REAR SEAT OCCUPANT PROTECTION IN FRONTAL CRASHES

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ABSTRACT

Though a significant body of literature exists on the safety performance and effectiveness of various types of front seat occupant restraint systems, there is a paucity of data on the performance of rear seat occupant restraint systems. A research program was initiated to better understand rear seat restraint performance. Research included examining real world data using National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) and Fatality Analysis Reporting System (FARS) as well as conducting full frontal vehicle crashes into rigid barriers with dummies restrained in rear seats. Child dummies (Hybrid III 6 year-old) and adult dummies (Hybrid III 5th percentile female and 50th percentile male) were used for this purpose. The dummies were placed in rear outboard seats with lap/shoulder belts as well as in the center seating position where the lap/shoulder belts were integrated to the seat.

A double-paired comparison study using FARS data files suggested that while occupants younger than 50 years of age benefit from sitting in rear seats in frontal crashes, restrained adult occupants older than 50 years are significantly better off in the front seats than the rear seats. The most injured body region for restrained children in rear seats is the head while that for restrained adults is the thorax. The major injury source for restrained occupants, not in child safety seats, is the seat belts while that for unrestrained occupants is the front seat back. The injury measures of restrained adult dummies in rear seats in frontal crash tests were generally higher than those of dummies of the same size in the driver and front passenger seat. The seat backs of integrated rear seats experienced excessive forward rotation in frontal crash tests, thereby causing the dummy's head to hit the console or front seatback, resulting in high head and neck injury measures. The field and vehicle crash test data indicate that rear seat restraints could be further optimized to mitigate injury in frontal crashes for older rear seat occupants.

INTRODUCTION

While the dynamic performance of front seat lap/shoulder belts is evaluated in dynamic crash tests in FMVSS No. 208 - Occupant Crash Protection, the performance of rear seat belts and seats are only evaluated in static tests as per FMVSS No. 209 - Seat Belt Assemblies, and FMVSS No. 210 - Seat Belt Anchorages. Prior to 1989, only lap belts were required in rear outboard seating positions. Rear seat outboard lap/shoulder belts were first required in passenger cars after December, 1989 and in convertible passenger cars, light trucks, vans and sport utility vehicles after September, 1991. Pursuant to Anton's Law passed by Congress in 2002, NHTSA published a final rule in December 2004, requiring lap and shoulder belt assembly for each designated rear seating position in a passenger motor vehicle with a gross vehicle weight rating of 10,000 pounds or less.

Evans (1987) conducted a double-paired comparison analysis of the FARS data files and estimated an 18±9 percent effectiveness of rear seat lap belts and 41±4 percent effectiveness of front passenger seat lap/shoulder belts in mitigating fatalities. Dalmotas (1987) examined the Canadian accident database, TRIAD, and found similar effectiveness of lap and lap/shoulder belts in rear seating positions as Evans (1987) using the FARS databases. Padmanaban (1992) examined the FARS database and state accident data and found no appreciative difference between the safety performance of lap belt and lap/shoulder belts in the rear seats.

Morgan (1999) found that the change from lap to lap/shoulder belts has significantly enhanced rear seat occupant protection in frontal crashes with rear seat lap/shoulder belts being 25 percent more effective than lap belts alone in reducing fatalities. Morgan also noted that rear outboard seat belt use rate is significantly lower than front outboard seat belt use, and the use rate is 7-10 percentage points higher with laps/shoulder belts than with lap belts alone.

More recently, Paranteau and Viano (2003) examined field data of rear seat adult occupant injuries and found that for lap-shoulder belted rear seat occupants in frontal crashes, thoracic injuries from the seatbelt are by far the dominant injury type. For unbelted rear seat occupants, the extremities and head are injured by the B-pillar, seatback and other interior surfaces. The authors found the risk of serious injury for rear seat occupants in lap belts to be the same as those in lap/shoulder belts. Paranteau noted that possible improvements in rear seat occupant protection include load limiting belts, pretensioners, improved belt geometry, and energy absorption padding to the front seat back.

Smith and Cummings (2004) examined NASS-CDS data files for the years 1993-2000 and estimated that the rear seat passenger position may reduce the risk of death in a motor vehicle crash by about 39% and reduce the risk of death or serious injury in a crash by 33%, compared to the front seat passenger position.

While research has been conducted on comparing the effectiveness of lap/shoulder belts and lap belts in rear seats as well as comparing the risk of injury and death for occupants in front and rear seats, there is a paucity of data on the effectiveness of rear seat lap/shoulder belt restraints with respect to front seats restraints in frontal crashes. This paper examines the NASS-CDS and FARS databases to examine the effectiveness of rear seats in mitigating fatality and injury in frontal crashes compared to that of the front seats for different age occupants. The real world data was compared to the observations from vehicle crash tests.

REAL WORLD DATA

ANALYSIS OF FARS DATABASES

The Fatality Analysis Reporting System (FARS) data files for the years 1993-2003 were analyzed. Only frontal crashes (no rollovers) of passenger cars and LTVs of model years later than 1991 were considered.

A double-paired comparison study was conducted according to the procedure developed by Evans (1987) to determine the risk of death of outboard rear seat occupants relative to that of the front seat passenger. The driver in these crashes was considered the control group. This method of double paired comparison uses two groups of fatal crashes. The first group consists of fatal crashes where a driver and front outboard seat passenger are present and at least one of them was killed. The second group consists of fatal crashes where a driver and a rear outboard seat passenger are present and at least one of them was killed. Each of these groups is further subdivided into different age categories of the passenger and the restraint status of the driver and passenger: restrained driver and passenger, unrestrained driver and passenger. Effectiveness was estimated separately for the presence and absence of passenger side air bag.

Children younger than 5 years old who are properly restrained in child safety seats or booster seats are considered restrained. Unrestrained children include those with misuse of child restraint systems and belt systems. All other restrained occupants in front and rear seats are with lap/shoulder belts.

As an example of the double-paired comparison procedure, consider the category of restrained driver and passenger. For a given age category of the passenger, if F_1 is the number of driver fatalities and F_2 is the number of front passenger fatalities in the first group, and F_3 is the number of driver fatalities and F_4 is the number of rear passenger fatalities in the second group, then the effectiveness of rear seat restraints compared to those of the front seat for that age category of the passenger is given by Equation 1.

$$\boldsymbol{E} = 100 \times \left(1 - \frac{\boldsymbol{F}_4 / \boldsymbol{F}_3}{\boldsymbol{F}_2 / \boldsymbol{F}_1}\right) \qquad (1)$$

Significance testing (at 95 percent confidence level) of the effectiveness estimates was conducted using the chi-square test. The error ranges in the estimates was computed according to Evans (1987) as shown in Equations 2 and 3.

$$\sigma = \sqrt{0.01 + 1/\boldsymbol{F}1 + 1/\boldsymbol{F}2 + 1/\boldsymbol{F}3 + 1/\boldsymbol{F}4}$$

$$\boldsymbol{E}_{lower} = 100 \times [1 - \boldsymbol{e}^{Ln(1-E/100)+\sigma}] \qquad (2)$$

$$\boldsymbol{E}_{upper} = 100 \times [1 - \boldsymbol{e}^{Ln(1-E/100)-\sigma}] \qquad (3)$$

Appendix C presents the FARS data used in the double-paired comparison study. Figures 1 and 2 present the effectiveness of rear outboard seats relative to the front outboard passenger seats with and without frontal air bag for restrained and unrestrained occupants. When the error bars in the effectiveness estimates (also presented in Figures 1 and 2) do not pass through zero, it implies that the effectiveness estimate is significant.

