



Child Restraints and Airbags

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Title

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Abstract

Airbags are a proven safety feature however it is not clear if caution is warranted for young children travelling in proximity to active airbags. RACV commissioned this research on behalf of our members to determine the safety risk associated with placing children in child restraints close to airbag systems. Current advice supports seating children in the rear up to twelve years of age and discourages placing rearward facing restraints in a front seating position. No known cases of injury or death to correctly restrained children from deploying side, thorax or knee airbags have been identified although fatalities have been reported of improperly restrained children from early airbag designs. The greatest risk to children is being unrestrained and improperly restrained as out of position children are at the highest risk of injury from deploying airbags.

Key Words

child restraints; airbags; safety; side; thorax; knee; frontal, passenger; children; fatality; injury; rearward facing; forward facing; booster

Executive Summary

Airbags are a proven safety feature however it is unclear what the safety implications are for young children travelling close to airbags. In particular, there is very little information regarding any potential risks to children from side or curtain airbags.

Advice on airbag safety for children generally relates to front passenger airbags and advises against seating children in the front if there is a passenger airbag present. This is consistent with the current Victorian legislation requiring children under seven years to be restrained in the rear seat. Children between four and seven can only sit in the front seat when rear seats are occupied by younger children. With advances in airbag technology, it is not clear if this caution is warranted and at what age it is safe to place children in proximity to an active airbag.

RACV commissioned this research on behalf of our members to determine the safety risk associated with placing children in child restraints close to airbag systems. It reviews the types of airbags available on the market and examines relevant crash data from international and Australian studies. The study reports on evidence of injuries to children caused by airbags and recommendations on children and airbag safety are made. Opportunities for future research are explored due to the significant gaps in evidence and a lack of clear and relevant Australian data.

Results

The research reports that frontal airbags manufactured prior to 1998 aggressively deployed rearward and this, combined with unrestrained children, led to some children being killed by the interaction with a deploying airbag. The research also found that first generation airbags have injured or killed infants seated in a rearward facing restraint fitted to a frontal position.

Recent designs of passenger frontal airbags initially inflate upwards and are less likely to injure occupants. While modern airbag designs appear to pose less risk to child occupants in forward facing restraints, the evidence on the level of risk is not clear and there is a need for further research. The practice of discouraging the use of rearward facing restraints in a frontal passenger position is warranted due to the risk of interaction with a deploying airbag.

There have been no known cases of injury or death to correctly restrained children from deploying side, thorax or knee airbags. Examination of the Australasian New Car Assessment program (ANCAP) data found that in rear seating positions, a curtain airbag is fully inflated prior to contact with the dummy. There is no reliable data to indicate whether contact with a child's head and a fully inflated airbag poses any risk of head or neck injury.

While the research suggests that the risk of injury from second generation depowered airbags appears to be low in comparison to first generation airbags that deploy aggressively, there are risks associated with improperly restraining children and their consequent interaction with an airbag. Although there have been no reports of injury from side airbags, the actual risk to young children has not been investigated. There is a need for further research to determine the actual risk to children from airbags, however correct seating remains important in the prevention of injury.

Conclusions

In Australia, the reports of injury from airbags are low. However there is a need for further research to better understand the risk to young children. In summary:

- Children are always safer in the rear seat when using dedicated child restraint systems.
- The risk of injury from a side airbag in the rear seat is low for properly restrained and positioned children.
- The greatest risk to children is being unrestrained and improperly restrained as these children are more likely to be out of position.
- Out of position children are at the highest risk of injury from deploying airbags.

The risk of injuries and fatalities from deploying airbags can be minimised by properly restraining children in an age appropriate child restraint in the rear seat.

Recommendations

The law outlines the minimum requirements in order to keep children safely restrained in vehicles. The recommendations on safe practices include:

- Children aged twelve years or younger should not be in a seating position with a front passenger airbag if there is an available rear seat position.
- Rear facing child restraints should not be used in a seating position with a front passenger airbag due to the high risk of injury.
- Front passenger seats should be moved to their rearmost position if children are required to be restrained in proximity to a frontal airbag.
- Older children should be discouraged from leaning forward when in a frontal seating position.
- Children should always be appropriately restrained and encouraged to sit correctly wherever practically possible.

