REAR SEAT OCCUPANT PROTECTION IN FRONTAL CRASHES AND ITS FEASIBILITY

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ABSTRACT

As part of NHTSA's Rear Seat Occupant Protection Research Program, the Fatality Analysis Reporting System (FARS) and State Data System (SDS) for Florida, Pennsylvania and Maryland were utilized to estimate relative fatality rates and injury risk ratios between the front and rear seat passengers. In addition, a parametric study of rear-seat restraint parameters was performed to assess chest deflection and head excursion trends for different belt load limits, pretensioner location(s) and stroke, and impact speeds with the Hybrid III (HIII) 50th percentile male and 5th percentile female dummies. Simulation data were validated using 48 km/h frontal impact sled tests with a standard belt system in outboard rear seats of a mid-size passenger car buck.

The real world data suggests that the fatality and serious injury risk in frontal crashes is higher for older occupants in rear seats than for those in front seats. In addition, the relative effectiveness (to mitigate serious injury and death) of rear seats with respect to front seats for restrained adult occupants in newer vehicle models is less than it is in older models, presumably due to the advances in restraint technology that have been incorporated into the front seat position. The simulations demonstrated that adult dummy injury measures in the rear seat can be reduced by incorporating restraint technology (load limiting and pretensioning) used in the front seat, even in the absence of an air bag and knee bolster for load sharing. A force-limiting belt with a pretensioner in the rear seat can maintain or reduce head excursion relative to a standard belt, while significantly reducing chest deformation and thoracic injury risk. In fact, 42 sets of restraint parameters were identified that reduced both head excursion and chest deflection of the 50th percentile male relative to the baseline belt.

INTRODUCTION

Rear seat occupants constitute 14 percent of all vehicle occupants in passenger cars and LTVs. Among these rear seat occupants, 85% are in outboard seating positions and 69% are fourteen years-old or younger and are 5 feet 4 inches or shorter.

Kuppa et al. (2005) reported on NHTSA's initial efforts to examine rear seat occupant protection and presented a double-paired comparison study using the Fatality Analysis Reporting System (FARS) data files to determine the relative effectiveness of the rear seats with respect to the front passenger seat position in frontal crashes. The results indicated that restrained occupants older than 50 years were significantly better off in the front seat than in rear seats. In addition, the presence of a front passenger air bag reduced the relative effectiveness of the rear seat compared to the front seat for all age groups except for children in child safety seats. The most injured body region for adults in the rear seat was the thorax with the source of injury being the shoulder belt. The rear seat position offered improved protection over the front passenger seat for unrestrained occupants of all ages.

Cummings and Smith (2005) conducted a matched cohort analysis of the FARS data files to determine the risk of death of rear seat passengers compared to front seat passengers in motor vehicle crashes. In agreement with the Kuppa et al. (2005) paper, this study indicated that while the fatality risk is lower in the rear seat, the protective effect of the rear seat position decreased with increasing passenger age and with restraint use. The rear seat position offered no additional protection to restrained adults in vehicles with front passenger air bags.

Swanson et al. (2003) found that the average front end stiffness of passenger cars computed from the data collected in the New Car Assessment Program (NCAP) frontal crash test program for model years (MY) 1982 to 2001 shows an increasing trend for newer vehicle models. In particular, there is a significant increase in the stiffness of passenger cars for MY 1998-2001 compared to the previous vehicle models. Concurrently, the NCAP frontal crash test rating program indicates an improvement in vehicle frontal crash test rating with a large percentage of the vehicle fleet for MY 1999 and newer obtaining the highest NCAP scores (NHTSA, Five Star Crash Test Rating, 2007). Vehicles with stiffer front-end structures experience more severe crash pulses, and thus depend more on the occupant restraint system (ie., airbag, seat belts, pretensioners, etc.) to manage the crash energy. In recent years, the front seat occupants have benefited from advanced restraint concepts such as belts with pretensioners and load limiters, which provide a clear safety benefit in frontal crashes in the field (e.g., Foret-Bruno et al. 1998), and also lead to an improved NCAP frontal crash test rating. For example, Walz (2003) estimated that the combination of pretensioners and load limiters reduced the HIC values by 232, peak chest acceleration by an average of 6.6g, and peak chest deflection by 10.6 mm for HIII dummies in the driver and right front passenger positions. The NCAP frontal crash testing, however, evaluates only the injury risk to front seat passengers, so it has not stimulated the development of similar or other advanced restraint technology in the rear seat.

While previous studies examined the effectiveness of rear seats with respect to front seats, no attempt has been made to examine the effect of changes in vehicle front-end stiffness and the emergence of advanced restraint systems on the performance of rear seats relative to the front seats.

The current paper examines the trends in rear seat occupant protection relative to front seat protection for changing vehicle designs and restraint systems. In addition, the paper examines the feasibility of improvement in rear seat adult occupant protection using advanced restraints similar to those available for the front seat. Sled tests were conducted with a rear seat sled buck of a representative mid-size vehicle with the Hybrid III 50th percentile male (AM50) and 5th percentile female (AF5) dummies. Mathematical simulations of the sled tests using MADYMO were also conducted to determine the effect of pretensioners and load limiters on the kinematics and injury measures of the dummies in the rear seat. This paper presents selected results of sled tests used to benchmark the computational model, as well as the full computational study.

Additional sled tests are ongoing and will include testing with pediatric dummies, additional adult dummies, and adult cadaveric subjects with typical contemporary rear-seat restraints and advanced rear-seat restraints.

REAL WORLD DATA

ANALYSIS OF FARS DATABASES

Kuppa et al. (2005) conducted a double paired comparison study using the FARS data files for the years 1993-2003 to determine the risk of death of outboard rear seat occupants relative to the right front seat passenger. The drivers in those crashes were used as the control group. That analysis examined the fatality risk ratios for front and rear seat occupants by occupant age and restraint status. The effects of advanced restraint systems for the front seat occupants and the increasing vehicle stiffness on the relative effectiveness of rear seats with respect to front seats were not examined in that study. In addition, no attempt was made to examine the effectiveness of rear seats relative to front seats with respect to non-fatal injury. The current study examines these issues by reanalyzing the FARS datafiles and also examining the State Data System files.

The introduction rate of pretensioners and load limiters into the US vehicle fleet is presented in Figure 1. Before 1999, less than 10% of the vehicle fleet was equipped with a load limiter or a pretensioner. Approximately 40% of the MY 1999 vehicles were equipped with load limiters and 25% were equipped with load limiters and pretensioners. Among MY2002 vehicles, 56% were equipped with pretensioners and 74% equipped with load limiters.

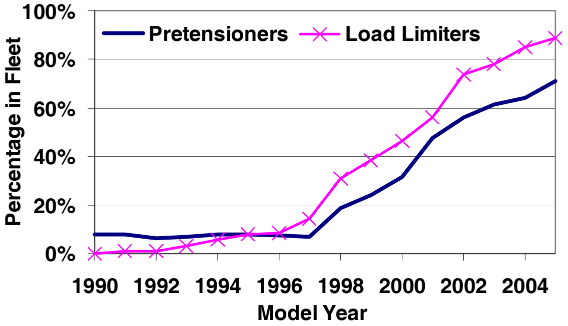


Figure 1. Introduction of advanced belt restraints into the passenger and LTV fleet in the United States.

As shown in Figure 1, there is a bilinear trend in advanced restraint fitment into the passenger car and LTV fleet, with a rapid increase starting at approximately model year 1998. The review by Swanson et al. (2003) of NCAP tests indicated a similar increase in front-end stiffness of passenger cars during this time period. Therefore, in order to examine the effect of advanced restraints and vehicle front-end stiffness on the relative effectiveness of rear seats with respect to front seats, two categories of vehicle model years were considered in this study: 1991-1998 and 1999-2006.

A double paired comparison analysis was conducted using the FARS data files for the years 1993 to 2005 in a similar manner as described by Kuppa et al. (2005). In particular, the relative effectiveness of outboard rear seats compared to the front passenger seat for mitigating fatalities of restrained occupants was examined for the different model year categories and different age groups. Restrained outboard occupants involved in frontal crashes of MY 1991-2005 vehicles with no rollovers were considered. The restrained driver was used as the control group for this analysis.

Two groups of fatal crashes were considered for the double paired comparison study. The first group consisted of fatal crashes where a driver and front outboard right seat passenger were present and at least one of them was killed. The second group consisted of fatal crashes where a driver and a rear outboard seat passenger were present and at least one of them was killed. Each of these groups was further subdivided into different passenger age categories.

