

Relationship between Seatback Stiffness/Strength and Risk of Serious/Fatal Injury in Rear-Impact Crashes

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ABSTRACT

To determine the relationship between seatback stiffness or strength and the likelihood of serious/fatal injury for drivers and rear seat occupants in rear-impact crashes, analyses were performed using 1995-2006 police-reported crash data from eleven states. Seatback stiffness and strength data was included for 29 different seatback designs used in 40 vehicle models (model years 1995-2006). Results indicate there is no statistically significant relationship between seatback stiffness or strength and the risk of serious/fatal injury in rear-impact crashes. Factors shown to have statistically significant effect on the likelihood of serious/fatal injury in rear-impact collisions include occupant age, gender, and alcohol impairment; vehicle type; and vehicle mass ratio.

INTRODUCTION

The role of seatback stiffness/strength in mitigating serious/fatal injuries in rear-impact crashes has been the subject of numerous studies for the past three decades. A comprehensive review of the earlier seatback-related research and rulemaking activity can be found in a 1991 paper by Warner et al., and more recent studies are summarized in papers by Prasad et al. (1997) and Viano et al. (2007).

In the United States, Federal Motor Vehicle Safety Standard (FMVSS) No. 207, which specifies the strength

requirements for vehicle seatbacks, went into effect for passenger cars in 1968 and was later extended to all light vehicles [Code of Federal Regulations, 2007]. FMVSS 207 requires that all forward-folding seatbacks should be able to withstand:

- Forward load of 20 times the weight of the seatback;
- Rearward static moment of 3,300 lb-in. applied by a force at the uppermost cross member of the seatback frame.

Since the introduction of FMVSS 207, vehicle seatbacks have always by far exceeded the strength requirement set by the standard. However, manufacturers have also tried to make the seatbacks yielding enough to account for occupant dynamics and minimize injury exposure in both frontal and rear-impact crashes. The US National Highway Transportation Safety Administration issued a Request for Comments [NHTSA, 1989a], granting consideration to several petitions to amend FMVSS 207, including one that would increase the minimum strength requirement for seatbacks by about 17 times (to 56,000 lb-in.). Multiple research groups took part in evaluation of the latter proposal (see Docket No. 89-20 [NHTSA, 1989b] for full list of comment submittals). The arguments presented during the rulemaking comment period can be summarized as a debate between allowing seats to deform in rear impact collisions and limiting or eliminating this deformation.

In 2004, concluding more than a decade of research efforts, NHTSA acknowledged that “improving seating system performance is more complex than simply increasing the strength of the seat back” and that “further study is needed to make a definitive determination of the relative merits of different potential rulemaking approaches in this area”.

This study uses police-reported crash data from eleven states to provide a comprehensive statistical analysis of the real world performance of seatbacks with differing strengths and stiffnesses in rear-impact crashes.

METHODOLOGY

The study was carried out in three stages. First, 29 vehicle seatback designs used in 1995-2006 model-year passenger cars and light trucks were tested, and stiffness and strength data using several metrics was obtained. Then the state accident databases were searched to obtain crash records for 1995-2006 calendar-year rear-impact crashes involving 1995-2006 model-year vehicles for which seatback stiffness and strength had been measured. Finally, logistic regression analyses were performed and the contributions of different factors associated with odds of serious injury/fatality were evaluated.

The study was restricted to *belted* drivers and *belted* rear seat passengers, and the following selection criteria were used:

- Each crash involved exactly two vehicles.
- The impact to the *struck* vehicle was coded as occurring in the 5, 6, or 7 o'clock angular interval (rear impact), and the impact direction for the *striking* vehicle was in the 11, 12, or 1 o'clock interval (frontal impact).
- The *struck* vehicle did not roll over.
- The crash did not involve vehicle fire.

Only the struck vehicle occupants were considered in this analysis, and hence only the struck vehicle seatback parameters were required to be available in the selection process.