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1 Introduction

Royal Automobile Club of Victoria (RACV) commissioned this research to examine whether there is a safety risk associated with seating children in close proximity to vehicle airbags. This project includes a study of relevant published literature, contacting experts in the field of child occupant safety, examination of crash test video footage and examination of deployed airbag systems. While there are laws and recommendations that children should be restrained up to the age of seven years, little is known about their interaction with airbag systems. This report provides a review of the issues and outlines gaps in current knowledge that should be filled by further research on this subject.

The scope of the project includes child occupants properly restrained in rearward facing child restraints, forward facing child restraints or booster seats, using a top tether strap where appropriate. The scope does not include children restrained by a seatbelt only or by a seatbelt/child harness combination (i.e. not using a booster) or unrestrained children. The report considers the issues for child occupants restrained in the front seat exposed to frontal, curtain and side airbags and rear-seated restrained child occupants exposed to curtain and side airbags.

Children are defined as aged twelve years or less. However, the current project focuses on children in child restraints since under current Australian law children must use a child restraint up to the age of seven years.

2 Background

2.1 Types of airbags

Figure 1 illustrates the types of airbags that should be considered when children travel in vehicles.



Figure 1 Types of airbags ¹

2.1.1 Passenger frontal airbags

Passenger frontal airbags are located in the dashboard in front of the passenger. In Australia they are known as supplementary restraint systems (SRS) because they are intended to work in conjunction with seatbelts to reduce the risk of injury to occupants in a crash. Frontal airbags deploy in a severe frontal collision, typically about 30 milliseconds (ms) after the start of the crash. They are usually fully inflated by 70ms. The occupant's head typically makes contact with the airbag shortly after it is fully inflated. The airbag then acts as a cushion, helping to spread the loads on the body, in conjunction with the seatbelt. The airbag starts to deflate as soon as it is fully deployed and this helps to absorb some of the crash energy. The most injurious stages of a crash are usually over by 100ms (FORS, 1996).

The first generation of passenger frontal airbags were designed to deploy mostly rearwards, like the driver airbag mounted in the steering wheel hub. However recent designs of passenger frontal airbags are installed on top of the dashboard and initially inflate upwards where they contact the windscreen and are deflected rearwards in a rolling manner. This is less likely to injure the occupant. Very few cars (new or used) in Australia are fitted with first generation airbags however some are still present in the fleet.

Various other advanced airbag features have been introduced to reduce injury risk. Dual stage airbags vary the amount and speed of inflation depending on crash severity and other parameters. Some systems detect the size or mass of the occupant and the position of the seat to adjust the deployment accordingly. Some systems automatically detect if a child restraint is located in the seat and deactivates the airbag; very few Australian vehicles have this feature.

¹ <http://boronextrication.com/2011/11/2012-chevrolet-sonic-body-structure/>

2.1.2 Passenger frontal airbags in North America

To meet US regulations, early passenger frontal airbags were required to be crash tested with dummies not using a seatbelt. These first generation airbags generally had to deploy with higher velocity and expand to a larger volume than more recent second generation airbags as they were the primary restraint system in vehicles.

The high velocity deployment and large inflated volume of first generation passenger frontal airbags were identified as the cause of injuries and deaths in child occupants. In particular, the dangers posed by the interaction between first generation passenger frontal airbags and rearward facing child restraints were a cause for concern and in part led to regulatory changes in the US to allow for less aggressive airbag design (Hollowell et al., 1999). Section 3.3.4 describes this further.

2.1.3 Passenger frontal airbags in Australia

Almost all new cars currently sold in Australia have a front passenger airbag. Australia has a relatively old vehicle fleet, with an average age of about eleven years therefore the current population of all vehicles can be expected to have similar proportion of safety features to that of new vehicles eleven years ago. In an analysis of the West Australian car population, Paine (2002) estimated that, in 2002, 50% of new cars had a passenger front airbag. Based on this analysis it is estimated that about 50% of the current Australian car population (new and used) has a passenger frontal airbag.