If F1 and F2 are the number of driver and front passenger fatalities, respectively, from the first group and F3 and F4 are the number of driver and rear passenger fatalities from the second group, then the relative fatality risk ratio (R) and the effectiveness (E) for the rear seats relative to the front passenger seat is given by Equations 1 and 2

$$R = \frac{F_4 / F_3}{F_2 / F_1} \qquad [1]$$

$$E = 100 \times (1 - R) \qquad [2]$$

The standard error of the log of the risk ratio (standard error of the log odds = σ) and the error ranges in the effectiveness estimates are given by Equations 3 and 4

$$\sigma = \sqrt{\frac{1}{F_1} + \frac{1}{F_2} + \frac{1}{F_3} + \frac{1}{F_4}} \qquad [3]$$

$$E_{lower} = 100 \times [1 - e^{Ln(R)+\sigma}] \qquad [4a]$$

$$E_{upper} = 100 \times [1 - e^{Ln(R)-\sigma}] \qquad [4b]$$

The results of the analysis are presented in Figures 2 and 3. Note that all the vehicles of model years 1999-2006 are equipped with front passenger air bags, so the rear seat effectiveness for the condition of no passenger air bag could not be computed for this model year category.

When the error bars in the effectiveness estimates presented in Figures 2 and 3 do not pass zero, it implies that the effectiveness estimate is significant ($p<0.05$). The effectiveness estimates of rear seats relative to front passenger seats for vehicle models 1991-1998 (Figure 2) are similar to that reported earlier by Kuppa et al. (2005). Occupants older than 50 years have a lower risk of death in a frontal crash when sitting in the front passenger seat than in rear seats. The data presented in Figure 3 suggest that the effectiveness of rear seats relative to the front seats is lower for the newer vehicle models than the older models, though the sample size is not yet sufficient to yield a statistically significant difference. Presumably, advances in front-seat restraint technology are at least a partial explanation for this trend.

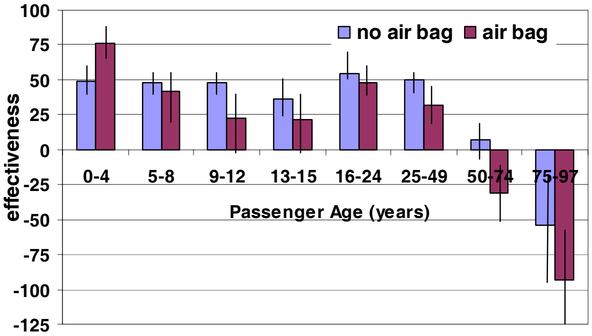


Figure 2. Effectiveness of outboard rear seats compared to front outboard passenger seats with and without front passenger air bag in mitigating fatalities for restrained occupants in MY 1991-1998 vehicles.

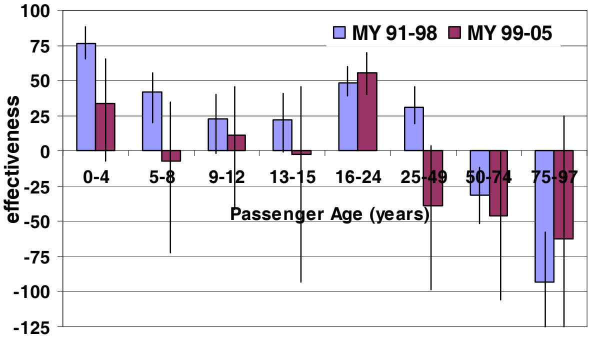


Figure 3. Effectiveness of outboard rear seats compared to front outboard passenger seats in mitigating fatalities for restrained occupants in MY 1991-1998 and MY 1999-2005 vehicles (all vehicles equipped with air bags).

In order to augment the FARS analysis, state data files from the Pennsylvania, Maryland, and Florida were analyzed to determine relative injury risk (including non-fatal injuries) between front and rear seat passengers. The state data files are a compilation of all police accident reports (PARs) of crashes that meet a certain set of criteria. The database contains information describing crash characteristics, and the vehicles and people involved. The data from these three states were selected for analysis because the VIN numbers of the involved vehicles, the crash type, belt status of occupants, the occupant injury severity secondary to the crash, and details of the uninjured occupants were available in the data files. In Florida, the inclusion of a case into the state database is at the discretion of the police officer, while in Maryland and Pennsylvania at least one vehicle had to be towed for the case to be included in the State Data System.

State data files for the years 1993-2003 were used to extract cases of vehicles (passenger cars and LTVs) of model years 1991 to 2005 involved in frontal crashes. Only frontal crashes with no rollovers were considered in the analysis. The injury severity was grouped into two broad categories. The occupant was classified into the "No Injury" category when he/she sustained no injury, or no evident injury, or evident but non-incapacitating injury. The occupant was classified into the "Injury" category if he/she sustained an incapacitating injury (defined as any injury that is fatal or prevents the injured person from walking, driving, or continuing normal activity that he/she was capable of performing prior to the vehicle crash).

Again, a double paired comparison analysis using the driver as the control group was conducted to estimate the effectiveness (as defined by Equation 2) of the rear seat to mitigate incapacitating injury in frontal crashes compared to the front passenger seat. Restrained drivers and restrained outboard front and rear seat passengers were considered in the assessment of advanced restraints and vehicle stiffness on the injury risk ratio. The analysis was conducted taking into consideration the passenger age, vehicle body type (passenger cars and LTVs), and vehicle model year (MY 1991-1998 and MY 1999-2005).

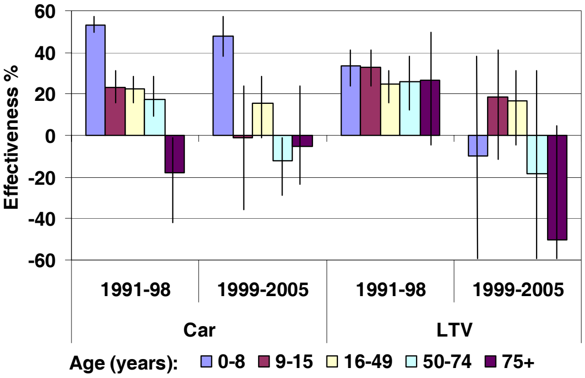


Figure 4. Effectiveness of outboard rear seats compared to front outboard passenger seats in mitigating incapacitating injuries for restrained occupants in MY 1991-1998 and MY 1999-2005 vehicles.

The double paired comparison study of the state data indicates that older occupants (75+ years) are at greater risk of injury in the rear seats than in the front seats (Figure 4). As in the Smith and Cummings (2005) study, the state data indicate that the protective effect of the rear seat position decreases with increasing passenger age. The relative effectiveness of rear seats compared to the front passenger seat was lower in vehicle models 1999-2005 than in vehicle models 1991-1998 for both cars and LTVs. Due to the small sample size of crashes of LTVs and crashes involving newer vehicle models in the state data files, the relative effectiveness of rear seats for the newer vehicle models and for LTVs are not significant, but both the FARS data and the state data suggest that the introduction of advanced restraints and the greater vehicle front end stiffness may play a role in reducing the relative effectiveness of rear seats compared to front seats.

PARAMETRIC STUDY OF RESTRAINT CHARACTERISTICS – METHODS

The results of the field analyses described above, coupled with the findings from Kuppa et al. (2005) that the most frequently injured body region for restrained adults in the rear seat is the thorax with the source of injury being the shoulder belt, justify further study on the feasibility of incorporating front-seat restraint technology (load limiting and pretensioning) into the rear seat environment. There is an intrinsic tradeoff associated with seat belt load limiting: head excursion increases as chest deformation decreases. This tradeoff is managed in the front seat by load sharing with the air bag and knee bolster, which limits head excursion and mitigates head contacts with the interior vehicle structure. The front seat pan can also be designed to restrict pelvic motion, providing another load-path for restraint and allowing further control of occupant kinematics. In the rear seat there is no air bag to limit head motion, there is less control of knee motion, and the seat pan geometry is dictated largely by the structural requirement of the vehicle chassis. Thus, the belt design alone must address most of the challenge of reducing chest deflection without allowing excessive head excursion. As a preliminary assessment of this tradeoff in the rear seat environment, a computational parametric study was undertaken.

MADYMO version 6.3.1 was used to simulate frontal (12:00 PDOF) impacts with Hybrid III 50th percentile male (AM50) and 5th percentile female (AF5) dummies seated in the outboard rear seating position of a contemporary mid-size sedan (Figure 5). The MADYMO model used in the parametric study was developed using the data collected during a series of rear-seat sled tests of AM50 and AF5 dummies. Three tests were conducted with each dummy at each of two impact velocities, 29 km/h and 48 km/h. Data collected during these tests included head, chest, and pelvis acceleration, chest deflection, neck loads and moments, femur loads, and belt loads.

