Development of Occupant Protection Systems: Leaving the Rear Seat Behind

Beck, B., Brown, J., Bilston, L.E.
The Prince of Wales Medical Research Institute & University of New South Wales, Randwick, NSW
email: b.beck@powmri.edu.au

Abstract

Major gains in occupant protection in automotive crashes have been made over the last few decades, with the introduction of integrated occupant safety systems such as seat belt pretensioners and load-limiters, and airbags. However, beyond requiring the provision of seat belts in the rear seat under Australian Design Rule (ADR) safety systems, rear seat passengers in Australia have received little regulatory, consumer, or research attention. This is despite the fact that rear seat passengers are estimated to account for more than 20% of all moderate and serious injuries.

This paper compares the number of installed restraint technologies in the front seat with the number installed in the rear seat, and how this has changed over time. Analysis was conducted by reviewing the technologies available in top-selling Australian vehicles, including model years from 1994 to 2009. The average total number of technologies per vehicle for front seat occupants increased from 2.28 to 6.93 over the study period, while rear seat technologies increased from 2.07 to 3.10. These data suggest that technologies in the rear seat have not been introduced at the same rate as the front seat and there is scope to improve rear seat occupant protection and push for further consumer assessment of the safety of the rear seat.

Keywords
Rear Seat, Restraints, Occupant Protection

Introduction

Over the last few decades, vehicle safety systems have been constantly evolving, resulting in improved crash protection for occupants. In newer model vehicles, occupant protection is achieved through the utilisation of a ‘system’: a combination of vehicle crush characteristics, enhanced seat and seat belt technologies, such as seat belt pretensioners and load limiters, and airbags. This has largely been a result of consumer and regulatory assessments evaluating the performance of the system, rather than regulating the presence of any single component. Since these assessment programs evaluate the protection provided in the front seat only, there has been less motivation for vehicle manufacturers to develop and implement these technologies in the rear seat, and the extent to which such technologies are available in the rear seat is not documented.

Historically the driver and front seat occupant have been the highest priority because these positions are occupied most often and therefore account for the greatest numbers of casualties [1]. The introduction of airbags, seat belts and other advanced safety systems in front seating positions, along with vehicle structural improvements, has led to a significant reduction in the number of casualties and fatalities among vehicle occupants [2, 3]. Less attention has been paid to the rear seat because to date, the rear seat has been considered safer than the front seat [4, 5]. Recently, however, a number of recent North American studies have been conducted showing instances of lower levels of protection for rear seat occupants compared to front seat occupants [6-9].

Smith and Cummings [8] conducted a matched cohort analysis of data from the National Highway Traffic Safety Administration Fatality Analysis Reporting System (FARS). Vehicles of model years 1990-2000 were included in the study and it was shown that front seat occupants were better protected than rear seat occupants, and that the protective effect of the rear seat decreased with restraint use and increasing passenger age. This finding was supported by research conducted by Kuppa et al. [9] while examining both the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) and FARS. Kuppa et al [9] also reported that in comparison to the rear seat, the front seat provided significantly improved protection to restrained occupants 50 years of age and older. These authors also investigated the NHTSA rigid barrier frontal tests and found that the dummies in the rear seat, as compared to those in the front seat, had higher values for head acceleration, neck injury values and chest injury measures.
Kent et al. [10] analysed the State Data System (SDS) and FARS and demonstrated that the ability of the rear seat safety systems to mitigate serious injury, as compared with the front seat, decreases with newer model year vehicles. Similar to the findings reported by Smith and Cummings [8], Kent et al. reported that occupants of age 50 years or older have a greater chance of survival in front seating positions, as compared with the rear seat.

Esfahani and Digges [6] investigated rear occupant injuries in the National Automotive Sampling System’s Crashworthiness Data System (NASS CDS) over the years 1993-2006. They determined that the relative risk of injury was significantly higher for belted rear seated occupants in newer model year vehicles. For model years 1993-1999 to 2000-2006, the risk of obtaining a MAIS2+ injury rose from 1.6% to 5.1%, while front seat occupant injury risk dropped from 7.8% to 6.3%. There was also a significant rise in risk of AIS2+ head injury for belted rear occupants.

