Update on the Effectiveness of High Retention Seats in Preventing Fatal Injury in Rear Impacts

DAVID C. VIANO and CHANTAL S. PARENTEAU

ProBiomechanics LLC, Bloomfield Hills, Michigan

Received 24 February 2014, Accepted 13 May 2014

Purpose: Starting in 1997, General Motors (GM) introduced high retention seats in new model vehicles to improve rear impact safety. The seat allowed the occupant to pocket into the seatback and had increased strength and improved head restraint coverage. The initial 4-year safety trends were evaluated using the 1991–2000 Fatality Analysis Reporting System (FARS). The reduction in odds of fatal injury was 30.4% (95% confidence interval [CI], 0.9–51.1, \(P < .05\)). This study updates the earlier one by adding 8 years of FARS data.

Methods: The 2001–2008 FARS was analyzed for rear impacts of 1992 to 2008 model year GM vehicles that transitioned to high retention seats. The number of fatal and nonfatal injuries to drivers and right-front passengers was determined in vehicles with baseline (earlier designs) and high retention seats. The odds ratio for fatal injury and the change in fatality risk were determined with \(\pm 95\%\) confidence intervals, \(z\)-statistic, and significance level. The data were further subdivided by passenger car, light truck (truck, SUV, and van) and driver-only crashes.

Results: Based on 9,570 drivers and right-front passengers in fatal rear impacts in 1991–2008 FARS data, the fatality risk was 16.6% (95% CI, 15.1–18.3) in vehicles with high retention seats and 27.1% (95% CI, 26.1–28.1) in vehicles with baseline seats. The reduction in odds for fatal injury was 46.3% (95% CI, 39.3–52.4) with high retention seats and it was statistically significant with \(z = 9.982, P < .0001\). The reduction in odds for fatal injury was similar for occupants in passenger cars at 45.4% (95% CI, 35.4–53.8) and light trucks, SUVs, and vans at 45.0% (95% CI, 28.8–57.5) using 2001–2008 FARS; however, the fatality risk was higher in passenger cars, at 23.1% (95% CI, 20.6–25.7), than in light trucks, SUVs, and vans, at 8.7% (95% CI, 7.0–10.7).

Conclusions: Vehicles with high retention seats significantly reduced the odds for fatal injury by 46.3% (95% CI, 39.3–52.4, \(P < .0001\)) in rear impacts compared to vehicles with earlier seat designs. The new generation of yielding seats has significantly improved occupant safety in rear impacts.

Keywords: rear crashes, fatalities, seats, injury risks

Introduction

During the early 1990s, research was conducted on occupant interaction with the seat in rear impacts (Viano 2002). This built on the understanding of the yielding seats for occupant protection in rear impacts (Blaisdell et al. 1993; Farmer et al. 2003; Partyka 1992; Prasad et al. 1997; Severy et al. 1976; Strother and James 1987). This led to the development of a quasistatic test (QST) of the seat, which loaded a Hybrid dummy rearward into the seatback to determine the load supported by and energy transferred as the seat yielded rearward (US Patent and Trademark Office [USPTO] 1995). The testing led to the finding that seats typically included structures across the seatback that increased stiffness of the seat as the strength increased. These early designs acted like an “ironing board” when loaded by the occupant and most of the yield was by seatback rotation. The stiff seatback also acted like a “ramp” that could allow the occupant to slide up with sufficient rotation of the seatback. These understandings led to the development of a high retention seat, which used a perimeter frame that removed the cross-seatback structures and allowed the occupant to “pocket” into the seatback (USPTO 1996). The pocketing provided low yield stiffness and increased occupant retention. The perimeter frame seats became known as high retention seats when they met certain specifications.

General Motors (GM) adopted requirements for high retention seats in February 1995 for use in all new models starting in 1997. Because GM purchased seats from many suppliers, they granted royalty-free access to the perimeter frame patent for use in GM vehicles. As a result, most seat suppliers became familiar with the background and functionality of high retention seats by 1995. In adopting new seat requirements, GM set 3 performance requirements in QST seat testing, including (1) a moment strength > 1,700 Nm (15,000 inlb) about the
H-point, (2) no separation of hardware causing 2 kN (450 lb) force drop and 10° change in seatback angle, and (3) seatback twist not to exceed 15° for seatback angles up to 60°. There was also a body engineering requirement that the floor attachments of the seat should withstand the higher loads supported by a high retention seat.  