High-speed video was used to capture the motion of the occupants, as well the shoulder belt retractor payout and belt slip at the buckle. The baseline MADYMO model for each occupant was evaluated against these measurements for the case of no belt load limit and zero pretentioner stroke for the 29 km/h and 48 km/h conditions, placing higher importance on head excursion and chest deflection. Additional benchmarking characteristics included chest acceleration, shoulder belt retractor payout, and belt loads. The initial positions of the head and H-point, as well as the angles of the H-point, torso, femur, and tibia, were adjusted to mimic the initial occupant position from the sled tests. At this position, the face of the 50th percentile male is 540mm from the rear surface of the headrest on the front passenger seat in its rearmost fore-aft track adjustment position. In other words, in the sedan considered here, the head strikes the front seat back, in its rear-most fore-aft adjustment position at a forward excursion of X_h = 540 mm (Figure 5). This distance is used as representative of a minimum level of available excursion distance in a typical mid-size passenger car.

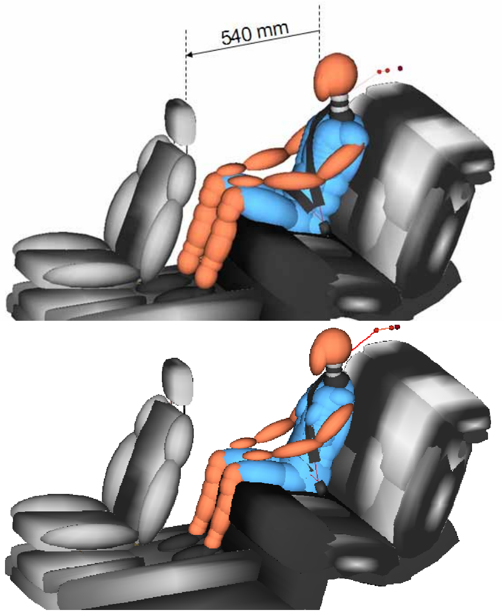


Figure 5. MADYMO rear-seat occupant model with AM50 (top) and AF5 (bottom). Front seat is in the rear-most fore-aft adjustment position.

The model used a hybrid belt system made up of finite element lap and shoulder belts connected with standard MADYMO belt elements. These elements allowed belt slip between the lap and shoulder belts at the buckle and included a force-payout characteristic to capture the film spool effect at the retractor. The force-payout characteristic was determined from data collected during the rear-seat sled tests. The force was measured by the upper shoulder belt load cell, while the payout was measured by a high-speed camera focused on the shoulder belt, which was marked incrementally at the retractor. Modifications to the retractor, buckle, and lap belt attachment points allowed for pretension at any combination of these locations. When active, the pretensioners triggered at 12ms after the onset of the acceleration pulse (Figure 6).

The parameters considered and the values used in the simulations are listed in Table 2. All possible combinations of values were simulated. Future work will include additional impact speeds and occupant sizes (including children), as well as an assessment of injury tradeoffs with outcomes weighted for field exposure. For this preliminary study, however, the goal was to identify sets of parameters that hold potential for improving the performance of the baseline restraint condition. Two primary outcome metrics were considered in this assessment. First, since the field data indicate an increase in chest injury for older occupants, the maximum chest deflection (C_{max}) was considered. Second, since the clear tradeoff with belt load limiting is an increase in head excursion, the maximum forward (X-axis) displacement of the head center-of-gravity relative to the vehicle (X_h) was considered.

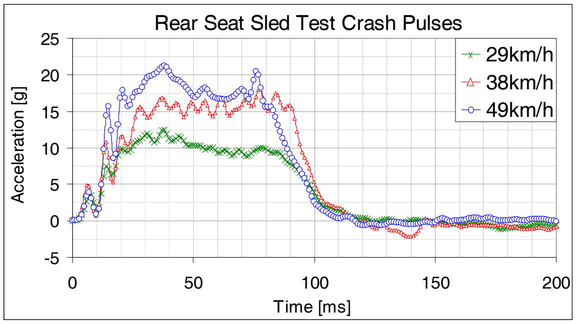


Figure 6. Sled pulses (sled and MADYMO).

A statistical analysis of the simulation data was conducted using general linear models. Regression and MANOVA analyses were performed, and mean injury measures were compared for different levels of the independent variables (load limit, ΔV, pretensioner location(s), and stroke), taking into consideration main and interaction effects. All covariates were considered to be fixed effects. The dependent variables considered in the statistical analysis were X_h, HIC15, maximum chest acceleration, and C_{max}.

Table 2. Parameters and values considered in simulation matrix.

Parameter	Values simulated
Occupant	AM50, AF5
Sled ΔV (km/h)	29, 38, 48
Load limit (kN)	2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 8, None
Pretensioner arrangement	1 - Buckle only, 2 - retractor only, 3 - buckle + retractor, 4 - buckle + retractor + lap
Pretensioner stroke (mm)*	0, 25, 50, 75

*In simulations with multiple pretensioners, all pretensioners had the same stroke.

SIMULATION RESULTS

BENCHMARKING OF MODEL

Figure 7 illustrates the general agreement between the MADYMO model and the test data. The chest deflection, shoulder belt tension, and chest acceleration are shown at 29 km/h and 48 km/h with the baseline (no load limiting, no pretensioning) restraint system. Figure 8 shows images throughout the 48 km/h impact sequence, illustrating the kinematic behavior of the model relative to the sled tests.

ANALYSIS OF VARIANCE AND OUTCOMES

The statistical analysis indicated that impact velocity and load limit had significantly greater influence on injury measures for both dummies than did pretension stroke and arrangement. Impact speed had greater influence on X_h, HIC15 and chest acceleration than did load limit, while C_{max} was mainly influenced by load limit. Increase in pretension stroke reduced X_h and HIC15, but had minimal effect on chest acceleration and C_{max}. Buckle pretensioning had higher X_h and HIC15 than other pretension arrangements, with arrangement 4 (lap+retractor+buckle) having significantly lower X_h and HIC15 than the other arrangements. Finally, the sensitivity of injury measures to load limit increased at higher ΔV, but the sensitivity of X_h and HIC15 to pretension stroke and arrangement was not significantly changed for different ΔV.

DESCRIPTIVE ANALYSIS – AM50

The baseline restraint condition resulted in AM50 C_{max} of 22.7 mm, 26.0 mm, and 29.9 mm at 29 km/h, 38 km/h, and 48 km/h, respectively. The maximum AM50 X_h at those three speeds was 138 mm, 178 mm, and 224 mm, respectively. In only two situations (2 kN limit with a single pretensioner, 0 and 25 mm of stroke, 48 km/h) was X_h sufficient to allow the AM50 head to strike the front seat back in its rearmost position. The head impact velocity relative to the seat back was 6.7 and 7.6 m/s in those cases, but they are not considered to be restraint conditions likely to be used in the fleet. Furthermore, head strike is not a valid criterion for limiting head excursion; variability in vehicle geometry, occupant positioning, collision obliquity, and other factors not