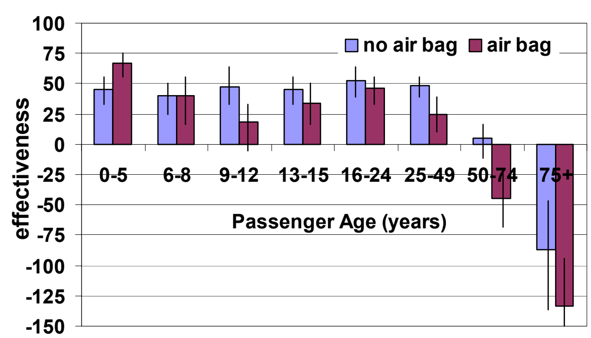

Figure 1. Effectiveness of outboard rear seats compared to front outboard passenger seats with and without front passenger air bag in mitigating fatalities for restrained occupants.

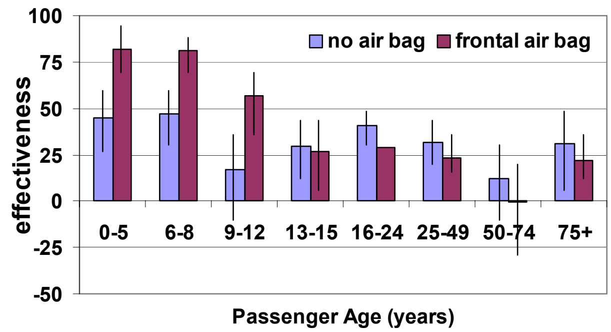

Figure 2. Effectiveness of outboard rear seats compared to front outboard passenger seats with and without front passenger air bag in mitigating fatalities for unrestrained occupants.

The FARS double-paired comparison study suggests that while the rear seats are significantly effective in mitigating fatalities for occupants younger than 50 years old (restrained and unrestrained), they demonstrate significantly reduced effectiveness (130 % reduction in effectiveness) compared to front seats for restrained occupants older than 50 years of age. In general, rear seats are significantly effective compared to front seats in frontal crashes for unrestrained occupants of all ages.

Rear seat effectiveness is increased by the presence of front passenger air bag for children 5 years old and younger restrained in child safety seats. However, the effectiveness of rear seats is reduced by the presence of passenger air bag for restrained occupants older than 8 years of age. The presence of passenger air bag reduces the effectiveness of rear seats for restrained occupants older than 50 years. This suggests the added benefits of air bags to older occupants.

The presence of front passenger air bag increases the effectiveness of rear seats in mitigating fatalities for unrestrained children 12 years old and younger suggesting the harmful effects of air bag deployment for unrestrained children. For unrestrained occupants older than 12 years of age, the presence of front passenger air bag reduces the effectiveness of the rear seat suggesting the benefits of air bag for unrestrained occupants in this age group.

ANALYSIS OF NASS-CDS DATABASES

The NASS-CDS data files were examined to get a better understanding of the injuries sustained by rear seat occupants. The NASS-CDS data files for the years 1993 to 2003 were analyzed. Only frontal crashes of passenger cars and LTVs of model years later than 1991 with no rollovers were examined. The data presented in this section are weighted by weighting factors in NASS/CDS to represent national estimates of towaway crashes.

The risk of AIS 2+ or AIS 3+ injury for a restraint condition is estimated as the ratio of the number of AIS 2+ or AIS 3+ injured occupants in the specified restraint condition to the total number of occupants in that restraint condition. The risk of injury to rear seat occupants and the distribution and source of injury was examined as a function of age, and restraint status.

Ninety percent of rear seat occupants are in the second row seat with 78 percent in outboard seats and 18 percent in center seats. Sixty-four percent of outboard rear seat occupants involved in frontal crashes are belted and among these restrained rear seat occupants, 64 percent are 12 years old and younger and 78 percent weigh less than 160 lbs.

Among children 0-3 years, 75 percent are in child safety seats, 4 percent are in belts, and 21 percent unrestrained. Among children 4-8 years in age, 7 percent are in child safety seats, 43 percent are in belts, and 50 percent are unrestrained.

The risk of injury and the distribution of injury was estimated only for outboard front and rear seat passengers. Children 5 years of age and younger were considered restrained if they were properly restrained in child safety seats. Occupants older than 5 years of age were considered restrained if they were restrained by lab shoulder belts.

While the risk of moderate to fatal injuries among restrained front seat occupants in frontal crashes is 5.2 percent, the risk for restrained rear seat occupants is only 1.6 percent. Though children 12 years and younger constitute 64 percent of rear seat occupants, they only represent 32 percent of the MAIS 2+ injured rear seat occupants and 26 percent of the fatally injured rear seat occupants.

Figures 3 and 4 present the risk of AIS 2+ and AIS 3+ injuries as a function of occupant age, for restrained and unrestrained passengers in rear outboard seating positions.

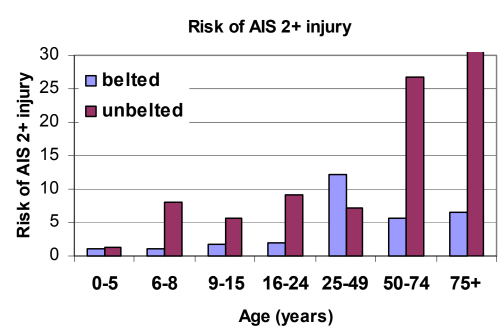

Figure 3. Risk of AIS 2+ injury for belted and unbelted passengers in rear outboard seats

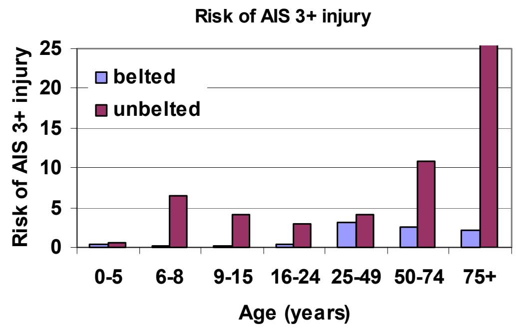

Figure 4. Risk of AIS 3+ injury for belted and unbelted passengers in rear outboard seats.

While the average risk of AIS 2+ and AIS 3+ injury is relatively low for restrained rear seat occupants, the risk of injury is higher for older occupants than younger ones.

Figures 5 and 6 present the distribution of AIS 2+ and AIS 3+ injuries to different body regions for restrained passengers in rear outboard seats as a function of occupant age. While the head is the dominant AIS 2+ and AIS 3+ injured body region among restrained children, the thorax is the dominant injured body region among adults.