2.1.4 Head protecting side airbags

Inflatable curtains are now the most common way of providing head protection in side impacts. As illustrated in Figure 1, head protecting side airbags can be designed to protect all rows of seats. Figure 2 shows the combination airbag that provides head protection (also known as a combo airbag). This airbag inflates from the side of the seat and has a section to protect the head and a section to protect the thorax.



Figure 2 Combination airbag²

2.1.5 Head protecting side airbags in Australia

It is estimated that about 60% of all new cars currently sold in Australia have head protecting side airbags. The prevalence of these types of airbags have only become common in recent years. It is estimated that less than 10% of all cars on Australian roads have head protecting side airbags (based on Paine, 2002).

2.1.6 Thorax side airbags

Thorax side airbags are located in the side of the seat or the door trim of vehicles. They deploy in severe side impacts and are designed to reduce the risk of chest or other thoracic injury to the occupant. They typically deploy approximately 25ms after the start of a collision and have a much lower inflated volume than frontal airbags.

2.1.7 Thorax side airbags in Australia

It is estimated that about 60% of all new cars currently sold in Australia have thorax side airbags. Similar to head protecting side airbags, these have only become common in recent years. It is estimated that 10% of all cars on Australian roads have thorax side airbags (Paine, 2002).

2.1.8 Knee airbags

Knee airbags are located in the lower dashboard and are designed to reduce the risk of upper leg and hip injury in a severe frontal crash. They deploy at the same time as frontal airbags but have a smaller inflated volume.

² <http://new.skoda-auto.com/en/models/HotspotDetail?HotspotName=102%20-%20Bo%20C4%8Dn%20C3%AD%20airbagy%20Head-Thorax&WebID=00362382-4553-4ac7-820c-abf2797fec03&Page=interior>

2.1.9 Knee airbags in Australia

It is estimated that a small percentage of all new cars currently sold in Australia have a driver knee airbag (ANCAP, 2011). Currently only a few models of luxury cars have passenger knee airbags.

2.2 Current advice on installing Australian child restraints

As discussed in section 2.1.2, the early reported risks around the use of child restraints in seating positions fitted with airbags have been dealt with differently in different jurisdictions. The concern of an increased risk of injury to children using rearward facing restraints in front passenger positions fitted with frontal airbags led NSW to implement legislation banning the use of rearward facing restraints in this position. However this was the only Australian state that dealt with this concern through legislation. Other states, road safety and child safety advocates did however address this concern when providing advice to road users.

There is no up to date advice about installing Australian child restraints in seat positions that have an airbag.

In general, motoring organisations, child safety advocates and vehicle manufacturers generally recommend that children using a child restraint should not use a seating position where a frontal airbag may deploy and that, for older children, rear seating positions should be utilised before frontal seating positions are utilised.

2.2.1 National advice

The advice provided in “A Simple Guide to Child Restraints” (Australian Transport Safety Bureau [ATSB], 2007):

- Never use an infant restraint in the front passenger seat if your car has a front passenger airbag. The airbag may hurt or kill your baby, especially if your infant restraint faces towards the back of your car. Even if your car does not have a front passenger airbag, your baby is much safer if you place the restraint in the back seat.
- In Australia, there have been no known cases of injury to correctly restrained children from deploying side airbags. Side airbags are generally smaller than frontal airbags and consequently pose less risk to small occupants. However, the manufacturer of your vehicle is the best source of information regarding the proper use of child restraint systems near the airbags in your vehicle.
- Children are always safer in the back seat. If you must have your child sit in the front seat with a front passenger airbag, you should make sure that your child sits a safe distance back from the airbag. If the seat is adjustable, move it rearwards to keep your child away from any danger of a deploying frontal airbag. Check that the seat position still allows the seatbelt to fit your child correctly. The lap belt should touch across the hips and the sash belt should touch across the chest and shoulder.