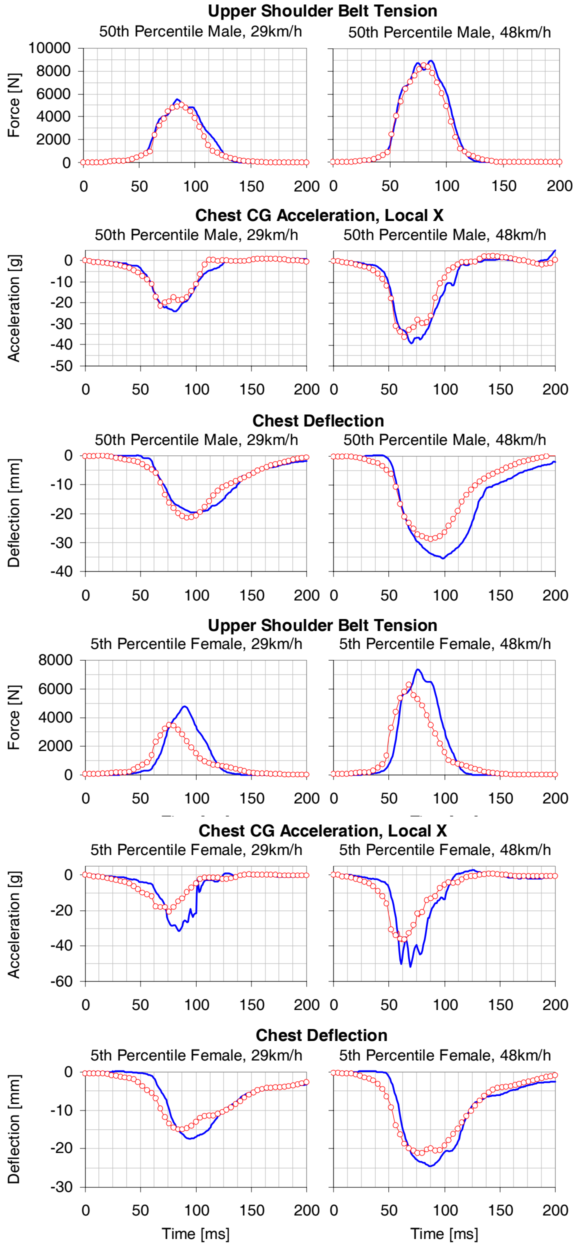
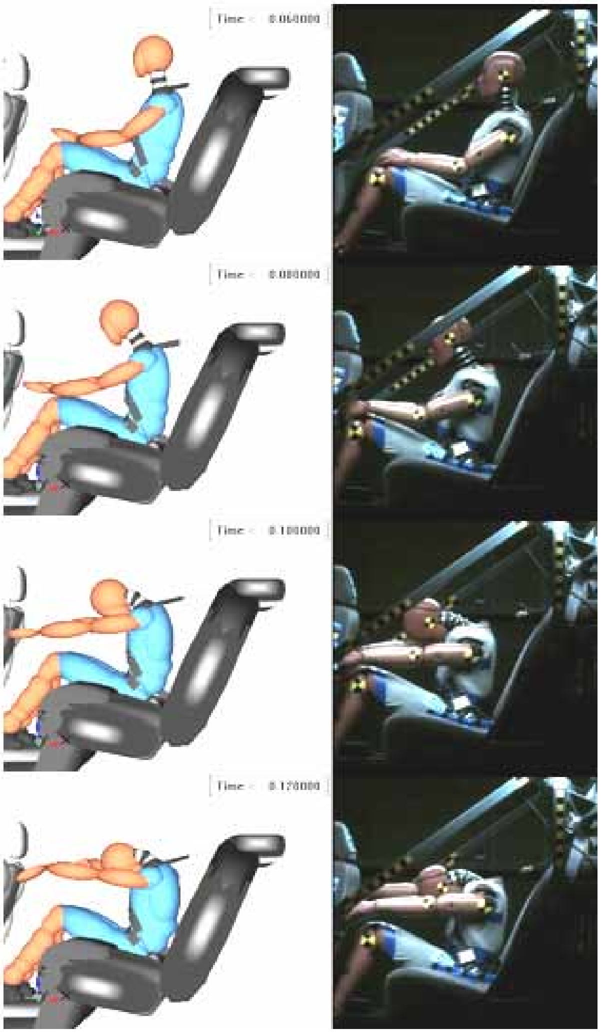


Figure 7. Benchmarking the MADYMO models, with test data in solid blue and MADYMO data in red circles.



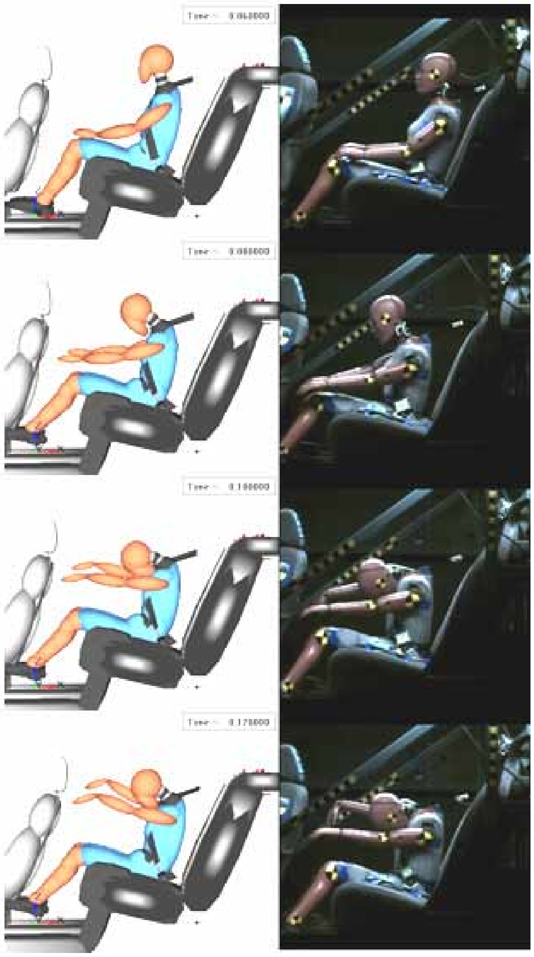


Figure 8. Comparison of computational and experimental kinematics for the AM50 (left) and the AF5 (right).

considered in these simulations require a more conservative approach to establishing an allowable X_h threshold. Though some increase in X_h relative to the baseline is probably tolerable, the initial presentation of these results will consider only those sets of restraint conditions that reduced both X_h and C_{max} relative to the baseline values. These sets of restraint conditions will be referred to as "improved" restraints. At 29 km/h, there were 101 sets of conditions that were "improved", at 38 km/h there were 69, and at 48 km/h there were 44. There were 42 sets of conditions that were "improved" at all three speeds (Table 3).

Due to the low occupancy rates in the rear seat, it is desirable to minimize the cost of any restraint that is used there, so these "improved" sets of restraint parameters must be evaluated in that light. The most expensive component of a restraint system is the pretensioner, so "improved" restraints that involve fewer pretensioners would be more economically feasible for implementation in the rear seat. Unfortunately, as expected there were no sets of restraint conditions that reduced both X_h and C_{max} at all speeds without the use of at least one pretensioner. There was also, as expected, a clear tradeoff between belt load limiting and the amount of pretensioning needed to satisfy the definition of "improved." The "improved" restraint having the lowest load limit (4.5 kN) required two or three pretensioners, each with 75 mm of stroke, in order to qualify as "improved". Of "improved" systems having a single pretensioner, the lowest load limit was 5.5 kN, and the required pretensioner stroke was 75 mm. The buckle pretensioner was less effective at limiting X_h relative to the retractor pretensioner, but was more effective at reducing C_{max}. Given the distance available prior to head contact with the front seat back (540 mm), and the importance of thoracic injuries identified in the field data portion of this study, this tradeoff is an important area for additional study. If the buckle pretensioner can indeed provide a substantial reduction in C_{max}, it may be a desirable alternative to the retractor pretensioner. Even though the buckle pretensioner allowed more X_h in these simulations, the X_h generated with either pretensioner is well below a tolerable level.

Table 3. Conditions (AM50) that reduced both X_h and C_{max} at all speeds relative to baseline (bold). Systems discussed in the text are in italics.

Load limit (kN)	Preten. arrange-ment	Preten. stroke (mm)	X_h (mm)*	C_{max} (mm)*
None	**None**	**0**	**138,178,224**	**22.7,26.0,29.9**
4.5	*3*	*75*	*56,115,219*	*18.8,20.7,20.6*
4.5	*4*	*75*	*45,99,195*	*19.4,21.7,21.1*
5	3	50	72,123,221	19.0,21.2,21.5
5	4	50	71,124,221	19.3,21.8,22.7
5	3	75	55,103,191	19.2,21.9,21.5
5	4	75	39,88,170	19.3,23.1,22.9
5.5	3	50	67,114,201	19.4,22.5,23.4
5.5	4	50	62,121,194	18.9,22.8,23.7
5.5	*1*	*75*	*103,137,219*	*17.3,18.2,17.7*
5.5	*2*	*75*	*65,111,201*	*21.2,25.0,25.2*
5.5	3	75	51,98,169	19.2,22.5,22.6
5.5	4	75	39,84,150	19.7,23.4,24.0
6	3	25	100,148,224	20.6,24.1,24.7
6	4	25	101,146,222	20.5,24.2,24.7
6	1	50	87,123,205	16.8,19.6,19.4
6	2	50	91,133,219	21.9,25.9,26.6
6	3	50	63,102,177	19.2,22.2,23.9
6	4	50	66,104,177	19.8,21.8,25.0
6	1	75	94,125,203	17.4,17.7,18.5
6	2	75	64,110,184	21.2,25.4,26.7
6	3	75	47,97,148	19.3,22.3,23.1
6	4	75	36,77,135	19.9,23.6,25.5
8	1	25	107,142,197	20.8,23.9,27.8
8	3	25	94,131,187	21.0,24.0,28.6
8	4	25	92,137,183	20.7,24.9,27.8
8	1	50	80,118,158	17.6,20.6,22.6
8	3	50	54,92,138	19.6,22.9,25.7
8	4	50	60,95,143	20.0,22.6,26.8
8	1	75	88,112,160	18.4,18.1,21.3
8	2	75	58,97,148	21.6,25.1,29.4
8	3	75	43,78,136	19.9,21.8,26.3
8	4	75	33,64,121	20.4,23.5,26.9
None	1	25	107,142,197	20.8,23.9,27.8
None	3	25	90,131,171	21.0,24.7,28.5
None	4	25	88,133,176	21.0,24.9,28.0
None	1	50	81,106,152	18.2,20.7,23.0
None	3	50	55,90,149	20.0,23.1,26.5
None	4	50	49,93,147	19.7,22.6,26.4
None	1	75	82,109,150	17.8,18.3,21.5
None	2	75	55,91,141	21.9,25.6,29.3
None	3	75	41,84,116	20.0,23.0,25.8
None	4	75	30,62,113	20.5,23.8,27.2

