STANDARD & INTEGRATED RESTRAINT FIRST ROW SEAT PERFORMANCE IN REAR-IMPACT CRASHES

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Paper Number 11-0381

ABSTRACT

In rear impact crashes, seats provide basic occupant restraint. Using 11 years of NHTSA's NASS CDS data (1997-2007), the performance of first row standard and integrated restraint seats were compiled and contrasted to each other and also to belt restraint performance in frontal crashes. This paper defines integrated restraint (IR) seats as those where the shoulder belt anchor is attached to the seat back frame instead of the vehicle body. IR seats have strengthened frames designed to support the frontal crash belt loads. NHTSA data indicates that more than 500 make/model/model year vehicles have an occupant position with an integrated restraint seat. In this study, vehicles with IR seats were identified using NHTSA data and confirmed by individual photographic review.

The median Delta V value for occupants in rear impact crashes was about 20 kph (12 mph); the same as for occupants in frontal crashes. In rear crashes, standard seats deformed or failed (per NHTSA coding) 25% of the time. In frontal crashes, seat belts (which comprise the basic frontal restraint system) failed 0.36% of the time (rate 69 times lower). The median Delta V for all reported seat failures and deformations was 27 kph (16.2 mph). Occupants reached MAIS= 3 (at least one serious injury) at half the Delta V level in rear crashes (19 kph) compared to belted occupants in frontal crashes (38 kph).

The maximum Abbreviated Injury Scale (MAIS) levels were also compiled for integrated versus standard seats. No occupant in an IR seat in a rear crash reached more than MAIS= 1. 50% of all occupants in rear crashes in standard (non-IR) seats experienced injury(s) resulting in MAIS=3 by a Delta V of 19 kph. IR seats were found to significantly reduce the rate of injury (MAIS>0) in rear impact crashes compared to standard seats (p=.05).

INTRODUCTION

In a rear impact crash the primary restraint device is the occupant's seat.(1) In a front impact crash, the primary restraint device is the 3 point belt (which may be supplemented by an airbag). A literature review indicates that this paper may be the first to compare the effectiveness of Integrated Restraint (IR) and non-IR (standard) seats using contemporary data. This study uses the term “standard” to mean “non-IR seat”.

Prior Studies - Prior studies the authors reviewed do not address the focus of this paper. Some of the studies used State, FARS or GES data. None of these datasets contain Delta-V, NASS-AIS injury codes, or seat deformation or failure codes. The injury scaling system used in FARS, GES and State databases is the police KABCO injury system. This system does not reliably identify non-fatally injured occupants with NASS-AIS severity scores of 3 to 6.(2) The papers using the above data sources do not correct for these confounding factors. Several papers do use NASS-CDS (like our study), which does include Delta V, NASS-AIS codes and Seat Deformation/Failure codes. However none of the papers used the available CDS seat Deformation /Failure information. None of the referenced papers used the comprehensive NHTSA list of vehicles with integrated restraint seats. Some of the papers use data that is now up to 28 years old, involved rollovers or were based on experimental data and contained no field data at all.(3,4,5,6,7,8,9,10,11, 12,13,14) At least one study found that standard seats are as effective in reducing injuries in rear crashes as available restraints are in frontal crashes, a premise explored in this paper using more current data. That paper also found that stiffer seats (such as Cab-reinforced) increase injuries in rear impact crashes.(3)

Purpose - This paper employs NHTSA NASS-CDS field data to compare the performance of standard, IR and Cab-reinforced first row outboard occupant seats in rear impact crashes.(15, 16) Cab-reinforced seats are those fitted to pickup trucks where the rear cab bulkhead limits the rearward deflection of the seat back. The performance of these types of seats in rear impact crashes is compared with

occupants protected by standard restraints in equivalent frontal crashes. This same approach was also used in reference (3). The purpose of this paper was to use field data to examine if:

- Standard seats in rear impact crashes offered similar performance to the restraints available in frontal crashes of similar severity.
- IR seats were associated with reduced or increased injury risk in rear impact crashes
- Cab-reinforced (low yielding) seats were associated with reduced or increased injury risk in rear impact crashes.
- Seat performance in terms of deformations or failures varied by Make or Model.