Thus, we have seen a recent trend of increasing relative injury risk for rear seat occupants in comparison to occupants in the front seat. While there is no current Australian data on the exact proportion of casualties of rear seat occupants, data from the US Fatal Accident Reporting Scheme (FARS) in 2005 shows that rear seat passengers make up 23% of all moderate and serious injuries and about 9% of fatalities. If this American data reflects the magnitude of the problem in Australia, there may be scope for substantial reductions in casualty numbers by improving rear seat safety.

In a crash, an occupant undergoes rapid deceleration, and the aim of vehicle safety systems is to manage this deceleration and control the force transferred to the occupant. The way in which this is achieved is by maximising the distance over which an occupant decelerates, which is more commonly known as maximising the occupant’s ‘ride down.’ This is often achieved through a combination of vehicle design and occupant restraints. Vehicles are manufactured with engineered ‘crush zones’ in an attempt to absorb the majority of the crash energy. Restraints couple the occupant to the vehicle so that the occupant can decelerate at the same rate as the vehicle while distributing any forces exerted on the occupant to the strongest part of the body, such as the shoulder, chest and hips. Seat belts and secondary safety devices, such as airbags, are also used to reduce the likelihood of the occupant contacting structures within the vehicle, and control the relative motion between adjacent body parts. The seat also forms part of the restraint system by assisting in controlling occupant posture before and during impacts, controlling loads applied to the body, and in rear impact, controlling the relative motion between the head and the neck.

The Australasian New Car Assessment Program (ANCAP) provides ratings on vehicle occupant protection for different model vehicles in frontal and side crash scenarios. In 1992, the Australia program began using the same 35 mph full-width barrier tests as NHTSA (National Highway Traffic Safety Administration), and in 1999, adopted the same test methods and procedures as EuroNCAP. Despite the inclusion of two child dummies in the rear seat (TNO P1.5 and P3) throughout their frontal testing regime, ANCAP vehicle ratings have never incorporated performance requirements for dummies positioned in the rear seat.

In Australia, vehicle design is governed by the Australian Design Rules, or ADRs. The latest update for seat belts is ADR 4/04 which was published in 2009. It specifies that all outboard seats in passenger vehicles are required to have a 3 point belt, retractor, and an emergency locking retractor or automatic length adjusting and locking retractor. However, there is still no 3-point seat belt requirement for the rear centre seat.

Available Technology

As previously mentioned, occupant protection is achieved through a system of safety devices. These technologies include the following.

The Seat Belt

The seat belt is widely acknowledged to be the most effective restraint in a vehicle, being approximately 45% effective at preventing fatal injuries, and 67% effective at preventing serious injuries [11]. However, seat belts did not become available in new cars until the mid-1960’s and came in the form of a lap belt only [12]. Research at the time by Stapp [13] and Benedict [14], showed that lap belts allowed extensive
forward torso displacement, often resulting in severe lumbar spine injuries and the occupant’s head contacting interior structures of the vehicle. As a result, the 3-point belt was proposed. This system includes a sash (or shoulder) component and therefore provides better restraint of the upper torso than the lap only belt.

The conventional 3-point belt system now comprises a retractor and a buckle. The retractor is a spool which is attached to one end of the webbing; a spring applies a rotation force to the spool so it winds up any loose webbing. This system often incorporates either an automatic length adjusting and locking retractor (ALR), or an emergency locking retractor (ELR). The ALR includes a self-activating mechanism in the retractor which automatically locks the retractor at the length selected by the user. The ELR, on the other hand, locks under abnormal operating conditions. These devices are used to further restrict forward torso displacement in a crash.