*The three values listed in the cell correspond to the test speeds 29 km/h (left), 38 km/h (middle), and 48 km/h (right)

In order to represent the maximum chest deflection from the simulations in terms of risk of thoracic injury, the AIS 3+ chest injury risk model 6 of Laituri et al. (2005) for AM50 is used. The Laituri injury risk function (Equation 5) using occupant age and the AM50 C_{max} were derived from sled test data with cadaveric subjects and the AM50 at different impact velocites. The AIS 3+ injury risk function was verified against real world thoracic injury risk considering different impact velocities and occupant age and gender.

$$p(AIS\ 3+) = \frac{1}{1+e^{-(-12.597+0.05861Age+1.568{C_{\max}}^{0.4612})}} \qquad [5]$$

As mentioned above, no system without a pretensioner was “improved” relative to the baseline. Of systems without a pretensioner, however, there are some systems that may be considered as reasonable alternatives to the baseline since they reduce chest injury risk with a potentially allowable increase in X_h. At 5.5 kN of load limiting with no pretensioning, for example, X_h increased by 80 mm relative to the baseline, but C_{max} decreased from 29.9 mm to 23.5 mm. Using Equation 5 with the C_{max} in Table 3, this results in a risk reduction from 21.9% to 11.3% for a person of age 65. Since the head remains more than 230 mm from the front seat back at its maximum point of excursion, this level of load limiting may be a reasonable option for the rear seat, even without the use of a pretensioner. The tradeoff between X_h and chest injury risk (based on the Laituri model of C_{max}) in 29, 38, and 48 km/h impacts for different types of pretensioning is illustrated in Figure 9. While Table 3 includes only restraints that reduced both chest deflection and head excursion, the plots in Figures 9-11 include all the simulation results (Appendix A). As shown in Figure 9, there is a clear tradeoff between chest risk and head excursion, and this tradeoff exists at all three impact speeds. As the belt force limit is reduced, the chest risk decreases and the head excursion increases. An exponential regression to the AM50 data points reveals a slightly concave-up characteristic to the trend, indicating that the most gain in chest risk reduction is made before the head approaches the excursion limit. As the head approaches 540 mm of excursion, the slope of the tradeoff curve has flattened, and in some cases has actually become positive since the extreme forward torso pitch allowed by those low-force belts allows thoracic loading from the thighs. In contrast, the AF5 tradeoff exhibits a trend that is virtually linear (Figure 10). Presumably, this is due to the smaller head excursion values experienced by that occupant.

DESCRIPTIVE ANALYSIS – AF5

In general, C_{max} and X_h were lower for the AF5 than for the AM50. The baseline restraint condition resulted in AF5 C_{max} of 15.6 mm, 18.5 mm, and 21.6 mm at 29 km/h, 38 km/h, and 48 km/h, respectively. The maximum AF5 X_h at those three speeds was 153 mm, 177 mm, and 201 mm, respectively. None of the simulations resulted in sufficient X_h to allow head contact with the front seat back. As with the AM50 results, there were many sets of restraint parameters that reduced both X_h and C_{max} relative to the baseline (Appendix A). At 29 km/h, there were 115 sets of conditions that were "improved", at 38 km/h there were 96, and at 48 km/h there were 77. As with the larger dummy, there were no restraint conditions that reduced both X_h and C_{max} at all speeds without a pretensioner.

The AF5 experienced less X_h than the AM50 for the same set of restraint parameters. Thus, the AM50 is the more appropriate model for assessing the minimum acceptable belt load limit. The AF5 results are more useful as an indication of the degree of thoracic benefit that can be realized by a smaller occupant if the belt loads are reduced to a level that retains sufficient head restraint for the AM50. As discussed above, 5.5 kN was the lowest belt load limit for a single-pretensioner system that was "improved" relative to the baseline. This system (5.5 kN, buckle pretensioner with 75-mm stroke) provided a safety benefit to the AF5, as well. Head excursion was reduced at all impact speeds, and C_{max} was reduced to 13.9 mm, 16.6 mm, and 19.8 mm. These gains are modest, however, and argue for a lower load limit even at the expense of some increased X_h for the AM50 – particularly since the AF5 is a better representation of the size of occupants typically in the rear seat. When the same pretensioner was used with the load limit decreased to 3 kN, the AF5 C_{max} dropped to 12.9 mm, 14.7 mm, and 16.8 mm. The tradeoff in AM50 X_h may be tolerable even at this relatively low load limit. At 48 km/h, the AF5 X_h remained below 280 mm, and the AM50 X_h was below 400 mm (i.e., nearly 150 mm clearance remained before the AM50 head contacted the front seat back). The AM50 C_{max} benefit was also substantial at 3 kN with the 75-mm buckle pretensioner, dropping to 13.7, 13.0, and 14.1 mm for the three speeds considered. That load limit is probably not acceptable without a pretensioner, however, since the AM50 X_h approached 480 mm at 48 km/h (Figure 10, Figure 11).

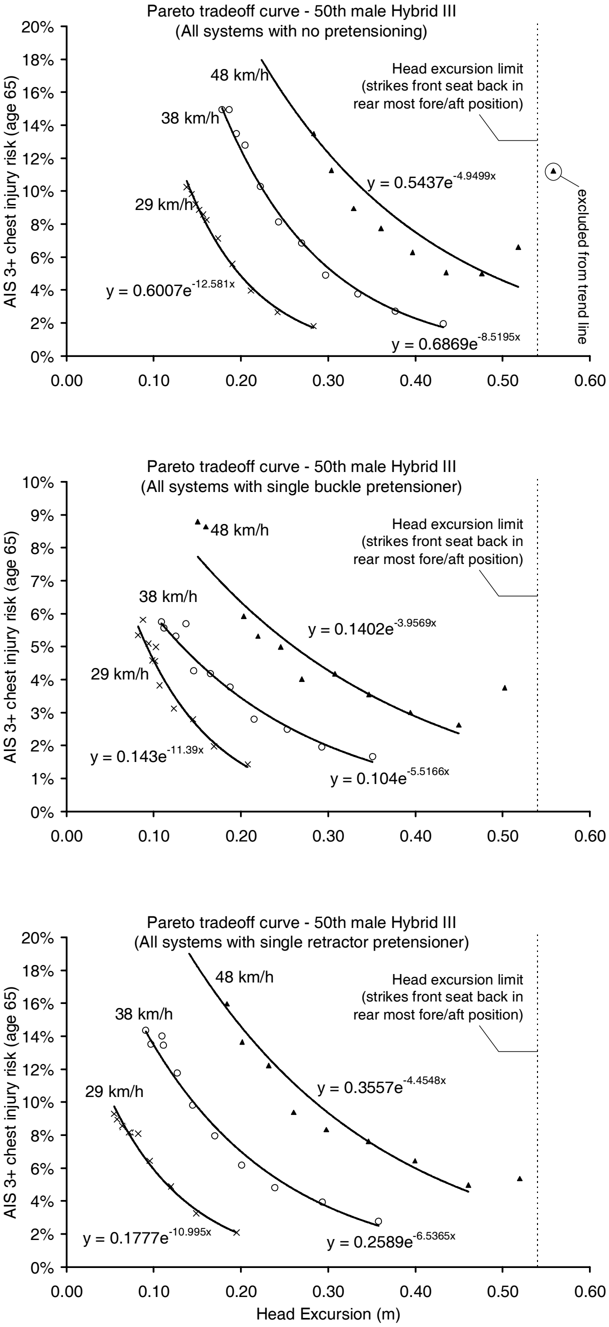


Figure 9. Tradeoff curves for all AM50 simulations involving restraints with no pretensioning (top), a single 75-mm buckle pretensioner (middle), and a single 75-mm retractor pretensioner (bottom). Note change in scale of the ordinate.