In response to media reports on US fatalities involving small adults and unrestrained or incorrectly restrained children being killed by airbags, The Federal Office of Road Safety [FORS] (1996) monograph suggested that the US problem with airbags should not happen in Australia because:

- Airbags fitted to Australian cars inflate with less force than those in the US.
- Australian child restraints are designed for use in rear seats.
- There have not been reports of similar problems in Australia.
- Australian cars and child restraints have warning labels advising of the dangers.

The monograph also provides the following advice:

- NEVER install rearward facing infant/child restraints (eg., baby capsules) in the front seat, as serious injury may result from the force of the inflating front passenger airbag.
- If a forward facing child restraint is suitable for your child and is used in this front passenger seat position, always move the seat to its rearmost position, and buckle and tighten the seatbelt.

All children aged four to six years are also required to sit in the rear seat if the rear seat is not fully occupied by younger children². This legislation ensures that all children in rear facing child restraints and almost all forward facing child restraints are seated in the rear seat.

² New national child restraint laws effective 2009-10 require children under four years to be rear seated if one is available. This became effective 2009/2010, after the ATSB and FORS publications.

2.2.2 RACV

The following advice was provided on the RACV (2011) website:

- Always place children in the back seat. If there is no other option to the child sitting in the front, make sure the child is wearing the seatbelt and is not seated closer than 30cm to the passenger airbag.
- If a car has two or more rows of seats, then children under four years must not travel in the front seat.
- If all seats, other than the front seats, are being used by children under seven years, children aged between four and six years (inclusive) may travel in the front seat, provided they use an approved restraint or booster that is properly fitted.
- If your child must travel in the front seat and the car has a passenger frontal airbag, the seat should be moved as far back as possible. Always check the vehicle owner's manual for advice on airbag safety.

2.2.3 NRMA

The following information was provided on the NRMA (2011) website.

- Airbags save lives.
- In NSW, it's illegal to use a child restraint in a front passenger seat if there's a passenger-side airbag³.
- To avoid unnecessary injury:
 - never use a rearward facing infant restraint in the front passenger seat
 - fit all child restraints in the back seat.
- If you don't have a rear seat and have to use a forward facing child seat or booster in the front passenger seat:
 - position the adult seat as far back on the seat slide as you can
 - make sure the restraint's top tether (if provided) is attached firmly
 - discourage the child from leaning forward.

2.2.4 Holden Commodore Utility (2011) owner's manual

The Holden Commodore utility has a single row of seats. The passenger seat has a top tether anchorage and a frontal airbag. There is no disable switch for this airbag.

The owner's manual for the Commodore utility has illustrations of forward facing child seats and boosters being used in the passenger seat. There are side thorax and head protecting side airbags for the passenger seat but there are no warnings about child restraints for these airbags.

The Holden Commodore Utility manual contains the following advice:

- Where legally allowable you may install a forward facing child restraint in the passenger's seat but always move the seat back as far as it will go.
- Warning: Always move the passenger seat as far back as it will go before installing a child seat. This locates the child as far from the passenger airbag as possible.

Figure 3 shows similar advice for using booster seats and an extreme hazard warning that rearward facing infant capsules must not be used.

2.2.5 Ford Falcon Utility (2011) owner's manual

The Falcon Utility has a single row of seats. The passenger seat has a top tether anchorage and a frontal airbag. There is no disable switch for this airbag.

The Falcon Utility has side thorax and head protecting side airbags for the passenger seat but there are no warnings about child restraints for these airbags.

The owner's manual for the Falcon utility also has an extreme hazard warning about using a rearward facing restraint in the passenger seat. Figure 4 indicates that forward facing child seats can be used but that the seat should be moved as far back as possible.

The Ford Falcon Utility also has a prominent label adjacent to the top tether anchorage. There are also side thorax and head protecting side airbags for the passenger seat but there are no warnings about child restraints for these airbags. Figure 3 and 4 below are examples of airbag warning labels.



Figure 3 Airbag Warning Label ³



Figure 4 Airbag Warning Label ⁴

^{3,4} Images courtesy of Ford.