For the rear seat occupants, an additional selection requirement was the presence of a belted occupant in the corresponding front seat. Thus, while left and center rear seat passengers (being behind the driver) were always included, right rear seat passengers were included in the selection only if the right front passenger seat was occupied.

VEHICLE DATA – To obtain consistent and verifiable seatback stiffness and strength data, 29 different seatback designs, used in 40 vehicle models, were tested as part of this study. The vehicle models tested for seatback stiffness or strength are summarized in Appendix A, along with seat integrated restraint system (SIRS) availability.

Test Setup – A “modified FMVSS 207 test” was performed for this study. The test protocol (which has been used in some form since the mid-1970s, and by the testing firm, Collision Research & Analysis, Inc., since 1987) uses a body block attached by cables to a hydraulic ram, which provides the pull (simulating a body forced against the seat at impact). The body block is positioned at an elevation of 14 inches above the seat cushion. A portion of the vehicle floor pan is also attached to the test fixture, so that the test can load the seat through its native attachments. The test seats were chosen from a wrecking yard, from subject vehicles that were each verified not to have been involved in an impact, rear-end loading environment over its lifetime.

Test Procedure – Prior to the test, the seat is positioned mid-track in the full upright recliner position (or approximately 22 to 23 degrees if the first upright recliner position is too vertical). The rearward pull is conducted horizontal to the fixture until one of the following prescribed termination criteria is reached:

- The backrest reaches an angle of approx. 45 to 50 degrees from vertical.
- The recliner mechanism or seat structural member(s) can no longer support a load.
- The load does not increase with displacement.
- The body block migrates more than several inches up the backrest during the pull.

Stiffness and Strength Measurements – Measurements were made with a load cell mounted at the end of the hydraulic ram, a string pot (for displacement), and digital inclinometers on both inboard and outboard backrest frames. All data was gathered with a data acquisition system, and five to eight video cameras documented the tests.

CRASH DATA – One of the primary sources of collision information is police-reported accident data maintained by state agencies. This study utilized data from the states of Alabama (1995-2006), Arkansas (1995-1996), Florida (1995-2005), Georgia (1995-2005), Idaho (1995-2006), Illinois (1996-2003), Maryland (1995-2006), Missouri (1995-2005), Nebraska (2000-2006), North Carolina (1995-2005), and Pennsylvania (1995-2005). These states are frequently used by auto safety researchers, including NHTSA, to evaluate the field performance of vehicles, since these states have accurate coding of vehicle identification numbers (VINs), crash type (rollover/non-rollover), collision impact direction, and occupant information. [Alabama, Nebraska, and Missouri do not provide complete demographic information for rear seat occupants and thus were used only for the injury risk analysis for drivers.]

The police reports, from which the state accident data files are compiled, code occupant injury on a five-point scale known as KABCO, where K = killed, A = incapacitating injury, B = non-incapacitating injury, C = possible injury, and O = no injury. To determine the

injury falls on the KABCO scale, police officers rely on the definitions provided by the 1976 National Safety Council manual on Classification of Motor Vehicle Traffic Accidents (1976). This injury coding scale is different from the AIS (Abbreviated Injury Scale) system used by NHTSA which is based on a life-threatening scale. Both AIS coding and KABCO coding use different injury classification schemes and therefore are not directly comparable.

Table 1 shows the numbers of belted drivers and belted rear seat occupants included in the study, and Figure 1 shows the age distributions of the occupants.