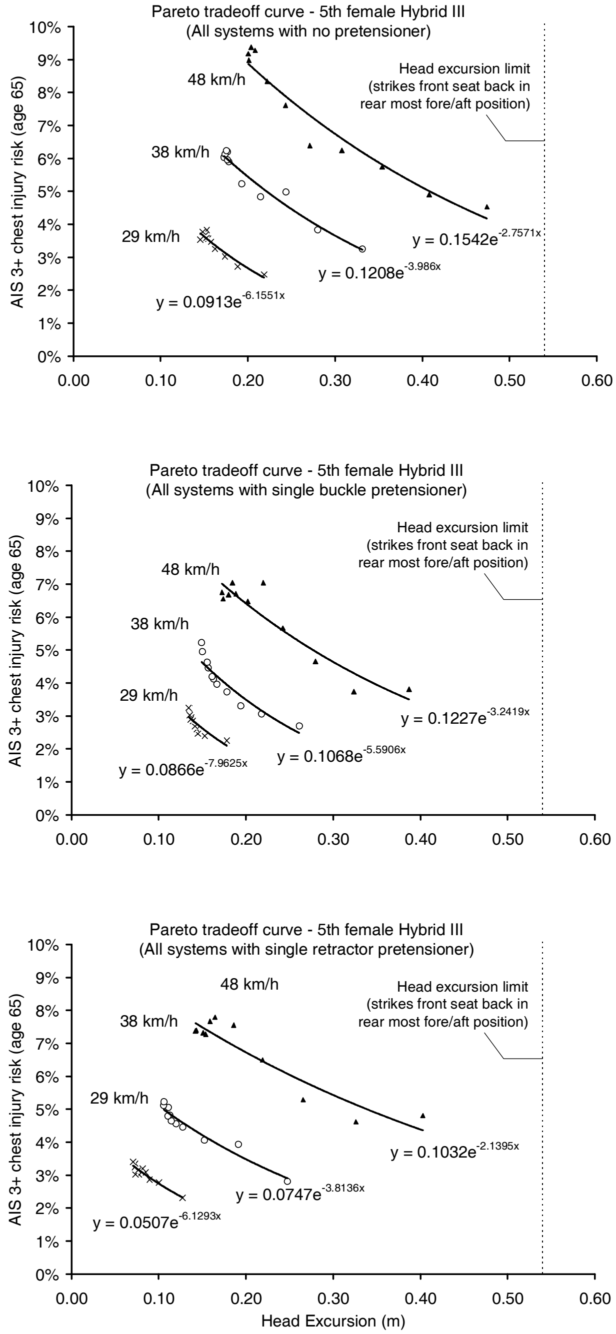


Figure 10. Tradeoff curves for all AF5 simulations involving no pretensioning (top), a single 75-mm buckle pretensioner (middle), and a single 75-mm retractor pretensioner (bottom). Note that the Laituri injury risk curve applied here for the AF5 was developed for the AM50.

DISCUSSION AND CONCLUSIONS

FIELD STUDY

Smith and Cummings (2004) estimated the risk ratio for death and serious injury for rear seat passenger compared to front seat passengers in motor vehicle crashes using the National Automotive Sampling System-Crashworthiness Data System (NASS-CDS) data files. They estimated that the rear seat passenger position may reduce the risk of death in a motor vehicle crashe by about 39%. Cummings imputed missing data in this survey sample and included crashes involving vehicles of model years 1948-2001. In general, older vehicle models are involved in more severe crashes than newer models. Thus, the inclusion of very old models in that analysis may have biased the sample towards more severe crashes involving vehicle models with poor crashworthiness compared to newer vehicle models. Later, those authors (Smith and Cummings 2005) performed a matched cohort study using the FARS database, though still with older vehicles included, and found greater rear seat effectiveness estimates than those found either by Kuppa et al. (2005) or in the current study. Limiting vehicle model year to 1991 and newer has the dis-benefit of reducing the sample size, but also increases the number of advanced, front-seat restraint systems considered in the analysis. This difference in model year inclusion criterion is a likely explanation for the lower rear seat effectiveness found here and by Kuppa et al. (2005) compared to the Smith and Cummings papers.

Evans (1991) and others have documented the safety benefit that rear-seat occupants enjoy relative to front-seat occupants. This benefit has been attributed to several characteristics of the rear-seat environment, including the distance from the striking vehicle in a frontal crash, and the relatively pliant structure of the front seat backs. The results of the current field study, however, indicate that this long-standing truism of automobile safety is becoming less certain, and for older adults is no longer true. As the front seat environment has evolved to incorporate more effective restraint systems, it has gotten closer to the safety of the rear seat. While this results in an overall benefit to all occupants, it invites research into how these advanced technologies might be incorporated into the rear seat, especially with the encouraging performance of load limiters in the front seat environment (Foret-Bruno et al. 1978, 1998, 2001, Kent et al. 2001). With a comparable restraint system, it may be possible to increase rear seat effectiveness (relative to the front seat) back to the levels it had in older model vehicles, which would be a further benefit to the overall vehicle fleet. Thus, a reasonable conclusion from this work is that additional research is justified into methods for reducing thoracic injury risk in the rear seat by incorporating restraint concepts currently offered in the front seat. A preliminary computational study illustrated the feasibility of such a strategy.

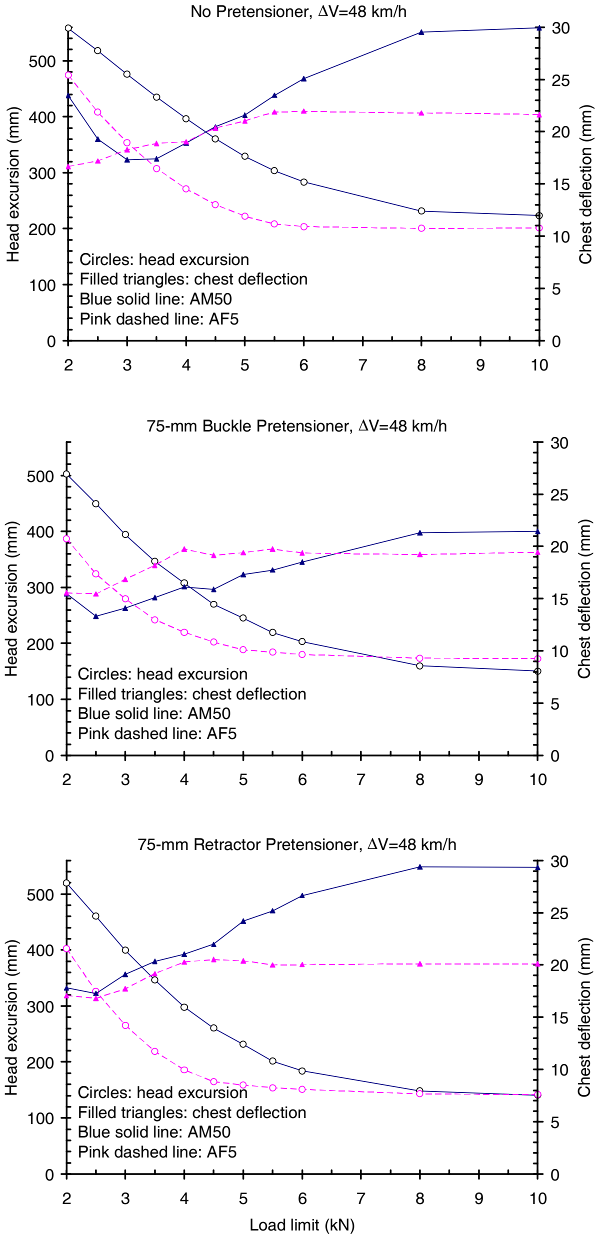


Figure 11. Effect of load limiting at 48 km/h ΔV for systems without pretensioning (top), with a single buckle pretensioner (middle), and with a single retractor pretensioner (bottom).

SIMULATIONS AND RESTRAINT DESIGN FOR THE REAR SEAT

The simulations considered here indicate that a belt load limit as low as 3 kN may sufficiently limit head excursion for the AM50 in a typical sedan at 48 km/h ΔV if a buckle pretensioner with 75-mm of stroke is used. This load limit and pretensioner would substantially reduce chest injury risk for older occupants of both sizes studied, while maintaining the head at least approximately 150 mm from the front seat back in all cases considered here. The results of this study, albeit limited in scope, indicate potential benefits for chest injury reduction with head excursion tradeoffs that are likely acceptable.

This study should not, however, be interpreted as a comprehensive assessment of rear-seat restraint design and performance. Additional work is ongoing in our laboratory to study the response of children in booster seats, and to expand these simulation results by including physical tests of both dummies and human cadavers. The primary goal of this simulation study was to assess the feasibility of load limiting in the rear seat, where an air bag and knee bolsters are not available for load sharing in a frontal collision. This work indicates that the consequences with respect to head excursion are likely not intractable if a load limiting belt is used to reduce chest injury risk in the rear seat. Even without a pretensioner, fairly low belt load limits generated a substantial reduction in chest injury risk for the elderly AM50 without an unacceptable increase in head excursion. If a pretensioner is economically feasible in the rear seat, then the belt load limits, and hence the chest deflection generated by the belt during the crash, are reduced further. Further analysis will examine the feasibility of an optimized belt system in protecting larger occupants as well as children. In the latter case, a study conducted by Van Rooij et al. (2003) demonstrated that the implementation of a pretensioner and a 4 kN force limiter can reduce the injury risk to a 6 year-old occupant without allowing a head excursion in excess of the FMVSS 213 limit.