The Seat

The seat plays a very important role in occupant protection. It is the primary support mechanism and forms the base element of many other restraint systems. The seat should place the occupant in an adequate position for effective application of the restraint systems. Normally, between 60 and 75 percent of body mass is supported by the seat cushion, and under high vertical accelerations, the seat can support up to 300 percent of body mass [10]. The aim of the cushion foam is to provide adequate and consistent support to the buttocks while minimising the chance of pelvic rotation and subsequent loading on the spinal column. Seat backs also work to distribute loads and control occupant motion.

Head restraints control the relative motion of the head and the torso in rear impacts. When the vehicle is accelerated forward, pushing the seat back against the body of the occupant, the head lags behind the torso and then is suddenly accelerated by the neck, resulting in the common ‘whiplash.’ The head restraint limits the neck distortion relative to the torso and decreases the likelihood of sustaining a neck injury.

Enhanced Seat Belt Technologies

During rapid deceleration, a high load is often applied to the occupant via the seat belt. This causes sudden deceleration of the chest, but the head continues to accelerate, creating a greater relative velocity difference between the head and the chest and often results in cervical spine injuries [15]. A load (or force) limiter reduces the force applied to the thorax, while controlling the kinematics of an occupant by allowing webbing to be pulled out to reduce the belt force. It is integrated into the retractor to control this force at a predefined level.

The load limiter is often coupled with a pretensioner. Pretensioners retract the seat belt to remove excess slack and can be integrated into the buckle or the retractor. The less slack, the better the occupant is tied to the vehicle’s deceleration, reducing the load exerted on the occupant. They can also reduce the forward movement of an occupant’s upper body, and, when integrated into the buckle, can reduce the tendency for submarining by controlling pelvic rotation [16].

The combination of these two devices allows the removal of any slack in the belt, while permitting belt payout while the belt is under load. This facilitates earlier application of load to the occupant and reduces forward excursion [16] and together they can substantially reduce chest deflection while maintaining control of chest excursion [17, 18]. Forman et al. [19] conducted frontal sled tests using a dual stage, progressive load limiter. This has two levels of force-limiting whereby the system is optimised for the large disparity in occupant anthropometries. Smaller occupants, or occupants in less-severe collisions are controlled by the first and lower stage of load limiting, while larger occupants or occupants in more severe collisions and protected by a greater, secondary load limit. This was shown to reduce the maximum internal dummy chest deflection by 29% in a Hybrid III 6 year-old, 30% in a Hybrid III 50% adult male, and 38% in a Hybrid III 5% adult female. It also improved the kinematics of the dummies by controlling torso rotation.
Airbags

Airbags first emerged as an occupant protection device in the 1970’s. They were initially designed as an alternative to the seat belt, but are now used as a supplementary restraint system to the seat belt, with the primary aim of reducing the likelihood of an occupant contacting rigid internal structures in the vehicle.

Airbags have been shown to significantly reduce the risk of serious of fatal injury in crashes [20]. Frontal airbags will generally deploy in head-on collisions when the impact direction is less than 30° and provide protection to the head and upper body. The technology has now developed to an extent that some vehicles are employing multi-stage airbags. These systems consist of multiple independent inflators that are deployed dependent upon the severity of the accident. This allows for a much more controlled deployment and can also be used to adjust for the size of the occupant.

Unlike frontal airbags, side airbags must deploy much faster as the occupant is much closer to the impacting object. Thorax airbags were introduced around 1994 and are mounted in the seat with a goal of protecting the occupant from lateral intrusion. In 1998, head protection airbags, or otherwise known as curtain airbags, were developed to prevent head and neck injuries in the event of a side impact. Like frontal airbags, these head airbags work to prevent contact between the occupant and the vehicle interior or intruding objects. The important parameters of head airbags include inflation time, fill capacity and also the duration that the airbag remains inflated to protect occupants in both side impacts and rollover events.