Because high retention seats were stronger than earlier seats, a requirement was also placed on the head restraint. The height of the head restraint had to reach the B-plane (horizontal plane through the head center of gravity of the 95th percentile seated occupant) and the front surface had to be within 20 mm (0.79 in.) of the back-of-head ellipse for the 95th percentile occupant. The back of head ellipse is based on the eye ellipse that represents eye locations for different percentile drivers. It is described in SAE J941 (Manary et al. 1998; Reed 2011; Society of Automotive Engineers [SAE] 2008). These geometric requirements on the head restraint typically meant that high retention seats had a head restraint that was 7.6 cm (3 in.) higher and 6.4 cm (2.5 in.) more forward than earlier designs. Because high retention seats allowed the occupant to pocket into the seatback at low load, the head and neck got early support in a rear impact. With support of the head, neck, and torso, the force on the occupant could be increased with minimal injury risks for a normally seated occupant.  

The first high retention seats were introduced in the 1997 Pontiac Grand Prix, 1997 Chevrolet Malibu, and other 1997 models. The GM vehicle fleet was transitioned to high retention as new models were developed. The transition occurred from 1997 to 2004. Delphi Corporation developed the first high retention seats and owned the patent for the perimeter frame seat or high retention seat (USPTO 1995). It was a subsidiary of GM that provided component parts for vehicles. Lear, JCI, Faurecia, and Magna also developed high retention seats for GM. GM maintained only one-year exclusivity on the high retention seat and thereafter encouraged Delphi to sell seats to other manufacturers. In 1998, Delphi sold its seat business to Lear Corporation. The sale included all intellectual property for seats, including the perimeter frame patent. Today, high retention seats are widely used in motor vehicles by GM, Chrysler, Ford, Nissan, Honda, and other manufacturers.  

In 2003, 27 high retention seats had been introduced in new GM models. The QST results for the high retention seats were compared to baseline (earlier) GM seats. Table 1 summarizes the results, which have been divided into conventional high retention seats using dual recliners and ABTS (all belts to seat) seats (Viano 2003c). The averages are reported with ± one standard deviation. ABTS seats typically use a single recliner but are stronger because the shoulder belt is integrated into the seatback. The high retention seat with dual recliners supported more than twice the moment (104% higher) as earlier designs and withstood 102% more load. These increases were achieved with only a small increase in seat stiffness (4% higher). The ABTS seats supported nearly twice the moment (199%) and withstood 159% more load with a small increase in stiffness (5% higher). Both types of high retention seats substantially increased the energy transfer capability to an occupant in a rear crash compared to earlier seat designs. Equally important was that high retention seats maintained the low stiffness of baseline seats. Maintaining a low stiffness is fundamental to lowering whiplash and more serious spinal injury risks (Viano 2003a, 2008).  

The main features of high retention seats are a perimeter frame that allows the occupant’s hips and lower back to pocket into the trim between the side frames of the seatback (USPTO 1996; Viano 2002). The pocketing allows for a low stiffness even as the strength of the frame is substantially increased. A flexible strap is added into the seatback to deform and absorb energy during occupant loading. The pocketing and greater strength increase occupant retention in the seat during severe rear impacts. Belted and unbelted occupants get higher retention by pocketing into the seatback. The pocket also reduces ramping and promotes pelvic drop, which lowers the head and neck with respect to the seatback and head restraint. High retention seats include a higher and more forward head restraint to support the neck and lower forces associated with whiplash.  

In 2003, the 1991–2000 Fatality Analysis Reporting System (FARS) was analyzed to study the initial field performance of high retention seats in fatal rear impacts (Viano 2003b). Based on 4 years of high retention seat use, the odds of fatal injury were reduced 30.4% (95% confidence interval [CI], 0.9–51.1, P < .05) for drivers and right-front passengers in vehicles with high retention seats. Though the initial trend was statistically significant, more years of data were needed to increase the understanding of the field performance of high retention seats. This study updated the earlier analysis by adding 8 years of field data from the 2001–2008 FARS. This provided a larger sample of crashes to determine the safety performance of high retention seats.  