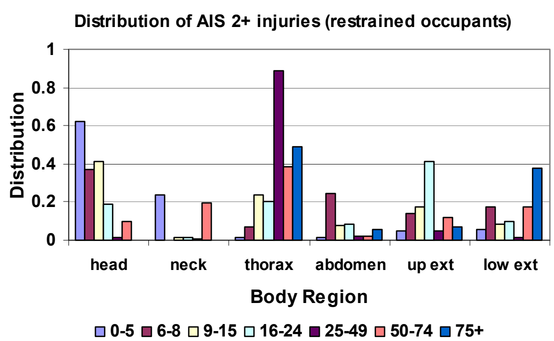

Figure 5. Distribution of AIS 2+ injuries to different body regions for restrained rear seat occupants as a function of their age.

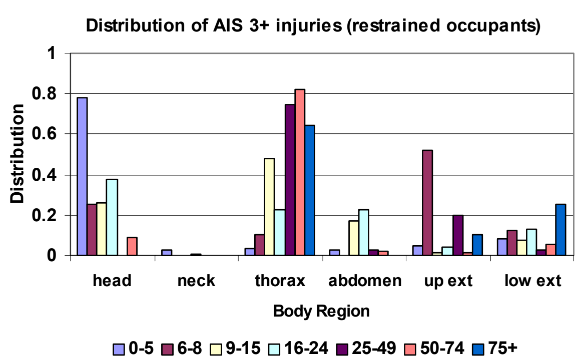

Figure 6. Distribution of AIS 3+ injuries to different body regions for restrained rear seat occupants as a function of their age.

The source of MAIS 2+ injury to restrained and unrestrained children (in child safety restraints) and restrained adults was examined. The data suggests that impact with the front seatback is the major source of head injury among unrestrained children in rear seats while the seat belt is the major source of thoracic and abdominal injury to restrained adult rear seat occupants. For children in child safety seats, the major sources of injury are the left and right interior vehicle surfaces and exterior surface.

With this understanding of the real world data, vehicle crash test data with occupants in the rear seats was examined. The injury measures of the dummies in the rear seats were compared to those in the front seats and the relative injury potential was compared to that observed in the real world.

VEHICLE CRASH TESTS

Full frontal rigid barrier vehicle crash tests were conducted at 48, and 56 km/h with adult Hybrid III dummies (Hybrid III 50th percentile male dummy - HIII 50M and Hybrid III 5th percentile adult female dummy - HIII 5F) in the front outboard seats and child (Hybrid III 6 year-old child dummy-HIII 6C) and adult Hybrid III dummies in rear outboard seats. Adult HIII and child dummies were also positioned in rear center seats of some vehicles where lap/shoulder belts were integrated to the seat (rear center integrated seats). The FMVSS No. 208 specified seating procedure was used to seat the dummies in the driver and front passenger seats. All vehicles were equipped with driver and front passenger air bags and the dummies in the front and rear seats were restrained by lap/shoulder belts. The HIII 6C dummies in the rear seats were in booster seats and used the available lap/shoulder belts. Appendix A presents a list of vehicle crash tests and the dummies used in the front and rear seats.

The computation of injury measures and the corresponding threshold values are in accordance with that specified in the FMVSS No. 208 Advanced Air Bag rule (65 FR 30680). The Nij intercepts and independent axial force limits for the adult dummies correspond to those specified for "in position" condition (Table 1). The neck tension and compression limits for the HIII 6C dummy are the "in position" limits specified by Mertz and Irwin (2003). In order to compare the injury potential indicated by various dummies used in these crash tests, the injury measures for each dummy were normalized by their respective injury threshold levels in Table 1.

Table 1. Injury threshold levels used to normalize dummy injury measures.

Injury Criteria	HIII 50 M	HIII 5F	HIII 6C
HIC15	700	700	700
Nij	1	1	1
Neck tension	4170	2620	1890
Neck Compression	4000	2520	1820
Chest Accel.	60	60	60
Chest Defl. (mm)	63	52	40

Figure 7 presents the normalized average HIC15 values for front and rear seat dummies in 48 and 56 km/h full frontal rigid barrier crash tests. In 48 km/h crashes, the average normalized HIC15 of the driver is 0.27±0.13 and that of the front seat passenger is 0.32±0.15 while the average normalized HIC15 of rear seat outboard passengers is 0.78±0.3 and that for occupants in center rear integrated seats is 0.84±0.29. The normalized HIC15 values for dummies in rear outboard seats as well as in rear integrated seats are significantly higher than those of the driver and the front seat passenger (95% confidence) in 48 ad 56 km/h crash tests.

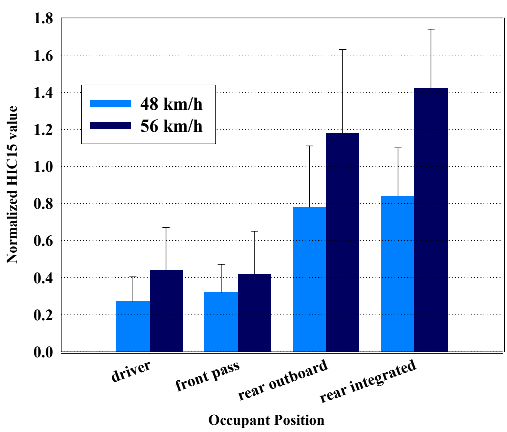

Figure 7. Average normalized HIC15 values of dummies in the front and rear seats in 48 and 56 km/h full frontal rigid barrier crash tests.

Table 2 presents the percentage of dummies in the driver, front passenger, and rear outboard seating positions in 48 km/h and 56 km/h full frontal rigid barrier crashes that exceeded the injury threshold levels of the various injury criteria in Table 1. The HIC15 values were in excess of the threshold limits for 23% of the rear seat dummies in 48 km/h crash tests and 36% of the rear seat occupants in 56 km/h crash tests while all the drivers and front seat passengers in 48 and 56 km/h tests had HIC15 values within the threshold level of 700.

Table 2. Percentage of dummies in the driver, front passenger, and rear outboard seating positions with injury measures in excess of the threshold levels.

Injury criteria	driver	front pass	rear outboard	rear integrated
48 km/h				
HIC15	0%	0%	23%	50%
Neck Ten	0%	0%	35%	25%
Nij	12%	0%	27%	0%
chest Ax	8%	4%	4%	0%
Chest Defl	8%	0%	19%	25%
56 km/h				
HIC15	0%	4%	36%	50%
Neck Ten	0%	0%	100%	50%
Nij	5%	0%	71%	50%
chest Ax	5%	4%	21%	25%
Chest Defl	0%	0%	7%	0%

The average neck tension for dummies in rear outboard seats was also significantly higher than that of dummies in front seats (Figure 8) in 48 and 56 km/h frontal crashes. The neck tension exceeded the allowable limit for all the dummies in rear outboard seats and 50 percent of the dummies in rear integrated seats in the 56 km/h crash tests. The average Nij values for dummies in rear outboard seats and rear integrated seats were also higher than the average Nij of dummies in front seats however, this difference was not significant.