2.3 Factors that contribute to variations in airbag performance

Variations in Australian vehicles affect how occupants will interact with airbag systems. Factors include:

- make
- model
- year of manufacture
- structural designs
- airbag designs
- number of airbags
- seat track length
- availability of seatbelt pre-tensioners
- variations in seat width
- impact conditions
- occupant pre-crash position
- pre-impact braking and the
- use or misuse of restraints.

Due to the array of differences between vehicles, it is difficult to establish a 'one size fits all' approach to developing policy in relation to airbag systems.

3 Review of literature and published studies

3.1 History of airbags

Multiple airbags are now common in Australian vehicles. More than half of all new vehicles sold in Australia now come equipped with six airbags. These include driver frontal, front passenger frontal, driver thorax, front passenger thorax, right hand side curtain and left hand side curtain airbags (ANCAP, 2011). Driver and passenger frontal airbags have been standard on most models since the late 1990s. Front seat thorax protecting side airbags and head protecting side airbags, such as side curtains, have also been standard on many models for several years. Further, rear side thorax airbags, driver knee airbags and front passenger knee airbags are available on some Australian vehicle models.

The USA and Canada have had airbags in vehicles for longer than Australia, partly to address the problem of unrestrained adult occupants (wearing of seatbelts on front seating positions is still not mandatory in the US state of New Hampshire). Front driver and passenger airbags became mandatory in new US vehicles in 1998. Early designs of airbags manufactured prior to 1998 tended to be more aggressive to cater for these unrestrained occupants. In addition, children often travelled unrestrained. The combination of early designs of airbags and unrestrained children led to cases of children being killed by interaction with a deploying airbag. As of December 1, 2000, the US National Highway Traffic Safety Administration had identified ninety-nine child occupants fatally injured by airbags (Okamoto, 2002).

3.1.1 Current law in Australia

Under the AS/NZS 1754 standard (VicRoads, 2012), Australian law requires children aged under four to not travel in the front seat if a vehicle has two or more rows of seats. Children aged younger than seven must be restrained in an age appropriate child restraint and may not be seated in the front passenger position unless all other rear seats are occupied by younger children. Current legislation allows for children aged seven years and older may be restrained by an adult seatbelt only and occupy the front passenger seating position.

3.1.2 Appropriate age for children to be seatbelted in the front passenger position

Despite the current Australian legislation, much of the literature (Braver et al., 1998; Cummings et al., 2002; Durbin et al., 2005; Durbin, 2011; Glass et al., 2000; Graham et al., 1998 & Lennon et al., 2008;) and many organisations (American Academy of Pediatrics, 2011; CREP, 2011; Kidsafe WA, 2008; NHTSA, 2011; QISU, 2007 & Transport Canada, 2011) recommend that children under the age of twelve be seated in the rear whenever practical. Once children reach the age of twelve, however, it is generally considered appropriate for them to occupy the front passenger position. This appears to be based on similarities in body size and bone development between twelve year old children and small adult females and also based research that has confirmed the appropriateness of front passenger seating positions for small adult females.

3.1.3 Comparison of small adult females and twelve year old children

Table 1 compares the characteristics of eleven and a half to twelve and a half year old children to those of small adult females as represented by the Hybrid III fifth percentile female (HIII5F) Anthropomorphic Test Dummy (ATD).

Table 1

Characteristics of 11.5 to 12.5 year old children in comparison to the characteristics of small adult females

	11.5-12.5 Year Old Children	Small Adult Female	Difference
Total Standing Height	1510mm	1500mm	0.33%
Seated Eye Height	648mm	709mm	9.41%
Hip Breadth	280mm	307mm	8.89%
Buttock to Popliteal Length	408mm	427mm	4.38%
Weight	44kg	49.1kg	13.44%

Notes: Bilston and Sager (2007) report the height of 11.5-12.5 year old children from the 50th percentile.

Small adult females are represented by HIII5F ATD (NHTSA, 2011 & Humanetics Innovative Solutions, 2011).

Total standing height and weight of children are representative of 12 year old girls.

Seated eye height for 5th percentile Belgian female used. Comparison standing height between 5th percentile Belgian female and HIII5F ATD is 1534mm and 1500mm respectively (Dinbelg, 2005).