**Methodology**

**FARS Data**

FARS (www.nhtsa.gov/FARS) is a census database that includes motor vehicle crashes resulting in the death of a vehicle occupant or nonmotorist within 30 days of the crash. FARS contains information on each fatal crash on U.S. roads. There are more than 100 coded elements characterizing the crash, vehicles, and people involved. In this study, the data were obtained for calendar years 2001–2008 and the number of fatally and nonfatally injured drivers and right-front passengers was determined. Occupants involved in rear crashes with GM (18 ≤ MAKE < 24) light vehicles (0 < BODY_TYP < 50) and model year 1992 to 2008 were determined. There were 35 passenger cars and 22 SUVs, vans, or pickup trucks in the analysis, with 15 passenger cars and 15 SUVs, vans, or pickup trucks with high retention seats. Table A1 (see online supplement) lists the vehicles included in the study. Vehicles were selected by make and model to compare the analysis to the earlier study with 1992–2000 FARS (Viano 2003b). A separate analysis was carried out for Saab vehicles (MAKE = 47).

**Definitions**

Rear crashes were defined as the PRINCIPAL-IMPACT (IMPACT2) variable equal to 5, 6, and 7 o’clock. Rollovers
were excluded (ROLLOVER ≤ 0). The following refined the search:

- Drivers were defined using the person type (PER_TYP = 1) variable.
- Single drivers were defined using the person type (PER_TYP = 1) and single occupancy (OCUPANTS = 1) variables. The nonfatal, single driver cases involved multivehicle impacts where a death occurred in the other vehicle or road user.
- Right-front passengers were defined using the seating position (SEAT_POS = 13) variable.
- Fatality was defined using the injury severity variable (INJ_SEV = 4).
- Nonfatalities were taken by subtracting the number of fatalities from the total exposed.

**Analysis**

The odds for fatal injury was determined by taking the number of occupants with fatalities and dividing by the number of nonfatally injured occupants. The risk for fatality was determined by taking the number of occupants with fatalities and dividing by the number of exposed occupants. The significance of the change in odds and risk between vehicles with high retention and baseline seats was determined using MedCalc statistical software (Ver. 13.0.2, Ostend, Belgium; www.medcalc.org). This included the z-statistic and \( P \) value for the change in odds and relative risk (Sheskin 2004). The 95% CI was determined for the change in the odds and risk for fatality using VassarStats statistical computation with a correction for continuity (Newcombe 1998).

**Results**

Table 2 summarizes the number of drivers and right-front passengers involved in fatal rear crashes in high retention and baseline seats. The number of nonfatally injured occupants. The risk for fatality was 16.6% (95% CI, 15.1–18.3) in vehicles with high retention seats and 27.1% (95% CI, 26.1–28.1) in vehicles with baseline seats. The reduction in odds for fatal injury was 46.3% (95% CI, 39.3–52.4). The reduction was statistically significant with \( z = 9.982, P < .0001 \). The reduction in relative risk was 38.6% (95% CI, 32.1–44.4) with \( z = 9.598, P < .0001 \) (see Table A2, online supplement, for the change in odds and risk).

There was a 24.5% reduction in fatality risk from 21.5% (95% CI, 16.0–28.1) in the earlier period to 16.2% (95% CI, 14.7–17.9) in the current period with a high retention seat. There was a 9.9% reduction in fatality risk with baseline seats from 28.2% (95% CI, 26.7–29.7) in the earlier period to 26.1% (95% CI, 24.7–27.5) during the current study period. There was a slight downward trend with time.