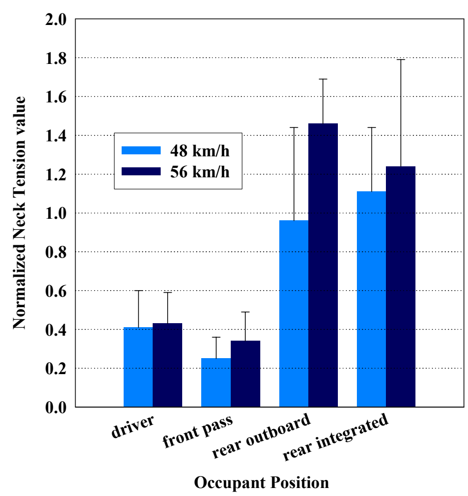

Figure 8. Average normalized neck tension values of dummies in front and rear seats in 48 and 56 km/h full frontal rigid barrier crash tests.

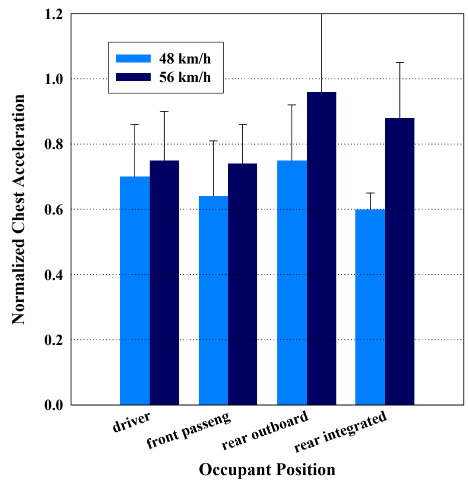

Figure 9. Average normalized chest acceleration of dummies in front and rear seats in 48 and 56 km/h full frontal rigid barrier crash tests.

While chest acceleration, and chest deflection were slightly higher for rear seat occupants than for front seat occupants, the difference was not significant (Figures 9-10). Chest acceleration and chest deflection measures for rear seat occupants exceeded the allowable values less frequently than the head and neck injury measures.

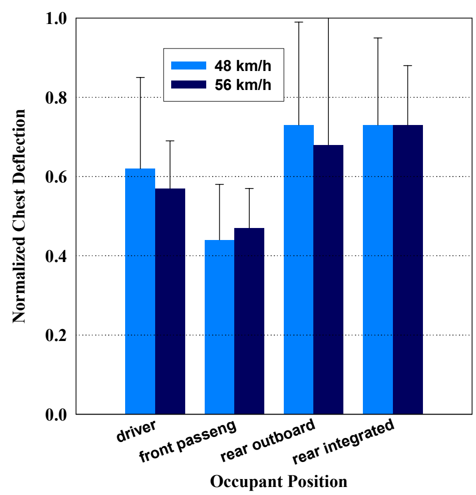

Figure 10. Average normalized chest deflection of dummies in front and rear seats in 48 and 56 km/h full frontal rigid barrier crash tests.

In most of these vehicle crash tests, adult dummies were used in the front seats while HIII 6C dummies were used in the rear seats. The higher normalized injury measures of the dummies in rear seats compared to those in front seats in these crash tests may be related to the different dummies used in the rear and front seats as well as the differences in the injury assessment values used to normalize the injury measures.

In order to compare the performance of rear seats and front seats in frontal crashes without the confounding effect of differences in dummies, only those tests were considered where the same size dummies were in the front and rear seats. Appendix B presents the test data of 5 full frontal rigid barrier 56 km/h crash tests with restrained HIII 5F dummies in the driver, front passenger, and rear outboard seating positions and 5 full frontal rigid barrier 48 km/h crash tests with unrestrained HIII 50M dummies in the driver and front passenger seats and restrained HIII 50M dummy in rear outboard seat.

Figure 11 presents HIC15 for the HIII 5F dummies in the driver, front passenger, and rear outboard seating positions in the 5 fontal crashes (Appendix B). The HIC15 values of the rear outboard HIII 5F dummy are higher than those of the HIII 5F driver and front seat passenger in all the five crashes and are higher than the allowable limit of 700 in two out of five 56 km/h frontal crash tests.

Figure 12 presents the HIC15 values for the unrestrained HIII 50M dummies in the driver and front passenger seats, and the restrained HIII 50M in rear outboard seat in 48 km/h frontal crashes (Appendix B). The restrained HIII 50M in the rear seat has higher HIC 15 measures than the unrestrained HIII 50M in the driver and front passenger seats in all the crash tests except that with the Liberty. The HIC15 of the HIII 50M dummy in the rear seat is lower than the allowable limit in all the five crash tests at 48 km/h.

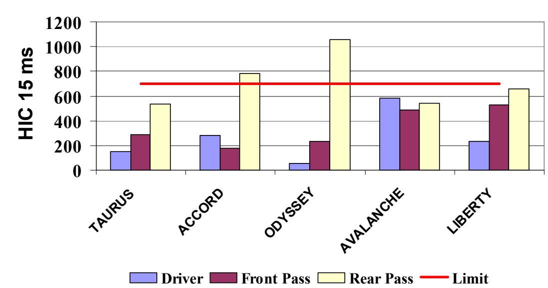

Figure 11. HIC15 for the HIII 5F dummy in the driver, right front passenger, and rear outboard seats in full frontal rigid barrier vehicle crash tests with 2004 model year vehicles at 56 km/h.

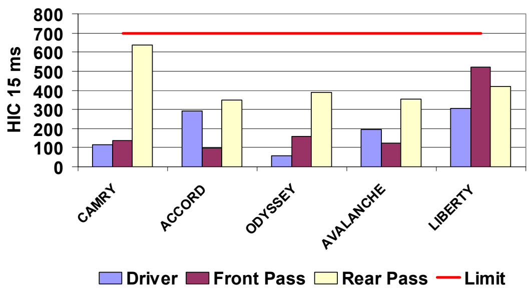

Figure 12. HIC15 for the HIII 50M dummy in the driver, right front passenger, and rear outboard seats in full frontal rigid barrier vehicle crash tests with 2004 model year vehicles at 48 km/h.

The neck tension of the HIII 5F in the rear seat exceeded the allowable limit of 2620 N in the crash test of the Honda Accord and the Honda Odyssey. The Nij of the HIII 5F in the rear seat also exceeded 1.0 in the crash test of the Odyssey and Avalanche. The chest injury measures of the HIII 5F dummy in the rear seat were within the allowable limits in all the tests. All the injury measures of the HIII 50M rear seat passenger were within the prescribed injury limits in the five crash tests. All the injury measures of the HIII 50M and HIII 5F in the driver and front seat positions in all the crash tests were within allowable limits.

The average ratio of HIC15, chest acceleration, chest deflection, neck tension, and Nij of the HIII 5F dummy in the rear outboard seat with respect to that of the HIII 5F driver and that of the HIII 5F front seat passenger in full frontal 56 km/h rigid barrier crashes of five 2004 vehicles is presented in Figure 13. The average ratio of the injury measures of the restrained HIII 50M dummy in rear outboard seats with respect to that of the unrestrained HIII 50M driver and front seat passenger in full frontal 48 km/h rigid barrier crashes of five 2004 vehicles is presented in Figure 14.