It is seen that the key body dimensions are similar for average eleven and a half to twelve and a half year old children and small (fifth percentile) adult females. In the current data set used, the height of fiftieth percentile twelve year old girls is actually greater than that of small adult females, however the difference is considered negligible.

The HIII5F female ATD represents a small adult female. Modern vehicle safety systems are designed to offer protection to fifth percentile adult females. For example, FMVSS 208, a regulatory occupant protection test in the US, requires that injury measures for the fifth percentile adult female are below specified values (Hollowell et al., 1999). Given that twelve year old children have similar anthropometric characteristics to small adult females as shown in Table 1, airbags designed to offer protection to small adult females are likely to offer similar protection to children aged twelve years and above.

3.1.4 Review of US databases

For children younger than twelve, several North American studies support the position that these children should not occupy front seating positions. A study of US Fatal Accident Reporting System (FARS) data by Cummings et al. (2002) supports advice that children younger than thirteen should not sit in front of an active airbag. Despite finding that second generation airbags pose lower risk to restrained children in front seating positions, Arbogast et al., (2005), supported the recommendation to seat children younger than thirteen years of age in the rear rows. In an analysis of US FARS data, Glass et al. (2000) found that the risk of death to restrained children aged nine to twelve in the front and exposed to a passenger frontal airbag was equal for restrained children of the same age seated in the rear and in this study passenger frontal airbags appeared to offer protection to restrained nine to twelve year olds.

However, in a study of motor vehicle crashes using US National Automotive Sampling System (NASS) cases, Newgard and Lewis (2005) concluded that children aged fourteen and under may be at risk for serious preventable injury when seated in front of a passenger frontal airbag. It should be noted that this data is US specific only and may not be directly applicable to Australia. Furthermore, the data is out of date as the data was for motor vehicle crashes from 1995 to 2002 and improvements in airbag design and vehicle structure since the report was published should be considered. Finally it should be considered that while some child occupants were restrained in child safety seats, other child occupants were restrained in a seatbelt only or were unrestrained.

More recently, Bilston et al. (2010) compared overall outcomes for front and rear seated occupants with vehicle model year in the US NASS database, and found that even in newer vehicles child occupants aged nine to fifteen have less risk of serious injury when seated in the rear, compared to the front. The results of this study also showed a decline in risk of serious injury to children aged nine to sixteen seated in the front for vehicles built between 1997 to 2007 compared to vehicles built between 1990 to 1996.

3.2 Comparison of restrained and unrestrained child occupants

Serious injury and death attributed to airbag deployment is higher for unrestrained and improperly restrained child occupants than properly restrained children (Arbogast et al., 1999; Hinojosa et al., 2005; Huff, 1998; Menon et al., 2002; Okamoto et al., 2001 & Quiñones- Sato et al., 2002). This is because the lack of restraint allows the child to move closer to the airbag during pre-crash braking and the initial stages of impact so that when the airbag does deploy the head and neck are in a more vulnerable position (Bailey et al., 2000).

The US Morbidity and Mortality Weekly Report (1996) reported that, of thirty-two cases involving a fatal injury to a child occupant aged less than twelve years caused by a passenger frontal airbag, unrestrained or improperly restrained child occupants accounted for more than 62% of fatalities (twenty-one cases). Of the restrained child fatalities, 28% (nine cases) were restrained in a rearward facing restraint and 6% (two cases) were restrained using adult lap-sash seatbelts only. The year range for the reviewed cases was 1993 to 1996.

As of December 1, 2000, the US NHTSA had identified 99 cases of airbag induced fatality in children younger than twelve years of age (Okamoto et al., 2002). Over 70% (71 cases) of fatalities involved unrestrained or improperly restrained children. Eighteen cases involved children in rear facing child seats, three cases involved occupants in forward facing child seats and in six cases the occupants were restrained using adult lap-sash seatbelts only. One case appears to be unaccounted for.