Table 3 subdivides the 2001–2008 FARS data by passenger cars and light trucks (trucks, SUVs, and vans). The reduction in odds of fatal injury was similar for passenger cars (45.4%; 95% CI, 35.4–53.8) and light trucks (45.0%; 95% CI, 28.8–57.5). However, the risk in passenger cars was greater than that in light trucks, irrespective of the type of seat used in the vehicle. High retention seats provided a similar reduction in odds of fatal injury in all vehicle types; however, light trucks have a lower overall risk of fatal injury in rear impacts. The fatality risk in light trucks, SUVs, and vans was 8.7% (95% CI, 7.0–10.7) and it was 23.1% (95% CI, 20.6–25.7) in passenger cars.

**Table 1. QST test results with high retention seats (modified from Viano 2003c)**

| # Tests | Dual recliner | % Diff | ABTS | % Diff | Foreign | Domestic |
|---------|---------------|--------|------|--------|---------|----------|
| 29      | 19            | 8      | 18   | 8      | 935     | 395      |
| H-point moment (Nm) | 1,092 | 2,232 | 104% | 3,262 | 199% | 1,384 | 958 | 147 |
| ±189    | ±393          | ±764   | ±393 | ±147   |
| Angle up to 1,700 Nm (°) | 56 | 39 | −30% | 30 | −46% | 56 | 60 |
| ±12     | ±14           | ±6     | ±10  | ±7     |
| Energy @ 60° (J) | 1,274 | 3,221 | 153% | 4,700 | 269% | 1,669 | 1,214 |
| ±390    | ±651          | ±1,407 | ±546 | ±586   |
| Peak force (kN) | 6.6 | 13.3 | 102% | 17.1 | 159% | 7.8 | 5.1 |
| ±1.3    | ±2.5          | ±4.9   | ±2.0 | ±1.4   |
| Stiffness (N/mm) | 24.7 | 25.8 | 4% | 26.0 | 5% | 31.7 | 23.2 |
| ±4.9    | ±4.3          | ±2.6   | ±7.0 | ±5.6   |

**Table 2. Driver and right-front passengers involved in fatal rear crashes in high retention and baseline seats**

|       | High retention | Baseline seats | Odds reduction | −95% | +95% |
|-------|----------------|----------------|----------------|------|------|
| 1991–2000 FARS (original study) | Fatal | 41 | 988 | 30.4% | 0.9% | 51.1% |
|       | Nonfatal | 150 | 2,516 | \( z = 2.011, P = .0443 \) |      |      |
|       | Risk | 21.5% | 28.2% |      |      |      |
| 2001–2008 FARS (current study) | Fatal | 337 | 989 | 45.1% | 37.1% | 52.2% |
|       | Nonfatal | 1,743 | 2,806 | \( z = 8.570, P < .0001 \) |      |      |
|       | Risk | 16.2% | 26.1% |      |      |      |
| 1991–2008 FARS | Fatal | 378 | 1,977 | 46.3% | 39.3% | 52.4% |
|       | Nonfatal | 1,893 | 5,322 | \( z = 9.982, P < .0001 \) |      |      |
|       | Risk | 16.6% | 27.1% |      |      |      |
Table 3. Driver and right-front passengers involved in fatal rear passenger car and light truck (truck, SUV, and van) crashes in high retention and baseline seats

|                | High retention | Baseline seats | Odds reduction | −95%   | +95%   |
|----------------|----------------|----------------|----------------|--------|--------|
| 2001–2008 FARS (current study) |                |                |                |        |        |
| Passenger cars |                |                |                |        |        |
| Fatal          | 251            | 736            | 45.4%          | 35.4%  | 53.8%  |
| Nonfatal       | 836            | 1,339          | z = 7.085, P < .0001 |
| Risk           | 23.1%          | 35.5%          |                |        |        |
| SUVS/pickups/vans |            |                |                |        |        |
| Fatal          | 86             | 253            | 45.0%          | 28.8%  | 57.5%  |
| Nonfatal       | 907            | 1,467          | z = 4.540, P < .0001 |
| Risk           | 8.7%           | 14.7%          |                |        |        |

Table 4 shows crashes involving only a driver in a passenger car or light truck (truck, SUVs, and vans). There was a greater reduction in odds of fatality in passenger cars that transitioned to high retention seats than in light trucks (49.8% versus 40.1%). However, the risk of fatality in driver-only crashes was higher than in crashes involving more than one occupant. The 2001–2008 FARS data were further subdivided by driver and right-front passenger in passenger cars and trucks, SUVs, and vans.