Table 1. Number of Belted Drivers and Belted Rear Seat Occupants in Rear-Impact, Non-Rollover Crashes

Seat Position	Total		Percent Seriously (K/A) Injured
	All Belted	Belted K/A Injured	
Driver	284,450	1,923	0.68%
Rear Seat	34,461	157	0.46%
Rear Seat, excluding CSS	27,903	141	0.51%

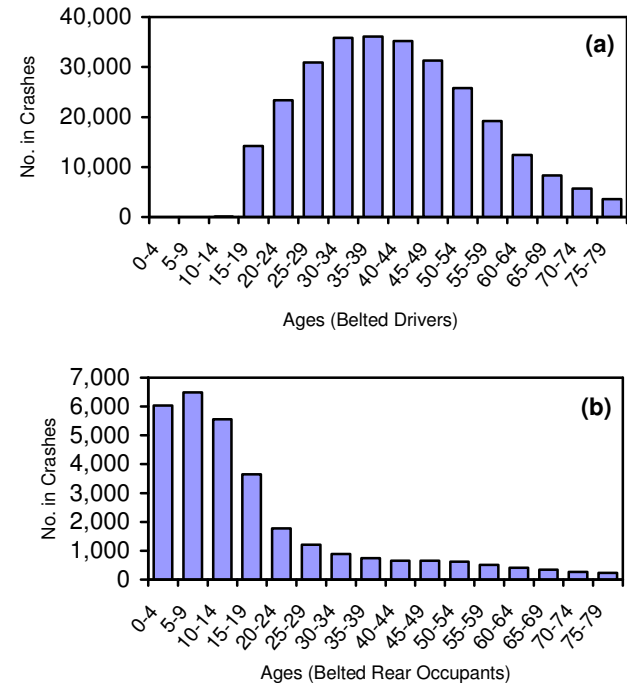


Figure 1. Age Distributions for (a) Belted Drivers and (b) Belted Rear Seat Occupants in Rear-Impact Crashes

LOGISTIC REGRESSION – Logistic regression is a generalization of a multiple regression method for data with a dichotomous outcome variable, which permits analysis at a case-by-case level using the maximum likelihood fit. For this study, logistic regression was used to model odds of serious/fatal (K/A) injury.

To properly measure the association between the injury level and a vehicular factor such as seatback stiffness or strength, the effects of other factors that might also influence injury outcome must be explored concurrently. Logistic regression facilitates that exploration.

The logistic procedure, PROC LOGISTIC, integrated within the SAS (Statistical Analysis System) statistical analysis software was used to perform the logistic model fit to the data [Allison, 1999].

Logistic regression models were developed for three groups of occupants: belted drivers; *all* belted rear occupants, including those in child safety seats; and belted rear occupants, *excluding* those in child safety seats. As is typically done in logistic regression analyses, both the parameter estimates and a hypothesis test of the significance of the parameter estimates being different from zero were examined (zero parameter estimates indicate there is no association between the predictor and the outcome variables). The commonly accepted standard significance threshold of 0.05 was used.

The key *vehicle* variables examined were: vehicle make/model/year (derived from VIN coding) to identify the seatback parameters, vehicle body type, and vehicle weight. The primary *occupant* variables considered were: injury severity, restraint use, age, gender, and alcohol involvement. The *collision* variables considered were: number of vehicles involved in the crash (limited to exactly two vehicles in each crash), type of crash (rear, non-rollover) and collision configuration (car-to-car, truck-to-car, car-to-truck, truck-to-truck).

A mass term was used to better address vehicle compatibility:

$$\log \frac{m_{Striking}}{m_{Struck} + m_{Striking}}$$

Two different metrics for seatback stiffness/strength were used in the logistic fit (one at a time): 1) linear stiffness (lb/in) up to strength, measured as 10 inches of horizontal displacement, and 2) the moment about the seatback reference point, which could produce up to 10 inches of rearward displacement. In addition, the presence of SIRS as standard equipment was also considered in the analysis since the availability of SIRS is typically associated with stiffer/stronger seatback.

Logistic models were developed for the following belted occupant groups: drivers; all rear seat occupants; left rear occupants; left rear and center rear seat occupants; all rear seat occupants, excluding CSS; left rear seat occupants, excluding CSS; and left rear and center rear seat occupants, excluding CSS. For each occupant group, linear stiffness or max moment by 10 inches were included in the logistic models for stiffness measurements.