Quiñones-Hinojosa et al. (2005) examined cases of low speed motor vehicle crashes from real world NHTSA and US National Pediatric Trauma Registry data. Out of 263 cases where airbag deployment caused injury or death in a child under nineteen years of age, only six (2.3%) were properly restrained. Of the 159 fatalities, 110 (69.2%) children were unrestrained, 47 (29.6%) were improperly restrained, and 1 (0.6%) was properly restrained. Of the 104 non-fatal injuries, 43 (41.3%) children were unrestrained, 52 (50%) were improperly restrained, and 5 (4.8%) were properly restrained. In this study occupants were considered improperly restrained if the Child Restraint System (CRS) was located in a front seat, despite being otherwise correctly fitted or if they were using a restraint not appropriate for their age.

In sum, unrestrained children are grossly over represented in real world cases of airbag induced injury and death.

The extent to which unrestrained or improperly restrained children's injuries were worse in the presence of the deploying airbag than they might have been in its absence is very difficult to ascertain from retrospective crash studies, and was not determined in Quiñones-Hinojosa et al. (2005).

There is no study that directly compares the outcomes for restrained versus unrestrained child occupants exposed to airbags. As described above, most studies categorise unrestrained children together with inappropriately or incorrectly restrained children. However, from these studies, it is clear that serious injury and death attributed to airbag deployment is higher for unrestrained and improperly restrained child occupants than properly restrained children.

3.3 Airbag induced fatalities and injuries in restrained child occupants

3.3.1 Cases of airbag related fatalities

To date, there have been no reported cases of child occupants killed or injured from passenger frontal airbags or any other type of airbag in Australia (Lennon et al., 2008). The first reported child airbag fatality occurred in the USA in 1993 from first generation airbags (Martinez, 2003). The majority of fatalities to child occupants from passenger frontal airbags are due to head and neck injury. For example, Hinojosa et al (2004) reported that all but 5.7% of fatalities and 19.2% of non-fatal injuries involved the head or the spine. Children are particularly susceptible to head and neck injuries and isolated head injuries occur more frequently in infants (Sato et al., 2002).

3.3.2 Atlanto-occipital dislocation

Atlanto-occipital dislocation, where the spinal column separates from the skull in shear, is characteristic of cases where an airbag deploys directly into the face of a child occupant in near proximity to the airbag (Bailey et al., 2000; Giguère, 1998; Okamoto et al., 2002 & Sato et al., 2002;). Bailey et al. (2000) describe atlanto-occipital dislocations in children caused by interaction with frontal passenger airbags arising from a combination of forces acting about the axial skeleton. *Extreme hyperextension, lateral flexion, hyperflexion and distraction along the long axis of the body may produce atlanto-occipital dislocation. Rupture of the tectorial membrane and alar ligaments results from hyperextension and lateral flexion, respectively. Giguère et al. (1998) states that the Alar ligament is the most powerful stabiliser of the atlanto-occipital joint; its disruption is disastrous for craniocervical stability.* Atlanto-occipital dislocation is an uncommon crash related injury outside of airbag induced child fatalities and was fatal in the majority of reported cases due to the high cervical spinal cord and brainstem injuries associated with it affecting vital functions.

3.3.3 Airbag module and gas propellant injuries

Injuries to the face and eyes of both adult and child occupants have been reported from contact with the airbag, airbag module cover and gas propellants. Facial injuries from these causes include lacerations, fractures, bruising and burns (Bailey et al., 2000; Duma et al., 2002 & Rosner 1996, as cited by Giguère, 1998). Hutt and Wallis (2004) describe three sources of burn injuries from airbags:

- chemical burns from release of sodium hydroxide (a by-product of the pyrotechnic reaction)
- thermal burns from contact with propellant gases generated through pyrotechnic reaction
- friction burns from contact with rapidly moving airbag material.

Alkaline chemicals in an airbag can cause inflammation of the cornea known as alkaline keratitis, and that sodium hydroxide, a by-product of the pyrotechnic reaction, can also irritate and damage the eye (Smally et al., 1992, as cited by Browning et al., 1999).

Contact with an airbag, or airbag module cover has also caused lacerations, bruising and fractures to other body regions, however these have been non-fatal (Bailey, 2000; Duma et al., 2002 & Giguère, 1998). Airbags have also caused burns to other body regions (Sato et al., 2002).