Of course, prior to implementation of these restraint concepts into the rear seat, additional work is necessary to understand the consequences of occupant mis-positioning, non-frontal collisions, non-planar collisions, and vehicle geometries unlike that considered here. The front seat experience may guide some of that work, but the differences in occupancy rate and occupant types must be considered.

Finally, the limitations of the Hybrid III family of dummies, their associated injury criteria, and their implementation into the MADYMO package must be considered in the interpretation of these results.

Significant challenges to the interpretation of these models, especially for use in the refinement of belt load limiting characteristics, have been identified in the literature (e.g., Morgan et al. 1994, Kuppa and Eppinger 1998, Butcher et al. 2001, Petitjean et al. 2002, Kent et al. 2003).

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APPENDIX A. Simulation Results

			AM50							AF5							
			Xh (mm)			Cmax (mm)				Xh (mm)			Cmax (mm)				
Load Limit (kN)	**Preten. arrangement**	**Preten. Stroke (mm)**	**29 km/h**	**38 km/h**	**48 km/h**	**29 km/h**	**38 km/h**	**48 km/h**	**Improved at all speeds?**	**29 km/h**	**38 km/h**	**48 km/h**	**29 km/h**	**38 km/h**	**48 km/h**	**Improved at all speeds?**	**Improved at all speeds for both AM50 and AF5?**
None	**None**	**0**	**138**	**178**	**224**	**22.7**	**26.0**	**29.9**	**NA**	**153**	**177**	**201**	**15.6**	**18.5**	**21.6**	**NA**	**NA**
2000	1	0	283	432	558	11.3	11.6	23.5		219	331	474	13.0	14.6	16.7		
2000	1	25	245	396	537	11.2	11.5	20.5		170	285	429	11.8	13.5	16.0		
2000	2	25	259	410	548	11.8	12.0	21.6		156	251	393	11.6	13.0	16.0		
2000	3	25	229	383	528	11.3	11.3	20.0		178	261	387	12.5	13.5	15.6		
2000	4	25	221	377	526	10.8	11.4	21.3		191	307	457	12.9	13.7	16.8		
2000	1	50	222	369	519	10.1	10.6	17.6		157	279	431	12.4	13.7	17.5		
2000	2	50	227	385	534	11.7	13.0	19.8		127	248	403	12.6	13.7	17.1		
2000	3	50	186	340	503	11.1	11.6	17.6		156	271	420	12.3	13.3	16.6		
2000	4	50	183	332	496	11.6	12.5	18.9		130	231	369	11.9	13.7	16.3		
2000	1	75	208	351	502	10.1	10.9	15.5		125	222	352	12.6	13.8	15.7		
2000	2	75	195	358	519	12.0	13.6	17.8		148	257	401	12.3	13.5	16.9		
2000	3	75	156	303	476	11.9	11.8	15.4		137	234	367	12.6	14.2	16.7		
2000	4	75	125	283	459	12.8	12.8	15.7		131	234	363	14.1	14.9	17.8		
2500	1	0	242	377	518	13.4	13.5	19.3		189	280	408	13.5	15.6	17.2		
2500	1	25	205	339	490	13.4	13.0	16.7		144	232	356	13.0	13.9	15.7		
2500	2	25	215	353	503	13.7	14.2	17.2		138	202	325	12.5	14.5	16.6		
2500	3	25	189	324	479	13.7	13.0	15.9		153	218	324	12.8	14.2	15.4		
2500	4	25	183	318	476	13.2	13.2	16.4		162	256	385	14.0	15.6	17.6		
2500	1	50	179	308	466	11.9	11.9	13.4		130	224	359	13.9	15.4	17.2		
2500	2	50	184	325	483	14.5	15.0	16.4		100	191	326	13.6	15.8	16.8		
2500	3	50	143	275	444	13.3	13.2	14.3		131	217	346	13.5	14.1	16.0		
2500	4	50	142	274	438	13.3	14.1	15.7		114	179	297	12.1	14.3	17.0		
2500	1	75	169	293	450	11.7	11.7	13.3		101	166	279	13.0	14.5	18.1		
2500	2	75	149	294	461	14.6	15.7	17.3		127	209	331	13.2	14.5	17.2		
2500	3	75	112	237	407	13.9	13.6	14.2		120	189	301	14.3	15.1	17.4		
2500	4	75	87	214	382	15.2	14.8	14.8		101	184	290	15.3	16.1	18.3		
3000	1	0	211	334	476	15.8	15.5	17.3		174	244	354	14.1	17.3	18.3		
3000	1	25	175	292	440	15.1	13.8	15.2		129	195	299	13.8	15.2	16.7		
3000	2	25	183	308	455	16.5	16.1	16.9		131	168	267	13.0	15.1	18.5		
3000	3	25	158	275	430	15.5	14.6	15.8		145	194	280	12.9	14.7	16.8		
3000	4	25	154	274	427	16.1	15.2	15.4		147	218	328	14.6	16.7	18.1		
3000	1	50	148	261	411	13.5	13.3	14.7		118	186	300	14.1	16.8	17.7		
3000	2	50	151	277	431	17.1	17.0	18.0		89	152	266	13.8	15.9	17.7		
3000	3	50	115	229	386	15.6	15.5	16.1		119	181	288	14.1	15.1	17.5		
3000	4	50	113	226	382	15.1	15.6	16.5		107	146	240	12.5	14.9	18.0		
3000	1	75	145	253	394	13.7	13.0	14.1		84	137	224	13.3	15.4	16.7		
3000	2	75	120	239	399	17.2	17.1	19.1		116	173	275	13.7	14.9	18.5		
3000	3	75	83	191	344	16.1	15.4	15.9		106	161	249	13.6	16.3	17.7		
3000	4	75	59	166	318	16.5	16.8	16.7		84	150	239	16.1	16.8	19.4		
3500	1	0	190	297	435	18.1	17.2	17.4		162	215	308	14.6	17.1	18.9		
3500	1	25	154	255	393	17.1	16.1	16.3		115	164	253	14.6	16.1	18.4		
3500	2	25	161	270	412	18.5	18.0	18.7		106	143	220	13.6	16.0	18.5		
3500	3	25	138	240	379	17.3	17.0	17.3		144	178	242	13.3	15.4	18.2		