Saab transitioned to high retention seats in the 1997 9–3 and 9–5. The seats included a self-aligning head restraint (Viano and Olsen 2001). There were only 4 fatalities in vehicles with high retention seats and the fatality risk was 22.2% (95% CI, 7.4–48.1) compared to 3 fatalities in earlier model vehicles with a fatality risk of 37.5% (95% CI, 10.2–74.1). The reduction in odds was 53.4% with high retention seats but the change was not statistically significant (z = 0.80, P = .42) because of minimal field data.

Figure 1 shows data from rearward loading of seats by a crash test dummy in a QST procedure (USPTO 1995). Only dual-recliner, high retention seats are plotted. They have an average strength of F = 13.3 ± 2.5 kN and stiffness of k = 25.8 ± 4.3 kN/m. The high retention seats supported higher loads than the benchmark of foreign seats tested during the development of the perimeter frame seat. Also shown is a trend for increasing stiffness with stronger benchmark seats (F = 0.20(k + 9.98), R = 0.76).

Discussion

This study extends the time period for evaluation of the field performance of high retention seats from the initial 4 years of FARS data from 1997 to 2000 (Viano 2003b) to 12 years of data from 1997 to 2008. The performance of the high retention seats was compared to earlier seat designs (baseline) used in similar GM vehicles.

Overall, high retention seats are effective in lowering the odds of fatal injury in rear impacts. There was a 46.3% (95% CI, 39.3–52.4) reduction in odds that was statistically significant (z = 9.982, P < .0001). The reduction in risk was 38.6% (95% CI, 32.1–44.4) and this was statistically significant (z = 9.598, P < .0001). The safety performance of high retention seats was similar in passenger cars and light trucks, SUVs, and vans (45.4% versus 45.0% reduction in odds).

High retention seats provide a design that allowed the strength of a motor vehicle seat to increase without increasing the stiffness of the seatback. Maintaining a low stiffness of the seatback is fundamental to lowering the risk of whiplash and more severe spinal injuries (Viano 2002, 2003, 2008). Table 1 shows that the baseline GM seats had lower strength and energy transfer capabilities than high retention seats (Viano 2003c). Figure 1 shows the increased strength of high retention seat without an increase in stiffness. There was a trend for increasing seat stiffness as the seat strength increased in the benchmark of foreign seats. Stiffer seats cause early loading of an occupant’s torso in a rear impact and early forces of the neck. This increases the risks for spinal injury. High retention seats include a perimeter frame seatback. This provides an open area for the occupant to displace rearward between...
the side frames and pocket into the seatback. The approach allows the strength of the seat to be increased while maintaining a low stiffness.

High retention seats involved a design change from earlier seats. The concept of pocketing an occupant into the seatback allowed stronger seats while maintaining support of the head, neck, and torso as load increased on the occupant. The goal was to minimize relative movement of the spine. High retention seat concepts are widely used today and provide a significant reduction in fatality risks and the odds of fatal injury in rear impacts.

Limitations

There are many limitations to this type of field accident study. For example, the field accident analysis is based solely on FARS. The crashes include at least one fatality to be entered into FARS. The field data are thus limited to fatal crashes and do not address the potential effectiveness of high retention seats in reducing the risk for serious and lesser injuries. The analysis did not include all GM vehicles. The vehicles were selected based on the prior study of FARS (Viano 2003b). That study selected vehicles with baseline seats that transitioned to high retention seats or were discontinued. The nonfatal counts were determined by subtracting the number of fatal occupants from the number of exposed occupants. The results do not account for occupants with unknown fatality status.