The ratio of head and neck injury measures are greater than 1.0 in tests with the HIII 5F and the HIII 50M dummies. The head and neck injury measures for rear seat occupants are significantly greater (95 percent confidence) than those of the driver and front passenger in tests with the HIII 50M and the HIII 5F dummies. This suggests an increased injury potential to the head and neck for an average restrained adult and small female in rear seats compared to that of an average unrestrained adult and a restrained small female in the front seats, respectively. Since the risk of injury to front seat occupants in frontal crashes is greater for the unrestrained condition than the restrained, the test data suggests that the injury potential for the average restrained adult in the front seat is also likely to be lower than that in rear seats.

The chest acceleration injury measures are not significantly different for the rear and front seat occupants (driver and front passenger) in tests with the HIII 5F as well as the HIII 50M dummy. While the chest deflection of the rear seat passenger and driver are not significantly different, the chest deflection of the rear seat passenger is significantly greater (at a 95 percent confidence) than that of the front seat passenger in tests with the HIII 50M and the HIII 5F dummies.

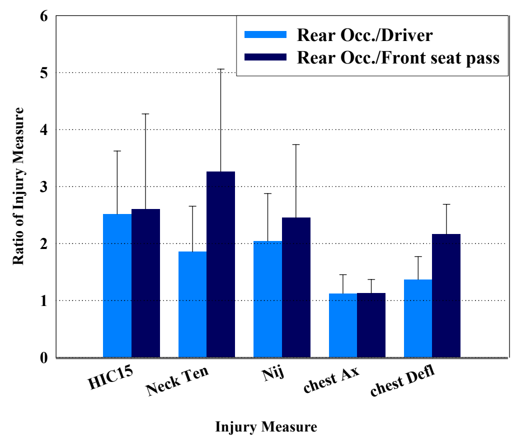

Figure 13. Average ratio of injury measures of restrained HIII 5F dummy in the rear seat to that of the restrained HIII 5F driver and front seat passenger in five 56 km/h full frontal rigid barrier crash tests.

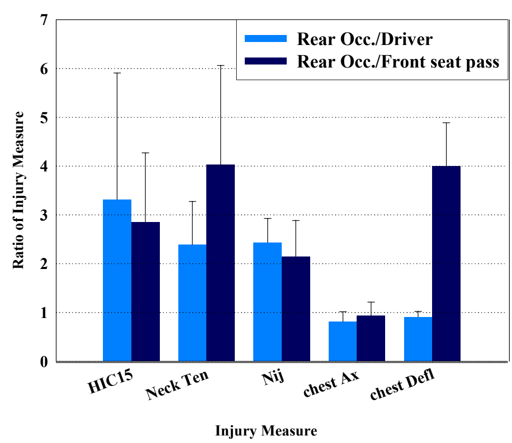

Figure 14. Average ratio of injury measures of restrained HIII 50M dummy in the rear seat to that of the unrestrained HIII 50M driver and front seat passenger in five 48 km/h full frontal rigid barrier crash tests.

CENTER REAR INTEGRATED SEAT PERFORMANCE

Integrated seats are seats where the seat belt assemblies are attached to the seat. Such seats have the potential of providing better belt fit to their occupants and the potential of preventing full or partial ejection in rollover and rear crashes. While integrated front seats are subjected to a dynamic crash test, rear integrated seats have to only meet the static test requirements specified in FMVSS No. 210 and 207. Ten 48 and 56 km/h frontal rigid barrier crash tests with HIII 50M, HIII 5F, and HIII 6C dummies in rear integrated center seats demonstrated that the seat back of integrated seats experiences excessive forward rotation due to inertial loading of the occupant resulting in the dummy head contacting the front seat back, the front console or its own knees. This generally results in high head and neck injury measures as is indicated in Figures 7 and 8. The forward rotation of the seatback results in less belt loading on the thorax, which results in lower chest acceleration and deflection (Figures 9 and 10).

DISCUSSION

A comparison of fatality rates among front and rear seat passengers suggests that although rear seat belts are effective in reducing death and serious injury (Morgan, 1999), their effectiveness compared to that of the front seat restraints in mitigating fatalities and serious injury depends on the age of the occupant. The data suggests that restrained occupants younger than 50 years benefit from sitting in rear seats in frontal crashes. However, restrained occupants older than 50 years of age have significantly improved protection in frontal crashes when seated in the front seat than in the rear outboard seats. Unrestrained occupants of all ages benefit from sitting in rear seats than front seats in frontal crashes.

The presence of a frontal air bag reduces the protection level of front seats for children 5 years old and younger who are restrained in child safety seats and for unrestrained children 12 years old and younger. This highlights the importance of having children 12 years old and younger sit in rear seats, as per NHTSA's recommendation. The presence of a frontal air bag improves the protection level of front seats for occupants older than 12 years of age.

Smith and Cummings (2004) demonstrated that in frontal crashes, the risk of injury to rear seat occupants is lower than that of front seat occupants. However, Smith did not examine this relative injury risk as a function of age. Though 64 percent of restrained rear seat occupants are younger than 12 years of age, they only represent 32 percent of the MAIS 2+ injured and 26 percent of the fatally injured rear seat occupants. This suggests that the overall reduced risk of injury and fatality to rear seat occupants may be related to the large representation of young occupants in rear seats.

The risk of AIS 2+ and AIS 3+ injury to restrained and unrestrained rear outboard seat occupants increases with occupant age. In addition, while the most injured body region for children is the head, the thorax is the most injured body region among adults and is significantly more prominent among older occupants. A major source of AIS 3+ chest and abdomen injuries for restrained rear seat occupants is the seat belt. These findings suggest that restraint systems of rear seats could be further optimized to afford better protection to the older population.

The head and neck injury measures of restrained adult dummies in the rear seat of 2004 model year vehicles tested were significantly higher than those of restrained and unrestrained adult dummies in the front seats. This suggests that the advanced restraint systems of the front seats in these newer vehicle models make the front seat position more effective than the rear seating position for adult occupants in reducing serious to fatal injuries.

The significantly higher chest deflection of the HIII 5F and HIII 50M dummies in rear seats compared to that of the corresponding dummy in the front passenger seat may be related to the fact that since there is more space available in the front passenger seat position, the air bag alone and the combination of air bag and belt restraints can be optimally designed to allow the occupant to take advantage of the ride down.

While field data indicates chest injuries to be the dominant injured body region among adult rear seat occupants in frontal crashes, the crash test data suggests a greater risk of head and neck injuries than chest injuries among restrained adult rear seat occupants. The differences in crash test data from real world data may be related to the prescribed injury threshold levels and differences in interaction of the dummy with the restraint system compared to human adults in rear seats.

Full frontal rigid barrier crash tests at 48 and 56 km/h with adult occupants in center rear integrated seats resulted in excessive rotation of the seatback thereby causing the dummy head to contact the front seatback, console, or its own knees, resulting in high head and neck injury measures. Neither rear nor center seat positions are required to be tested dynamically in FMVSS No. 208. The integrated restraints are evaluated statically in FMVSS Nos. 207 and 210. These crash test results, though very limited, suggest that the static test requirements of FMVSS Nos. 207 and 210 may not be sufficient to optimize the protection to occupants in these seating positions in severe frontal crashes. However, much more work is necessary to understand how the regulatory requirements might be altered.