A number of these points are raised in previously published papers.(3,4,5,6,7,8,9,10,11,12,13,14)
We examined adult (age >12) front outboard occupants, consistent with NHTSA definitions.(17) We did not include children in this study because of the complexity involved in eliminating the confounding effects of airbag caused injuries involving forward facing and rear facing child seat installations in passenger airbag equipped vehicles.(17)

MAIN BODY

Methodology

We used crash data from eleven recent years (CY 1997-2007) of the National Highway Traffic Safety Administrations' (NHTSA), National Automotive Sampling System (NASS), Crashworthiness Data System (CDS). NASS-CDS is a national probability sample of approximately 4,000 crashes in which a late model year light passenger vehicle sustained sufficient damage to require towing from the scene. Starting in 1996, NHTSA defines "late model year" as the four (+1 / -2) model years around the sampling calendar year.(18)
To identify vehicles with IR seats, we used a NHTSA supplied list of more than 500 make/model/model year vehicles with integrated restraints in one or more seating locations.(19) The vehicles on this list may have front row IR seats, a second or higher row seating position with an IR (such as found in the center seat position in some vehicles with split or fully folding rear seatbacks), or both. The methodology we employed with this list to identify <u>front</u> outboard IR seats is described later in this section.
CDS contains a variable called "Seat Performance" (OA54). In this variable NHTSA coders list which seats "deformed" or "failed" (NHTSA's terms). We used the NHTSA categories of deformation and failure.

Datasets

Using the 11 years of NASS-CDS data we collected two datasets with similar properties – one for Rear Impacts and one for Frontal Impacts. These datasets were used in all subsequent analyses, and are described below.

<u>Front Impacts</u> Information was collected on vehicles and their occupants that were struck in the front. The vehicles that were impacted in the front included the following. A driver must be present in the vehicle; the Delta V reconstruction must be completed for the vehicle and the Delta V results (in NHTSA's opinion), were reasonable compared to the damage observed on the vehicle (this selection provides the most reliable Delta V data); the vehicle did not rollover or catch fire; the primary general area of damage on the vehicle was the front, and the secondary area of damage was either blank (no 2nd damage) or also the front; the principle direction of force was from the front between 350 and 10 degrees. For the identified crashes and vehicles, the following information was collected: the crash year, primary sampling unit (PSU) and national weighting factor, the vehicle number, make, model, body type and wheelbase. Data was also collected for adult (age >12) occupants in the front row outboard seating positions including; the occupant number, manual and automatic belt use, manual and automatic belt failure data, seat performance data, occupant NASS-AIS MAIS (Maximum Abbreviated Injury Severity), and headrest information. This set of 11 years of data is referred to as the Frontal Impact Dataset.

<u>Rear Impacts</u> Information was collected on vehicles and their occupants that were struck in the rear. The selection criteria used for the vehicles that were impacted in the rear included the following. A driver must be present in the vehicle; the Delta V reconstruction must be completed for the vehicle and the Delta V results (in NHTSA's opinion), were reasonable compared to the damage observed on the vehicle (this selection provides the most reliable Delta V data); the vehicle did not rollover or catch fire; the primary general area of damage on the vehicle was the rear, and the secondary area of damage was either blank (no 2nd damage) or also the rear and the principle direction of force was from the rear between 170 and 190 degrees. For the identified

crashes and vehicles, the following information was collected. The crash year, PSU and national weighting factor, the vehicle number, make, model, body type, wheelbase. Data was also collected for adult (age >12) occupants in the front row outboard seating positions; including the occupant number, manual and automatic belt use, manual and automatic belt failure data, seat performance data, occupant NASS-AIS MAIS, and headrest information. This set of 11 years of data is referred to as the Rear Impact Dataset.

Integrated Seat Restraints A list of the Make / Model / Model years of vehicles in the Rear Impact Dataset was created. We cross-referenced this list with the NHTSA integrated restraint vehicle list to identify the vehicles with one or more IR positions. We then reviewed the NASS-CDS interior first row seat photographs of these vehicles, plus all vehicle Make / Models of MY 2000 or later to identify the vehicles with first row front outboard IR seats. Front row seats where the upper shoulder belt was anchored to the seat frame were considered an integrated restraint (IR) seat. Seats where the shoulder belt passes through a fairlead on the seat but anchors to the vehicle B pillar or similar non-seat structure were not counted as IR seats. We did not include aftermarket retrofit (non-factory installed) seats in the integrated seat group (1 seat identified). All vehicles found to have a factory installed first row outboard IR seat were also found in the NHTSA list, a test that confirmed the validity of the NHTSA list (at least for the vehicles in our rear impact dataset). The finalized front row outboard IR seat vehicle list (validated for vehicles in our Rear Impact Dataset) was used to identify these vehicles in all our analyses. The IR seat occupant group is a subset of the Rear Impact Dataset, so all the criteria enumerated in the Rear Impact Dataset section applies in addition to the IR seat.
Note that it would be difficult to use NASS-CDS photos to confirm the existence of rear IR seating positions. Split or folding rear seats are often an optional equipment item which are both difficult to positively identify in the CDS photographs and unlikely to be decoded using the truncated Vehicle Identification Number (VIN) available in CDS.