Leg injuries have also been highlighted as a problem, being the most frequent injury in frontal crashes for occupants who are protected by airbags and wearing seatbelts [6]. Knee airbags have been introduced to counter this problem and deploy toward the occupants legs, preventing contact between the knee and the interior panel or steering column. Knee bolsters are another safety feature and attempt to reduce the impact velocity of the legs into the dashboard. This is achieved by moving knee padding closer to the knees through the use of a pyrotechnic knee bolster.

The key goal of this study was to determine the relative change in available safety technologies in the front and rear seats, and how this has changed with time. Specifically, the restraint technologies available to front seat occupants in Australian vehicles and their evolution over the last decade are investigated and compared to rear seat technologies. We have used the total number of restraint technologies (irrespective of type and whether they are location-specific) as a metric. We hypothesised that the increase in the number of safety technologies in the front seat of vehicles is significantly greater than in the rear seat.

Methods

The source of data for this study was a combination of the Glass’s Research Data and vehicle manuals. Data was collected for 29 vehicles from 1994 to 2009 for between 3 and 6 of the top-selling passenger vehicles chosen from each of the relevant size classes, based on their percentage market share in the Australian fleet at the time. This data was obtained from the Federal Chamber of Automotive Industries (FCAI) vehicle sales database - VFacts.

The vehicles selected must have had model years ranging over the full investigation period. This only slightly affected which vehicles were selected, as most popular vehicles were well-established models and manufacturers. Inclusion also required the vehicles selected to have rear seats. The classes selected, as defined by the FCAI market segments, were as follows:

- Light Passenger Vehicle
- Small Passenger Vehicle
- Medium Passenger Vehicle
- Large Passenger Vehicle
- Sports Utility Vehicle (SUV)
- People Mover
- Pick-up/Cab-Chassis (PU/CC)
In this study, data was collected on the presence and number of the following technologies in the front and rear seat as a whole:

- 3-point seat belts
- Seat belt pretensioners
- Front impact airbags
- Side impact airbags (both thorax and head airbags)

For example, in a car with driver and passenger 3-point seat belts, driver and passenger airbags, and a driver seat belt pretensioner (but no other restraint technologies such as thorax or head airbags), the front seat score would be 2+2+1=5 points. The same car might have three 3-point belts in the rear seat, for which it would score a total of 3 points. Due to regulations outlined in ADR 4, it was assumed that all outboard seating positions had 3-point seat belts.

Note that not all technologies investigated in this study are necessarily applicable for both front and rear seat occupants. The aim of this study is to compare the total number of technologies installed in front and rear seating positions, rather than the implementation of specific technologies.

Note also that optional features were not included in this study as data on the uptake of optional features was not available; only standard features on base model vehicles were analysed.

All available restraint technology data was collected for the vehicles investigated in this study. This was then compiled and analysed to investigate the average number of technologies available per vehicle, and the variation of technologies within each vehicle. Tests for significance were conducted using the Chi-Square test or Fisher’s Exact Test where appropriate. The comparative rise over time of front seat restraints versus rear seat restraints was analysed using the repeated measures analysis of variance technique.

Results

From 1994-1998, a driver and/or front passenger airbag was available in 23% of vehicles. By 2009, approximately 96% of vehicles examined had driver and/or front passenger airbags. Seat belt pretensioners for front seat occupants were first observed in 2000 model year vehicles, (28% of vehicles). In the 2003-2006 model year (MY) vehicles, they were present in 70% of vehicles examined. In the newest MY vehicles, side and head airbags were observed in approximately 30% of vehicles.

The average number of technologies across all vehicle classes is shown in Table 1. A general trend of increasing available technology was observed in increasing model year vehicles. The average number of technologies per vehicle significantly increased over the study time period (p<0.05), and for individual vehicle classes (p<0.05).