Research efforts have been made in improving rear seat restraint systems. Haberi et al. (1987) presented the development of an ergonomic rear safety belt system used in the European BMW 7 series models that ensured improvements in use rate as well as in occupant protection. The restraint system is characterized by reversed shoulder belt geometry – the upper mounting points are inboard and the diagonal shoulder belt angle across the torso is in the opposite direction of what is customary. Haberi conducted full frontal vehicle crash tests to demonstrate that the forward location of the outboard buckle improves the belt fit and reduces the likelihood of submarining, making the pelvic restraint more effective in head-on collisions.

Zellmer et al. (1998) examined the feasibility and the protective effect of belt pretensioners and load limiters in the rear seats using MADYMO simulations and sled testing. The study showed that optimized belt systems significantly reduce thoracic loading on the rear seat occupant. More recently, Kawaguchi (2003) proposed the concept of optimal belt load control system to afford protection to all size occupants through MADYMO simulations.

The field data as well as the frontal crash test data indicate a need for improvement in frontal crash protection for older rear seat occupants. Advanced restraint systems in rear seats have the potential of improving frontal crash protection for rear seat occupants of all ages, and in particular for the elderly.

CONCLUSIONS

This paper presents the analysis of real world crash databases and crash test data to compare the effectiveness of rear seat restraints to those of the front seats. The findings from this study are as follows:

1. While occupants younger than 50 years of age benefit from sitting in rear seats in frontal crashes, the front seats offer significantly improved protection compared to rear seats in frontal crashes to restrained adults 50 years and older.
2. The most injured body region for restrained children in rear seats is the head while that for adults is the chest.
3. The main source of chest and abdominal injuries for restrained adult occupants in rear seats is their interaction with the seat belts. The major source of injury among unrestrained occupants is contact with the front seat back.
4. Protection of occupants in rear integrated seats may be optimized further by designing seat backs such that they do not experience forward rotation in a moderate to severe frontal crash sufficient to allow injurious contact with the vehicle interior.
5. Rear seat restraints may offer improved protection to occupants of all ages, and in particular, to the elderly, if they are optimized to dynamic crash conditions.

FUTURE RESEARCH

NHTSA is continuing its research program to better understand rear seat and rear integrated seat performance. The NHTSA Special Crash Investigations and CIREN programs will be conducting detailed examination of select crashes involving rear seat occupants with serious to fatal injuries. Different size dummies in rear seats will be added in frontal crash tests to continue evaluation of the dynamic performance of rear seats and rear integrated seats. Numerical simulations will be conducted to determine the feasibility of advanced restraint systems and improved restraint geometry in rear seats to improve rear seat occupant protection.

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APPENDIX A

Table A-1. Full Frontal Rigid Barrier Crash Test – Driver and Front Outboard Passenger

				Driver							Passenger					
TSTNO	Test Speed (km/h)	Make	Model	Model Year	HIII adult dummy size	15 ms HIC	Neck Tension (N)	Max Nij	Chest Ax (gs)	Chest Defl (mm)	HIII adult dummy size	15 ms HIC	Neck Tension (N)	Max Nij	Chest Ax (gs)	Chest Defl (mm)
3783	48	DODGE	GRAND CARAV	2001	5	190.2	1850.7	1.83	67.1	57.5	5	486.2	725.9	0.82	61.5	16.8
3784	48	FORD	ESCAPE	2001	5	134.3	1441.7	1.23	50.3	58.7	5	120.2	511.3	0.68	37.9	10.8
3796	48	FORD	F150 PICKUP	2001	5	136.8	645.9	0.29	34.8	29.0	5	111.1	443.3	0.31	41.7	10.3
4237	56	NISSAN	FRONTIER	2002	50	414.8	1965.0	0.31	45.5	37.7	50	329.3	802.9	0.24	41.8	29.3
4252	56	DODGE	DAKOTA	2002	50	653.9	3135.7	0.56	58.7	48.3	50	256.0	2040.7	0.65	41.0	26.2
4416	56	CHEVROLET	TRAILBLAZER	2002	5	617.2	1638.7	0.55	73.8	44.2	5	793.0	1955.8	0.75	67.4	36.7
4417	56	JEEP	LIBERTY	2002	5	244.8	1742.0	0.60	47.5	29.0	5	192.0	1470.7	0.85	41.7	23.2
4463	57	HONDA	ODYSSEY	2003	50	204.4	1273.2	0.19	41.4	32.4	50	237.1	836.2	0.18	37.1	27.1
4472	56	CHEVROLET	SILVERADO	2003	50	523.0	1957.2	0.33	44.8		50	629.0	2305.4	0.52	49.0	
4483	57	MERCEDES	E320	2003	50	288.2	1006.1	0.23	48.7	34.9	50	216.2	719.2	0.34	48.5	36.1
4486	57	TOYOTA	AVALON	2003	50	383.1	1196.4	0.27	43.0	26.2	50	340.6	1002.2	0.40	39.6	32.8
4487	56	SATURN	ION	2003	50	238.5	813.9	0.26	42.3		50	152.5	1078.3	0.20	35.9	
4493	56	VOLVO	XC 90	2003	50	419.1	1669.5	0.47	49.7	31.7	50	231.7	1676.9	0.38	58.0	35.7
4512	48	CHEVROLET	TRAILBLAZER	2002	5	144.9	1768.8	0.55	64.7	40.9	5	366.4	1682.2	0.70	58.9	38.4
4546	56	TOYOTA	4RUNNER	2003	50	466.8	1494.5	0.28	46.5		50	315.2	1121.3	0.23	45.3	
4549	56	CHEVROLET	TAHOE	2003	50	0.0	1751.0	0.35	52.6	28.6	50	433.3	2171.9	0.46	52.0	34.4
4671	48	BUICK	RENDEZVOUS	2003	50	327.2	1326.6	0.27	47.3	32.4	50	307.0	629.7	0.35	42.0	30.5
4672	48	DODGE	CARAVAN	2003	5	347.8	1352.8	0.48	42.2	24.2	5	292.4	520.9	0.44	41.6	23.7
4673	48	BUICK	RENDEZVOUS	2003	5	357.8	1875.9	0.79	39.9	23.2	5	325.2	756.1	0.44	40.4	25.8
4674	48	HONDA	CRV	2003	50	93.5	1002.0	0.26	36.3	26.2	50	101.8	876.3	0.18	35.1	22.8
4675	48	CHEVROLET	TRAILBLAZER	2003	50	237.1	1767.8	0.36	49.2	39.8	50	291.4	1807.3	0.52	46.2	34.8
4676	48	VOLKSWAGEN	PASSAT	2003	50	179.3	1296.8	0.25	36.3	32.5	50	157.1	1053.2	0.19	33.0	27.3
4681	56	NISSAN	MAXIMA	2002	5	344.3	1968.1	1.23	38.6	29.1	5	409.7	898.7	0.50	40.0	24.1
4682	56	HONDA	CIVIC	2002	5	108.0	1348.0	0.76	41.4	28.1	5	180.5	742.4	0.53	40.1	25.1
4683	56	HONDA	ACCORD	2002	5	69.7	1217.7	0.73	49.8	40.9	5	361.0	670.2	0.60	43.4	20.9
4686	48	HONDA	ACCORD	2003	5	159.1	1908.5	0.92	33.3	22.1	5	224.8	400.4	0.25	35.5	21.0
4687	48	VOLVO	V70	2003	5	120.8	1144.3	0.49	41.9	32.6	5	199.3	535.8	0.43	44.1	28.4
4689	48	ACURA	1.7 EL	2003	5	123.2	1612.9	0.95	37.5	25.4	5	133.7	467.8	0.45	33.2	20.8
4690	48	FORD	EXPLORER	2003	5	396.1	1965.3	1.14	53.7	35.6	5	387.4	714.2	0.53	44.2	29.1
4698	48	TOYOTA	MATRIX	2003	50	110.5	779.9	0.15	32.5	21.6	50	59.3	601.6	0.25	30.9	19.9
4701	56	VOLVO	XC 90	2004	50	288.1	1413.2	0.39	41.7	40.1	50	169.9	1702.1	0.25	48.3	
4776	57	FORD	TAURUS	2004	50	316.6	1284.6	0.30	43.0	27.7	50	146.9	1253.4	0.28	41.9	22.0
4780	48	DODGE	CARAVAN	2003	50	289.4	875.7	0.34	49.8	46.5	50	348.9	818.0	0.22	8.1	31.0
5092	56	VOLVO	S40	2004	50	185.0	1278.8	0.38	47.2	38.7	50	143.4	1070.8	0.21	43.5	31.0
5117	57	SUBARU	OUTBACK	2005	50	238.7	1067.7	0.23	38.9	28.6	50	178.6	911.9	0.17	44.0	29.7
5143	56	FORD	TAURUS	2004	5	166.0	1433.8	0.44	37.5	29.1	5	289.9	409.7	0.28	42.0	19.1
5144	56	HONDA	ODYSSEY	2004	5	56.8	917.6	0.43	32.4	24.4	5	233.2	918.9	0.49	38.1	14.5
5145	57	HONDA	ACCORD	2004	5	279.9	914.9	0.30	32.1	26.0	5	181.5	738.0	0.22	38.3	28.8
5164	48	MITSUBISHI	GALANT	2004	50	149.7	1240.7	0.29	39.7		50	182.0	1256.0	0.26	33.7	
5166	48	SUZUKI	SWIFT	2004	50	128.4	1228.8	0.26	36.6		50	185.4	1534.2	0.29	32.2	
5167	48	NISSAN	MAXIMA	2004	50	113.8	999.2	0.22	39.0		50	276.3	852.9	0.24	35.0	
5168	48	HONDA	ELEMENT	2004	50	110.8	1302.2	0.29	34.0		50	215.0	1344.6	0.31	35.1	
5173	48	MERCEDES	C230	2004	50	186.2	1085.6	0.24	46.3		50	214.5	808.3	0.21	40.7	
5174	48	HYUNDAI	TIBURON	2004	50	96.4	671.8	0.17	33.4		50	107.0	963.0	0.24	44.0	
5182	48	CHRYSLER	CONCORDE	2004	50	316.6	1295.5	0.33	43.4		50	128.5	1029.7	0.20	35.2	
5191	48	CHEVROLET	MALIBU	2004	50	172.8	1205.1	0.29	33.0		50	135.9	1113.6	0.32	34.6	
5203	47	TOYOTA	SIENNA	2004	5	126.7	1201.5	0.44	34.5		50	230.7	666.1	0.38	29.7	