Cab Reinforced Seats Using information contained in the vehicle file of NASS-CDS, pickup trucks with short cabs where the first row seatbacks are in close proximity to the cab rear bulkhead face were identified in the Rear Impact Dataset. These are usually the short wheelbase versions of these pickups. The identified group was reviewed using NASS-CDS case photos to confirm the short cab and the existence of head restraints at each occupant position (older pickup trucks were not required to have head restraints). The Cab-reinforced seat occupant group is a subset of the Rear Impact Dataset, so all the criteria enumerated in the Rear Impact Dataset section applies in addition to the identification of the Cab-reinforced seat.

Analyses

Using the four occupant groups listed above, Frontal Impacts, Rear Impacts, IR and Cab-Reinforced Seats (these latter two being subsets of the Rear Impact Dataset) we performed the analyses listed below. Unless otherwise noted, all results are related to these four occupant groups, and are presented using the weighted (national estimate) values included in NASS-CDS.

Crash Severity Analysis We computed the median Delta-V for each of the occupant groups as a metric to compare the crash severities of the four groups.

MAIS Analysis We computed the Delta V value at which each occupant reached successive Maximum Abbreviated Injury Scale (MAIS) levels.(20) From this we computed the median Delta-V for MAIS=3 (serious) injury for each of the four occupant groups.(21)

Seat and Belt Restraint Performance We examined the performance of seats in rear impacts and manual and automatic restraints in frontal crashes based on the coding of restraint failure or seat deformation and/or failure by NASS-CDS coders. CDS contains a seat performance variable called “Seat Performance” (OA54). This variable indicates which seats “deformed” or “failed” (these are NHTSA defined terms). We used these NHTSA categories of deformation or failure. The determination that a seat or restraint deformed or failed was made by NHTSA’s NASS-CDS coders.(1)

Risk of Injury IR versus non IR Seats We computed the risk of any injury for IR and non IR seats and whether the difference was significant or not based on both the national estimate and unweighted (actual count) case values.

Results

Table 1 summarizes the major findings, and includes two NHTSA crash test criteria for reference.(22,23) The median (half above/half below) Delta V value

for the occupants in rear impact crashes is 19.5 kph approximately the same the 19 kph median for restrained occupants in frontal crashes. While not shown in Table 1, the median Delta V for all occupants (restrained and not restrained) in frontal crashes is also similar at 19.5 kph. The rear impact median Delta V was similar for the occupants in IR seats (19 kph) and the occupants in Cab-reinforced seats (19.5 kph). Based on the similarity of these median values, we made direct comparisons of injuries and seat failure / deformation rates.

Rear impact crashes - The median occupant Delta V for a MAIS-3 (at least one serious injury) occurred at 19 kph, half the belted occupant Delta V in frontal crashes (38 kph). At 20 kph Delta V, 56% of occupants in rear impact crashes reached MAIS-3, compared to 6% of restrained occupants in frontal crashes at the same Delta V. Therefore at 20kph (near the median crash severity) more than nine times the percentage (56%/6%) of occupants sustained injury(s) resulting in a MAIS=3 in rear impact crashes relative to restrained occupants in front impact crashes.

Median delta V for seat failure - The median value for failure and deformation for occupied seats in rear impact crashes is 27 kph, about 7 kph above the median crash Delta V. Twenty-three percent (23%) of nation-wide rear impact crashes occurred at or above 27 kph Delta V. Twenty-five percent (25%) of all occupants in the rear impact dataset experienced seat failures or deformations in rear impacts - 69 times the failure rate of belt systems for restrained occupants in frontal crashes (0.36%). IR and Cab-reinforced seats had no seat failures and lower deformation rates of 6% and 1.5% respectively. The higher front outboard seat deformation and failure rates observed with standard seats were associated with a higher percentage of occupants reaching the MAIS=3 (serious) level.