3500	4	25	133	235	376	17.7	16.9	16.8		132	184	278	14.5	16.1	18.4		
3500	1	50	126	223	358	15.1	14.7	15.6		105	155	250	14.7	16.5	18.5		
3500	2	50	127	235	380	18.7	18.3	19.5		85	128	219	14.3	16.6	19.2		
3500	3	50	92	190	332	17.2	17.1	17.2		102	148	236	14.3	16.5	19.0		
3500	4	50	93	189	331	16.8	17.0	17.4		83	115	192	13.6	16.2	17.5	√	
3500	1	75	123	215	347	14.3	13.7	15.1		85	127	193	13.6	16.0	17.8	√	
3500	2	75	95	201	346	19.1	18.8	20.3		101	144	228	14.0	16.9	18.8		
3500	3	75	70	158	292	17.7	17.5	17.3		85	124	195	13.9	17.1	18.6	√	
3500	4	75	52	135	265	18.3	18.2	18.6		66	122	191	16.9	17.6	18.6		
4000	1	0	174	270	397	19.8	19.5	18.9		158	193	271	15.0	17.6	19.0		
4000	1	25	135	227	352	18.9	18.1	18.0		108	147	219	14.9	17.0	19.1		
4000	2	25	144	238	367	20.0	19.8	19.2		106	135	194	13.9	16.7	18.6	√	
4000	3	25	120	211	338	19.1	18.8	18.3		142	167	220	13.4	15.8	19.8		
4000	4	25	117	206	336	18.9	18.7	18.3		128	167	242	14.7	17.5	18.8		
4000	1	50	107	192	314	15.6	15.8	16.6		100	141	214	14.5	17.4	19.1		
4000	2	50	110	202	336	20.1	19.3	20.6		81	120	186	14.5	16.7	20.3	√	
4000	3	50	80	161	288	18.5	18.6	18.6		95	135	204	14.5	17.2	18.4		
4000	4	50	82	160	283	18.7	19.4	18.2		79	108	169	13.7	16.7	18.2	√	
4000	1	75	107	188	308	15.6	15.5	16.1		82	120	172	13.8	15.8	18.7	√	
4000	2	75	82	170	298	20.8	20.7	21.0		95	133	198	14.2	17.7	18.7	√	
4000	3	75	60	135	251	18.5	19.3	18.8		81	117	168	14.1	16.9	18.4	√	
4000	4	75	47	115	227	18.9	20.3	19.6		67	115	177	17.4	18.4	19.0		
4500	1	0	161	243	361	21.0	20.8	20.5		155	178	243	15.1	18.5	20.3		
4500	1	25	127	203	320	19.7	19.8	19.8		104	141	196	15.3	17.3	18.9	√	
4500	2	25	135	214	332	21.3	21.7	20.8		103	131	171	14.1	16.9	19.3	√	
4500	3	25	117	189	301	20.4	21.0	19.4		139	163	202	13.8	16.1	19.1		
4500	4	25	110	183	298	19.9	20.6	19.3		122	159	216	14.9	18.0	20.2		
4500	1	50	106	170	278	16.6	17.6	17.2		95	135	190	14.9	17.7	19.8	√	
4500	2	50	104	178	296	21.1	21.9	21.4		77	115	165	14.1	16.8	20.5	√	
4500	3	50	75	138	250	18.8	20.2	20.2		90	127	181	14.8	17.6	18.8	√	
4500	4	50	76	138	247	19.1	20.5	20.1		74	102	148	13.8	17.0	18.7	√	
4500	1	75	102	165	270	16.7	16.1	15.9		83	117	158	14.0	16.0	19.6	√	
4500	2	75	74	145	261	20.9	22.3	22.0		92	122	175	14.5	18.0	19.4	√	
4500	3	75	56	115	219	18.8	20.7	20.6	√	78	114	152	13.9	16.7	19.1	√	√
4500	4	75	45	99	195	19.4	21.7	21.1	√	67	114	163	17.9	18.7	19.9		
5000	1	0	157	222	329	21.3	22.7	21.6		151	177	222	15.3	18.8	21.0		
5000	1	25	120	181	284	20.0	21.1	20.0		100	134	178	15.4	17.4	19.5	√	
5000	2	25	127	192	301	21.7	23.1	23.2		100	126	159	14.3	17.0	19.8	√	
5000	3	25	108	170	272	20.4	22.1	21.3		137	161	189	14.0	16.2	19.4	√	
5000	4	25	105	167	269	20.0	22.3	21.5		120	153	198	15.2	18.2	21.1	√	
5000	1	50	97	151	248	16.9	18.4	17.9		92	134	173	14.9	18.2	20.4	√	
5000	2	50	97	158	264	21.3	23.6	22.7		73	113	159	14.1	17.1	20.4	√	
5000	3	50	71	123	221	19.0	21.2	21.5	√	88	123	167	14.9	17.7	19.4	√	√
5000	4	50	71	124	221	19.3	21.8	22.7	√	73	99	136	14.1	16.8	19.0	√	√
5000	1	75	98	146	245	16.7	16.3	17.3		80	116	150	14.2	16.2	19.3	√	
5000	2	75	72	127	232	20.9	23.9	24.2		90	120	161	14.9	17.9	20.4	√	
5000	3	75	55	103	191	19.2	21.9	21.5	√	76	111	141	14.2	16.6	19.5	√	√
5000	4	75	39	88	170	19.3	23.1	22.9	√	65	112	159	17.9	19.0	20.7		
5500	1	0	152	205	304	21.5	24.6	23.5		146	173	208	15.1	18.6	21.9		
5500	1	25	118	173	256	20.1	22.9	21.4		99	132	169	15.7	17.8	20.1		
5500	2	25	126	181	272	21.7	24.3	23.6		100	122	151	14.4	17.1	19.1	√	
5500	3	25	103	155	249	20.6	23.4	22.9		137	157	185	13.9	16.6	19.8	√	

5500	4	25	103	151	246	20.2	23.6	23.4		119	148	188	15.2	18.4	22.2		
5500	1	50	91	137	226	16.7	19.7	18.8		90	129	165	15.0	18.3	21.0	√	
5500	2	50	90	145	241	21.6	24.6	24.6		76	111	154	14.4	17.0	20.0	√	
5500	3	50	67	114	201	19.4	22.5	23.4	√	86	121	157	15.1	18.0	19.8	√	√
5500	4	50	62	121	194	18.9	22.8	23.7	√	70	96	131	14.3	17.1	19.3	√	√
5500	1	75	103	137	219	17.3	18.2	17.7	√	79	115	150	14.4	16.3	19.4	√	√
5500	2	75	64	111	201	21.2	25.0	25.2	√	87	118	155	14.8	18.4	20.3	√	√
5500	3	75	51	98	169	19.2	22.5	22.6	√	76	107	135	14.4	16.7	19.7	√	√
5500	4	75	39	84	150	19.7	23.4	24.0	√	64	110	153	18.3	19.0	20.6		
6000	1	0	148	195	283	21.8	25.1	25.1		148	174	204	15.5	18.7	22.0		
6000	1	25	119	161	235	20.5	23.8	23.1		97	130	165	15.7	17.9	20.2		
6000	2	25	122	169	254	21.8	25.7	25.6		99	120	149	14.6	17.5	19.5	√	
6000	3	25	100	148	224	20.6	24.1	24.7	√	136	156	180	14.1	16.8	19.4	√	√
6000	4	25	101	146	222	20.5	24.2	24.7	√	117	147	182	15.5	18.3	21.7		
6000	1	50	87	123	205	16.8	19.6	19.4	√	90	125	162	15.1	18.3	21.2	√	√
6000	2	50	91	133	219	21.9	25.9	26.6	√	72	111	151	14.5	17.4	20.0	√	√
6000	3	50	63	102	177	19.2	22.2	23.9	√	84	117	155	15.3	18.0	20.1	√	√
6000	4	50	66	104	177	19.8	21.8	25.0	√	70	94	128	14.5	17.3	19.2	√	√
6000	1	75	94	125	203	17.4	17.7	18.5	√	79	111	145	14.5	16.2	19.4	√	√
6000	2	75	64	110	184	21.2	25.4	26.7	√	87	116	151	15.0	18.3	20.7	√	√
6000	3	75	47	97	148	19.3	22.3	23.1	√	75	105	130	14.4	16.9	19.6	√	√
6000	4	75	36	77	135	19.9	23.6	25.5	√	63	107	149	18.4	19.1	21.1		
8000	1	0	144	187	232	22.3	26.0	29.5		153	175	201	15.2	18.9	21.8		
8000	1	25	107	142	197	20.8	23.9	27.8	√	110	143	171	15.1	18.1	20.1	√	√
8000	2	25	117	156	205	22.3	26.4	29.5		112	127	159	14.5	18.3	19.6	√	
8000	3	25	94	131	187	21.0	24.0	28.6	√	135	150	174	14.5	17.3	19.2	√	√
8000	4	25	92	137	183	20.7	24.9	27.8	√	127	155	187	15.4	18.1	21.2	√	√
8000	1	50	80	118	158	17.6	20.6	22.6	√	96	131	170	14.8	17.9	20.7	√	√
8000	2	50	81	125	175	22.0	26.2	30.2		73	106	143	14.8	17.5	20.1	√	
8000	3	50	54	92	138	19.6	22.9	25.7	√	99	130	163	15.2	17.9	19.4	√	√
8000	4	50	59	95	143	20.0	22.6	26.8	√	90	107	139	13.9	17.4	19.1	√	√
8000	1	75	88	112	160	18.4	18.1	21.3	√	78	107	140	14.8	17.3	19.0	√	√
8000	2	75	58	97	148	21.6	25.1	29.4	√	94	119	157	15.7	18.2	19.9		
8000	3	75	43	78	136	19.9	21.8	26.3	√	96	123	144	15.1	17.3	20.1	√	√
8000	4	75	33	64	121	20.4	23.5	26.9	√	63	102	148	18.8	19.4	21.9		
10000	1	25	103	145	183	21.0	24.6	27.3	√	108	141	167	15.4	18.3	20.3	√	√
10000	2	25	111	151	198	22.5	26.4	29.5		113	127	157	14.3	18.2	20.3	√	
10000	3	25	90	131	171	21.0	24.7	28.5	√	134	149	173	14.6	17.6	19.4	√	√
10000	4	25	88	133	176	21.0	24.9	28.0	√	124	153	185	15.7	18.3	20.9		
10000	1	50	81	106	152	18.2	20.7	23.0	√	95	131	163	15.3	18.0	20.6	√	√
10000	2	50	83	118	166	22.5	26.3	30.4		71	106	142	14.8	17.6	20.1	√	
10000	3	50	55	90	149	20.0	23.1	26.5	√	98	126	162	15.4	18.0	19.7	√	√
10000	4	50	49	93	147	19.7	22.6	26.4	√	92	107	134	14.3	17.5	19.2	√	√
10000	1	75	82	109	150	17.8	18.3	21.5	√	77	108	136	15.2	17.7	19.4	√	√
10000	2	75	55	91	141	21.9	25.6	29.3	√	92	117	148	15.7	18.5	20.5		
10000	3	75	41	83	116	20.0	23.0	25.8	√	94	121	140	15.4	17.5	20.3	√	√
10000	4	75	30	62	113	20.5	23.8	27.2	√	64	105	147	19.0	19.6	21.9		
Totals:									**42**							**66**	**32**