Note: **HIII Dummy Size: 50**: Hybrid III 50th percentile male dummy; **5**: HIII 5th percentile female dummy,

Table A-2. Full Frontal Rigid Barrier Crash Test Data – Rear Seat Occupant

TSTNO	Test Speed (km/h)	Make	Model	Model Year	occ. seat positon	HIII dummy size	15 ms HIC	Neck Tension (N)	Max Nij	Chest Ax (gs)	Chest Defl (mm)
Rear Outboard Seats											
3783	48	DODGE	GRAND CARAVAN	2001	3	6C	759.3	376.3	0.30	52.7	29.0
3784	48	FORD	ESCAPE	2001	3	6C	762.7	608.4	0.24	69.3	39.7
3796	48	FORD	F150 PICKUP	2001	4	6C	425.2	530.2	0.20	40.8	26.0
4252	56	DODGE	DAKOTA	2002	3	6C	476.8	2031.4	1.15	55.9	0.0
4463	57	HONDA	ODYSSEY	2003	4	6C	593.9	2230.0	0.89	39.0	0.0
4472	56	CHEVROLET	SILVERADO	2003	4	6C	0.0	2680.5	1.36	0.0	0.0
4483	57	MERCEDES	E320	2003	4	6C	724.2	2626.4	1.16	57.7	1.3
4486	57	TOYOTA	AVALON	2003	4	6C	887.4	2911.7	0.98	54.4	23.6
4487	56	SATURN	ION	2003	4	6C	0.0	2760.4	1.01	0.0	0.0
4493	56	VOLVO	XC 90	2003	4	6C	0.0	2954.1	1.27	53.7	38.1
4546	56	TOYOTA	4RUNNER	2003	4	6C	0.0	3504.3	1.42	0.0	0.0
4549	56	CHEVROLET	TAHOE	2003	4	6C	0.0	2487.0	1.03	36.8	25.5
4671	48	BUICK	RENDEZVOUS	2003	4	6C	730.0	3335.1	1.41	0.0	34.7
4672	48	DODGE	CARAVAN	2003	3	6C	481.8	2176.7	0.95	0.0	19.7
4682	56	HONDA	CIVIC	2002	4	6C	607.1	2339.2	0.85	0.0	40.8
4686	48	HONDA	ACCORD	2003	3	6C	416.3	1420.6	0.68	0.0	22.8
4687	48	VOLVO	V70	2003	3	6C	465.3	1500.7	0.56	0.0	40.8
4687	48	VOLVO	V70	2003	4	6C	319.4	1817.7	0.63	0.0	43.9
4689	48	ACURA	1.7 EL	2003	3	6C	684.0	2247.0	0.91	0.0	38.3
4689	48	ACURA	1.7 EL	2003	4	6C	665.3	2308.2	1.04	0.0	34.1
4690	48	FORD	EXPLORER	2003	4	6C	527.4	3413.8	1.43	0.0	43.8
4698	48	TOYOTA	MATRIX	2003	4	6C	545.8	2150.8	0.75	0.0	34.1
4701	56	VOLVO	XC 90	2004	4	6C	824.5	2628.1	0.99	88.3	36.2
4776	57	FORD	TAURUS	2004	4	6C	1020.7	2799.6	1.13	57.6	18.6
4780	48	DODGE	CARAVAN	2003	3	6C	1051.9	2741.3	1.32	0.0	42.9
5092	56	VOLVO	S40	2004	4	6C	0.0	3084.0	1.80	60.3	0.0
5117	57	SUBARU	OUTBACK	2005	4	6C	1477.8	3527.0	1.41	73.6	32.8
5143	56	FORD	TAURUS	2004	3	5	536.0	2378.3	0.89	42.0	32.8
5144	56	HONDA	ODYSSEY	2004	3	5	1057.0	3354.0	1.17	52.8	37.2
5145	56	HONDA	ACCORD	2004	3	5	783.0	2774.0	0.94	48.6	47.1
5164	48	MITSUBISHI	GALANT	2004	4	5	515.0		0.96	45.6	32.8
5167	48	NISSAN	MAXIMA	2004	4	5	270.0		0.70	47.4	35.9
5168	48	HONDA	ELEMENT	2004	3	5	642.0		0.96	41.3	33.7
5173	48	MERCEDES	C-230	2004	4	5	663.0		0.98	48.9	36.0
5174	48	HYUNDAI	TIBURON	2004	4	5	483.0		0.76	43.5	34.0
5182	48	CHRYSLER	CONCORDE	2004	3	5	373.0		0.87	46.3	38.0
5191	48	CHEVROLET	MALIBU	2004	3	5	343.0		0.72	51.7	34.6
5203	48	TOYOTA	SIENNA	2004	4	5	396.0		0.71	36.8	28.8
Seatbelts Integrated to Seat											
4416	56	CHEVROLET	TRAILBLAZER	2002	6	50	552.6	3170.5	0.65	41.4	44.6
4417	56	JEEP	LIBERTY	2002	6	50	684.0	3221.6	0.62	47.2	36.4
4493	56	VOLVO	XC 90	2003	6	6C	1411.9	3371.2	1.32	65.2	27.9
4512	48	CHEVROLET	TRAILBLAZER	2002	6	50	354.4	3688.4	0.70	32.8	65.8
4690	48	FORD	EXPLORER	2003	6	6C	795.0	2491.8	0.97	0.0	28.0
4701	56	VOLVO	XC 90	2004	6	6C	1324.5	3128.3	1.27	56.7	37.5
5166	48	SUSUKI	SWIFT	2004		5	480.0		0.84	38.6	32.1
5203	48	TOYOTA	SIENNA	2004	3	5	725.0		0.44	36.6	28.7