Occupants in an IR seat - No occupant in an IR seat in a rear crash was more than MAIS=1 (no injury above AIS=1) regardless of Delta V. In contrast, 50% of all occupants in rear crashes in standard seats experienced MAIS=3 injury by a Delta V of 19 kph. However, the relatively low number of IR equipped vehicles in rear impact crashes included in NASS-CDS causes the sample size to be relatively low – see Table 1.

Cab Reinforced Seats - One occupant experienced an AIS=3 level injury in a >30 kph Delta V crash and was MAIS=3. No occupant in a Cab-reinforced seat in a rear crash experienced an injury of AIS=2 and therefore all remaining occupants were MAIS=1 or less. As previously noted, 50% of all occupants in rear crashes in standard seats experienced an injury resulting in MAIS=3 by a Delta V of 19 kph. As with the IR occupant group, there are a relatively low number of short cab pickups in rear impact crashes included in NASS-CDS, and this causes the sample size to be relatively low.

Relative Risk We computed the relative risk of injury for occupants in IR seats relative to standard seats using a Chi-Squared test. As there are no IR seat occupants with MAIS=2 or higher in the NASS-CDS study data, the relative risk for MAIS=2 or higher is mathematically infinitely higher for IR compared to standard seats MAIS>1 levels (division by zero).

Risk of Any Injury We examined the risk of any injury (AIS=1 or higher) for IR versus standard seats. For this test any occupant with MAIS=1 through MAIS=7 (MAIS=7 is “injured but unknown severity”) was considered injured.(10) In this paper, Occupants with MAIS=0 were considered “uninjured” in the context of not having a codeable NASS-AIS injury.(16) We computed the relative risk of injury for occupants in standard seats versus IR seats two different ways to identify differences that might be caused by the sampling nature of NASS-CDS. This is similar to the approach NHTSA used to examine CDS data, and also taught by the authors in their SAE course "Accessing and Analyzing Crash and Injury Data from Online Databases ".(23,24)

National Estimate Using the NASS-CDS national estimates values, the relative risk of any injury for standard (non-IR) versus IR seated occupants was 1.40 times, $p<0.05$. If the IR results are adjusted by two standard errors (an approximation representing a 95% conservative case for the IR group) the relative risk result is 1.90 times relative risk and $p<0.05$.

Random Sample For our second method we treated the NASS-CDS cases as a random sample with all case weights of 1 (no national weighting factor used). The relative risk of any injury for standard (non-IR) seats was 1.41 times that of IR seats, $p=0.07$. Even with the relatively small Integrated Restraint seat group size, the relative risk results meet 93% to 95% confidence levels, depending on which of the above two methods we used.

Table 1.
Summary Information, Adult Front Row Outboard Occupants
Data Source: NASS CDS 1997- 2007

Front Impact Dataset Results	**kph**	**mph**	
Includes 8,700 Occupants with an equivalent National Estimate of 4,100,000			
Median Delta V, all frontal impacts	19.0	11.4	Restrained Occupants
Belt Restraint Failures	0.36%		Restrained Occupants
Median Delta V for MAIS 3 Serious Injury	38	22.8	Restrained occupants, includes belt failures
NHTSA 30 mph Frontal Test*	48	30	Barrier Speed*
	97.3%		Percentile of national frontal crashes

Rear Impact Dataset Results	**kph**	**mph**	
Includes 1,250 Occupants with an equivalent National Estimate of 760,000			
Median Delta V, all rear impacts	19.5	11.7	Restrained & Unrestrained Occupants
Median Delta V for Seat Deformation/Failure	27	16.2	Restrained & Unrestrained Occupants
Seat Deformation / Failure Rate	25.1%		Deformation & Failure Rate
	69		Times Risk relative to belt failure in frontals
Median Delta V for MAIS 3 Serious Injury	19	11.4	Belt and no belt, with and without failures
NHTSA 301 Rear Impact Test**	56	35	Delta V**
	98.8%		Percentile of national rear crashes

IR Seat Subset Results	**kph**	**mph**	
Includes 26 Occupants with an equivalent National Estimate of 5,200			
Median Delta V	19	11.4	Restrained & Unrestrained Occupants
Median MAIS 3 for IR Seats	none		No AIS-3 injuries for IR seats
Median MAIS 2 for IR Seats	none		No AIS-2 injuries for IR seats
Median MAIS 1 for IR Seats	19	11.4	All occupants
IR Seat Deformation Rate	6.2%		Deformation Only (No Failures Recorded)