Table 1: Summary of the average total number of technologies available in vehicle classes over model year groups. This data is a sum of both front and rear seat technologies.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>4.00</td>
<td>6.00</td>
<td>8.67</td>
<td>9.67</td>
</tr>
<tr>
<td>Small</td>
<td>4.17</td>
<td>6.00</td>
<td>9.00</td>
<td>9.67</td>
</tr>
<tr>
<td>Medium</td>
<td>4.75</td>
<td>6.00</td>
<td>9.00</td>
<td>13.0</td>
</tr>
<tr>
<td>Large</td>
<td>4.40</td>
<td>7.20</td>
<td>8.40</td>
<td>10.5</td>
</tr>
<tr>
<td>SUV</td>
<td>4.00</td>
<td>4.67</td>
<td>7.33</td>
<td>9.33</td>
</tr>
<tr>
<td>People Mover</td>
<td>6.00</td>
<td>8.67</td>
<td>8.67</td>
<td>9.00</td>
</tr>
<tr>
<td>PU/CC</td>
<td>4.75</td>
<td>4.75</td>
<td>4.00</td>
<td>7.17</td>
</tr>
</tbody>
</table>

Front v Rear Seat

To compare restraint systems offered to front and rear seated occupants, the first investigation looked at the total number of technologies in the front and rear seats per vehicle. Figure 1 shows that for the front seat, the average total number of technologies per vehicle rose from 2.28 prior to 1998, to 6.93 in the
2007-2009 group. This is compared to 2.07 technologies per vehicle for rear seat occupants in the pre-1998 group, to 3.10 in the newest MY vehicles.

Figure 1: The number and type of implemented restraint technologies in the front and the rear seat in four model year groups. The y-axis shows the average total number of technologies installed per vehicle, while the clusters show a breakdown of these technologies into broad classes.

Technologies offered

The composition of technologies within each vehicle was also investigated, and is represented within each clustered bar in Figure 1. Seat belts and airbags were the only advanced restraints available to the driver and/or passenger in pre-1998 MY vehicles, while in the 2007-2009 MY vehicles, front seat occupants were protected by a combination of advanced restraint systems, including front and side airbags, seatbelt pretensioners in addition to seatbelts. However, only 3-point seat belts and head airbags were available for rear-seated occupants in the newer model year vehicles.

Overall, it was shown that there was a significant difference in the total number of technologies offered to front seat occupants as compared to rear seat occupants and that this trend was observed over the full study period (p<0.0005). Although our primary goal was to simply compare the total number of technologies available, not to compare specific types or make judgements about the suitability of technologies for front and rear seat applications, we considered the possibility that due to the confined space in the rear seat, there are substantial challenges in developing restraint technologies for the rear seat that are not accounted for by simply comparing the total number of technologies. Thus, analysis was conducted by calculating the number of technologies installed in a particular vehicle as a proportion of the maximum number of currently implemented technologies that are installed in one or more vehicle models on the market in the most recent MY group. This maximum is 10 technologies for the front seat (i.e. two 3-pt belts, two frontal airbags, two side airbags, two head airbags and two seatbelt pretensioners), and 10 for the rear seat (i.e. three 3-pt belts, two side airbags, two head airbags and three...
Discussion

This study demonstrates that an increasing number of occupant protection technologies have been installed in front seating positions over the study period, and that the total number of technologies available to occupants is significantly greater in the front seat than in the rear seat.

There are few similar studies in the literature. Our observed rise in the rate of pretensioners installed in the front seat of popular Australian vehicles (0 prior to 1998 to approximately 30% in MY1999-2002) correlates well with Kent et al. [7] who observed a rise in the rate of pretensioners installed in the US vehicle fleet from 10% prior to 1999, to 56% in MY 2002 vehicles. Apart from the front 3-point seat belts which are installed in all vehicles, this rise in available restraints for front seat occupants is evident across all of the technologies investigated. Increases in the presence of 3-point seat belts in the rear centre seat, as well as head airbags for rear seat outboard passengers were observed, however both the total number of technologies and the change in the total number of technologies in the rear seat was less than was observed in the front seat.