In addition, FMVSS 301 (NHTSA 2003) was revised to a more severe impact using a lighter offset deformable barrier (weighing 3,015 lb) but at a higher test speed of 50 mph and 70% offset. The revised standard was phased in over 3 years beginning September 1, 2006, according to the following production percentages: 40%, 70%, and 100%. Vehicles manufactured after September 1, 2008, had to comply. Some of the newer vehicles with high retention seats may have had changes in rear structures to address the new requirements. These changes would have improved rear impact safety and would be factored into the effects reported for high retention seats. However, the fatality risk was determined per year from 2001 to 2008 for high retention and baseline seat vehicles. It showed a downward trend in risk for both groups. Because the baseline vehicles would not have been designed to meet the revised FVMSS 301, the parallel in downward risk seemed to indicate no specific effect in the high retention seat vehicles.

Supplemental Materials

Supplemental data for this article can be accessed on the publisher's website.

References

Blaisdell DM, Levitt AE, Varat MS. Automotive Seat Design Concepts for Occupant Protection. Warrendale, PA: Society of Automotive Engineers; 1993. SAE 930340.

Farmer CM, Wells JK, Lund AK. Effects of head restraint and seat redesign on neck injury risk in rear-end crashes. Traffic Inj Prev. 2003;4(2):83–90.

Manary M, Flannagan CA, Reed MP, Schneider LW. Development of an Improved Driver Eye Position Model. Warrendale, PA: Society of Automotive Engineers; 1998. SAE 980012.

Newcombe RG. Two-sided confidence intervals for the single proportion: comparison of seven methods. Stat Med. 1998;17:857–872.

NHTSA. FMVSS 301 Upgrade. Final Regulatory Evaluation. NHTSA-03-16523-2, November 2003.

Partyka S. Summary of Safety Issues Related to FMVSS 207, Seating Systems. Prepared by the NHTSA, Department of Transportation; 1992.

Prasad P, Kim A, Weerappuli DPV, Robert V, Schneider D. Relationship Between Passenger Car Seat Back Strength and Occupant Injury Severity in Rear End Collisions: Field and Laboratory Studies. Warrendale, PA: Society of Automotive Engineers; 1997. SAE 973343.

Reed MP. An Eyellipse for Rear Seats with Fixed Seat Back Angles. Warrendale, PA: Society of Automotive Engineers; 2011. SAE 2011-01-0596.

Severy DM, Blaisdell DM, Kerkhoff JK. Automotive Seat Design and Collision Performance. Warrendale, PA: Society of Automotive Engineers; 1976. SAE 760810.

Sheskin DJ. Handbook of Parametric and Nonparametric Statistical Procedures. 3rd ed. Boca Raton, FL: Chapman & Hall/CRC; 2004.

Society of Automotive Engineers. Motor Vehicle Drivers’ Eye Locations. Surface Vehicle Recommended Practices. Warrendale, PA: Society of Automotive Engineers; 2008. SAE J941.

Strother CE, James MB. Evaluation of Seat Back Strength and Seat Belt Effectiveness in Rear End Impacts. Warrendale, PA: Society of Automotive Engineers; 1987. SAE 872214.

US Patent and Trademark Office. Seatback load applying device. US Patent 5 379 646, January 10, 1995.

US Patent and Trademark Office. Vehicle seat with perimeter frame and pelvic catcher. US Patent 5 509 716, April 23, 1996.

Viano DC. Role of the Seat in Rear Crash Safety. Warrendale, PA: Society of Automotive Engineers; 2002. SAE R-317:1-491.

Viano DC. Effectiveness of High-Retention Seats in Preventing Fatality: Initial Results and Trends. Warrendale, PA: Society of Automotive Engineers; 2003b. SAE 2003-01-1351.

Viano DC. Initial Results and Trends. Warrendale, PA: Society of Automotive Engineers; 2003c. SAE 2003-01-0173.

Viano DC. Effectiveness of High-Retention Seats in Preventing Fatality: Initial Results and Trends. Warrendale, PA: Society of Automotive Engineers; 2003b. SAE 2003-01-1351.

Viano DC. High Retention Seat Performance in Quasistatic Seat Tests. Warrendale, PA: Society of Automotive Engineers; 2003c. SAE 2003-01-0173.

Viano DC. Seat design principles to reduce neck injuries in rear impacts. Traffic Inj Prev. 2008;9:552–560.

Viano DC, Olsen S. The effectiveness of active heads restraint in preventing whiplash. J Trauma. 2001;51:959–969.