Cab-Reinforced Seat Subset Results	**kph**	**mph**	
Includes 24 Occupants with an equivalent National Estimate of 14,000			
Median Delta V	19.5	11.7	All Occupants
Median MAIS 3 for Cab Reinforced Seats	n/a		One AIS 3 injury to one occupant
Median MAIS 2 for Cab Reinforced Seats	none		No AIS-2 injuries
Median MAIS 1 for Cab Reinforced Seats	33	19.8	
Cab-Reinforced Seat Deformation Rate	1.5%		Deformation Only (No Failures Recorded)

Notes: * Barrier approach velocity, Delta V would be higher by about 3mph due to rebound
** 3000lb moving barrier @ 50mph, Delta V varies with target mass

Cab-reinforced seats For Cab-reinforced seats there was one occupant with MAIS=3, no occupants with MAIS>3 and no occupants with MAIS=2. We performed the same injury / no-injury relative risk comparison as outlined above to determine if Cab-reinforced seats were associated with more injuries than standard seats. Using NASS-CDS national estimates, standard seats were associated with reduced risk of injury - 0.86 at $p<0.05$. However, the two standard error test reversed this result with standard seats showing 1.3 times higher risk at $p<0.05$. Results using unit weights (no

national weighting factor used) showed no difference in MAIS=1 and above injuries between standard and Cab-reinforced seats (p=0.56). Note that the existence of only one occupant with MAIS=2 or greater means that the above results are primarily driven by MAIS=1 occupants. These occupants have only minor level (AIS=1) injuries and therefore the difference at this low a severity level would require further analyses to determine if it was of practical benefit. Overall, the results indicate that Cab-reinforced seats were associated with a reduction in occupants reaching MAIS-2 and higher, but were not statistically different from standard seats for MAIS=1 level injury. Therefore the data used in this study does not support the conjecture that Cab-reinforced seats are associated with increased occupant injuries in rear impact crashes.

Make & Model We examined the percentage of seat deformation and failures in rear impact crashes by Make and Model. A preliminary analysis did not reveal any Make based differences that were statistically significant. A second analysis by Make and Model showed that seat failures & deformations in rear impact crashes may be associated with specific model lines (or perhaps with specific platforms or seat designs for which we did not have the detailed seat engineering information to statistically investigate). Model level analyses using NASS-CDS is limited by its relatively small sample size and its focus on only late model vehicles.

CONCLUSION

The rate of Non-IR seat failure/deformation in rear impact crashes is 69 times the rate of belt failures in equivalent severity frontal crashes. This is a cause for concern because it was associated with a difference in MAIS=3 injury risk. The median Delta V for all reported seat failures and deformations was 27 kph (16.2 mph). Approximately 25% of occupants in rear impact crashes were in crashes above the Delta V at which 50% of the non-IR seat failure/deformations occurred. Front seat failure could result in injury to children or adults riding in the seat directly behind the failing seat; a factor not included in this study.

In a Delta V crash of 20 kph, approximately the median rear impact crash severity, the percentage of occupants in non-IR seats experiencing injuries resulting in MAIS=3 was more than 9 times that of restrained occupants in frontal crashes. Based on this data, standard (non-IR) seats in rear impact crashes did not provide injury protection equivalent to existing restraints in frontal impacts.

No occupant in an IR seat experienced an injury above AIS=1 (all were MAIS=1 or less). For any injury level, (MAIS>0), occupants in non-IR seats were 1.4 times more likely to be injured than occupants in IR seats (p<.05). This result was the same whether weighted (national estimate) or unweighted (raw case) counts were used.

The available NASS-CDS injury data for occupants seated in front outboard IR seats indicates that IR seats were associated with fewer occupants (by percentage) reaching any MAIS greater than 1 in rear impact crashes compared to non-IR seats.

Stiff (non-yielding) seats, as represented by cab-reinforced seats, were <u>not</u> found to be associated with an increased risk of injury in rear impact crashes, contrary to previously published papers.

Only one occupant in a cab-reinforced seat experienced an injury resulting in an MAIS >1. The study data shows that Cab-reinforced seats were associated with fewer occupants (by percentage) reaching MAIS levels 2 and above in rear impact crashes compared to standard seats.

The currently available NASS-CDS data for IR seats in rear impact crashes indicates that IR seats were associated with reduced injury rates for all injury levels in rear impact crashes, and that IR seats potentially could provide injury protection comparable to existing restraints in frontal crashes.

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