Recent North American research [6-9] is indicating that the rear seat can no longer be regarded as being inherently safer than the front seat. This current study demonstrates that this correlates with the evolution and availability of more effective restraint systems to front seat passengers, as compared with those in the rear seat. There maybe scope for improving this situation by extending appropriate front seat technologies to the rear seat, however, little research has been conducted on the effectiveness of front seat technologies in the rear seat environment. In addition, some front seat technologies do not appear to be practical for the rear seat (e.g. frontal airbags) and other approaches to offer similar protection need to be developed specific to the rear seat.

Current research on rear seat restraints from North America suggests that focusing on improving the effectiveness of the seat belt will yield the best short-term results for improving occupant protection in the rear seat [7, 19, 21]. With 76% of AIS3+ injuries to belted rear seated occupants over the age of 13 occurring in the thorax [21], there is clearly a need to improve the rear seat belt system. The challenge is to reduce chest loads while not allowing excessive head and torso excursion. In the front seat head and upper torso excursion can be controlled to some extent by other energy absorbing devices such as air bags and knee bolsters. However these technologies may not easily be extended to the rear seat. Combinations of seat belt pretensioning and load limiting technologies in the rear seat have been shown to substantially improve the control of chest deflection, without compromising head excursion [10, 22]. Forman et al [19] demonstrated the potential benefits of dual stage, progressive force limited seat belts in controlling for variations in the size of occupants and in crash severity, and this could also address the large disparity in occupant anthropometries in the rear seat. These previous studies have used US data, and it is not yet clear that they are relevant to the Australian situation due to differences in the vehicle fleet and seat belt practices. In particular, the magnitude and scope of the rear seat injury problem in Australia remains to be clarified as high quality data is not available. Current research at the Prince of Wales Medical Research Institute is aimed at exploring these issues.

There is currently no consumer or regulatory assessment of the rear seat. In Australia, there is no requirement for the installation of 3-point seat belts in the centre rear seat, although 92% of current models provide this. Consumer tests conducted by ANCAP include child dummies in the rear seat for frontal impact tests, but there is no regulation for performance of the rear seat occupant protection system. This is also applicable for tests conducted by the US safety authority, the Insurance Institute for Highway Safety (IIHS). The Japan New Car Assessment Program (JNACP), however, has recently introduced a test procedure for evaluating rear seat occupant protection, placing a 10 year-old test dummy in the rear seat of all frontal impact tests. The data from the current study suggests that there is scope to use consumer programs to encourage further development of rear seat occupant protection systems.

In the front seat of the newest model year vehicles, over 92% of vehicles had driver and or passenger airbags, 77% had seat belt pretensioners, and 42% had side (thorax) airbags. This is contrasted by the rear...
seat in which the only available advanced restraint technology was the head airbag and this was observed in only 30% of vehicles. With the focus on front seat occupants in consumer testing, coupled with the rise in front seat restraint technologies, it seems likely that the lack of regulatory assessment in the rear seat has led to a disregard of improving rear seat occupant protection.

The limitations of this study included the inability to investigate other advanced restraint technologies such as seat design, anti-submarining pans, load limiters, knee bolsters, seat belt height adjusters and head restraints as this data was not always available in the data sources used.

It would be advantageous to investigate the implementation of these additional devices in both the front and rear seat. Also, a small number of vehicles were selected (29) and analysed over a limited range of model years. Combining this data with information of the whole fleet, rather than a selection of it, would provide a more robust analysis of the availability of restraints to front and rear seated occupants.

Conclusion

A significant increase has been observed in the number of installed restraint technologies available to front seat occupants as compared to rear seat technologies over the last couple of decades. With current research suggesting that the front seat is becoming relatively more effective at mitigating injuries [6-9], there is scope to improve the rear seat occupant protection system. The implementation of already available supplemental restraints available in the front seat and/or novel technologies, are potentially effective methods of improving safety in the rear seat.

Acknowledgements

This study was funded by an ARC Linkage Grant with partner funding from the NSW Centre for Road Safety, RTA. L.E. Bilston is supported by an NHMRC senior research fellowship. The authors wish to thank the NRMA Library for their assistance with data sources for this study.
References