a rigid rear seat, contact occurred between the 95th percentile male front seat occupant and 5th percentile rear seat occupant at H-point separations of 649 mm and 783mm. In general, for these simulations, increasing the front seat strength by three times eliminated dummy-to-dummy contact and reduced the MNIM for the front seat dummy. The rear seat dummy MNIM was either reduced or unchanged when the front seat strength is increased. The modeling results of the parametric study have not yet been validated with testing.

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