Note: **Occupant Seat Position: Position 3**: Right rear seat; **Position 4:** Left rear seat; **Position 6:** Rear center seat. **HIII Dummy Size: 50**: Hybrid III 50th percentile male dummy; **5**: HIII 5th percentile female dummy, **6C**: HIII 6 year-old child dummy.

APPENDIX B

Full frontal rigid barrier crash tests with the same size dummy in the front and rear seats

Table B-1. Full frontal rigid barrier crash test at 56 km/h with restrained HIII 5F dummies in the driver and front outboard seats and restrained HIII 5F dummy in the rear outboard seat.

				HIC15			Neck Tension (N)			Nij			Chest Accel. (gs)			Chest Defl (mm)		
tstno	Make	Model	Year	driver	Front Pass	Rear Pass	driver	Front Pass	Rear Pass	driver	Front Pass	Rear Pass	driver	Front Pass	Rear Pass	driver	Front Pass	Rear Pass
5143	FORD	TAURUS	2004	152.2	289.9	533.8	1433.8	409.7	2378.3	0.44	0.28	0.89	37.5	42.0	42.0	29.1	19.1	32.8
5145	HONDA	ACCORD	2004	279.9	181.5	780.8	914.9	738.0	2774.6	0.30	0.22	0.94	32.1	38.3	48.6	26.0	28.8	47.2
5144	HONDA	ODYSSEY	2004	56.8	233.2	1052.6	917.6	918.9	3354.0	0.43	0.49	1.17	32.4	38.1	52.8	24.4	14.5	37.2
5210	CHEVROLET	AVALANCHE	2004	579.5	483.9	540.5	1727.7	1770.2	2220.6	0.74	1.03	1.32	58.6	53.6	41.5	44.4	14.9	42.2
5211	JEEP	LIBERTY	2004	232.4	527.1	659.0	1755.3	1369.4	2519.5	0.79	0.78	0.92	44.8	42.8	51.2	31.1	24.2	49.2

Table B-2. Full frontal rigid barrier crash test at 48 km/h with unrestrained HIII 50M dummies in the driver and front outboard seats and restrained HIII 50M dummy in the rear outboard seat.

				HIC15			Neck Tension (N)			Nij			Chest Accel. (gs)			Chest Defl (mm)		
tstno	Make	Model	Year	driver	Front Pass	Rear Pass	driver	Front Pass	Rear Pass	driver	Front Pass	Rear Pass	driver	Front Pass	Rear Pass	driver	Front Pass	Rear Pass
5216	TOYOTA	CAMRY	2004	116.51	138.12	637.57	1650.1	559.52	3517.28	0.343	0.36	0.94	52.79	41.051	ND	33.06	14.74	ND
5215	HONDA	ACCORD	2004	293.57	97.394	348.5	1383.2	615.36	2374.12	0.256	0.272	0.792	58.06	35.039	37.86	54.52	11.36	55.81
5212	HONDA	ODYSSEY	2004	57.742	160.58	388.42	1371.7	415.94	2446.94	0.297	0.29	0.702	41.99	39.293	43.74	48.24	9.782	38.6
5213	CHEVROLET	AVALANCHE	2004	193.3	124.29	355.5	1599.2	1632.3	3876.41	0.321	0.357	0.598	44.2	35.926	ND	47.51	8.951	ND
5158	JEEP	LIBERTY	2004	306.74	523.21	419.56	604.53	1342.5	2352.12	0.298	0.578	0.632	54.83	66.593	41.24	41.62	12.03	37.77

APPENDIX C

FARS data (1993-2003) of frontal crashes (excluding rollovers) involving passenger cars or LTVs of model years later than 1991 that were used in the double-paired comparison study.

Restrained Occupants

	Front Passenger Seat Occupants				Rear Seat Occupants	
	Belted and no air bag		Belt+ Air Bag		Belted	
age group	Driver F1	RF Pass F2	Driver F1	RF Pass F2	Driver F3	rear Pass F4
0-5	95	93	25	41	428	230
6-8	90	82	44	40	219	120
9-12	91	72	81	41	200	83
13-15	145	94	96	52	140	50
16-24	625	572	506	403	257	111
25-49	697	852	569	478	190	121
50-74	644	997	623	635	139	205
75+	308	723	290	545	37	162

Unrestrained Occupants

	Front Passenger Seat Occupants				Rear Seat Occupants	
	No Belt and no air bag		No Belt+ Air Bag		No Belt	
age group	Driver F1	RF Pass F2	Driver F1	RF Pass F2	Driver F3	rear Pass F4
0-5	48	65	11	46	72	54
6-8	59	49	17	40	113	50
9-12	71	35	19	18	117	48
13-15	123	101	58	46	160	93
16-24	823	926	523	490	622	413
25-49	753	903	368	394	287	236
50-74	239	354	111	144	50	65
75+	92	211	54	109	24	38