3.3.4 Injuries and fatalities from passenger frontal airbags

Fatalities and serious injuries from passenger frontal airbags have been reported in several countries (Arbogast et al., 2005; Giguère et al., 1998; Grisoni et al., 2000; Huelke., 1997; Huff et al., 1998; Kindelberger et al., 2003 & Sato et al., 2002), however much of the literature examines fatalities and injuries caused by the first generation of airbag designs (prior to 1998) particularly in North America.

Figure 6 demonstrates the incompatibility of first generation passenger frontal airbags with rear facing infant restraints (Insurance Institute for Highway Safety, 2011). Rather than controlling deceleration, the airbag makes contact with the restraint during deployment, adding potentially injurious forces to the child occupant and lifting the restraint into the seat violently.



Figure 5 Deployment of a first generation airbag in close proximity to a rearward facing child restraint in the front passenger seating position

3.3.5 Comparison of airbag designs

Compared to current airbag designs, first generation airbags were particularly aggressive, deployment volume was much greater and deployment speed was higher (Hutt, 2004 & Lennon et al., 2008). First generation passenger frontal airbags were designed to offer protection to unrestrained occupants whereas modern airbag designs in the Australian fleet are designed to provide supplemental protection to restrained occupants. That is, they are designed to work in conjunction with a seatbelt. Due to injuries and fatalities being sustained by occupants from first generation airbags, changes were made to airbag designs to decrease the airbag deployment force (MacLennan, 2008).

These redesigned airbags (commonly known as ‘depowered’ or ‘second generation’ airbags) were less aggressive and less likely to cause injury (Lennon et al., 2008). They were introduced to the US fleet (and subsequently to the global fleet) from 1998 onwards (Olson, 2006 & MacLennan, 2008). Olson (2006) estimated that second generation airbags were 20-35% less aggressive than first generation airbags, having substantially less volume than previous designs. Moreover, these depowered airbags usually deploy in a different manner than first generation airbags. Rather than deploying rearwards straight from the dashboard, current designs deploy initially upwards (towards the windscreen) and then unfurl towards the occupant. For adult restrained occupants, they are designed to reach full deployment volume before the occupant comes in contact with the airbag.

Figures 6 and 7 below show the differences in deployment volume between first generation and later generation (depowered) passenger frontal airbags.



⁴ Figure 6 First generation airbag



Figure 7 Depowered airbag⁵

Furthermore, the difference in deployed volume and also the position of the airbag relative to the dummy's face are illustrated in figures 8 and 9 below.



Figure 8 2005 Toyota Landcruiser⁶



Figure 9 2010 Toyota Landcruiser⁷

⁴ Volvo 850, 1994 (Volvo Canada 2011).

⁵ Hyundai Veracruz, 2007 (Motortrend Magazine 2011).

^{6, 11} Images are courtesy of ANCAP.

Figure 8 shows the dummy's face has contacted the airbag prior to full deployment, whereas Figure 9 shows the airbag as being fully inflated prior to the dummy's face making contact. Contacting a deploying airbag can result in much higher forces and increases the risk of injury. It is also worth noting that the deployment timing is different between the two cases. Full deployment occurs around 72ms from the time of first impact in Figure 9 whereas full deployment occurs at around 60ms in Figure 9 along with less vehicle crush than the image on the left.

Some advanced airbag designs vary deployment characteristics based on occupant size and weight depending on whether the occupant is restrained (via seatbelt buckle contact switch), the position of the occupant's seat (seat track position sensor) or even the severity of the crash (combination of in-vehicle brake, yaw, pitch and acceleration sensors). These factors are sensed by in-vehicle sensors such as seat contact switches or infrared detectors. Identifying whether a vehicle is equipped with first generation, depowered or advanced airbags systems can be difficult as this level of technical information is generally not made publicly available by manufacturers. An educated guess can be made based on year model and sometimes the type of system can be identified if airbag deployment footage is available however it is not always conclusive. No accurate estimation of the number of first generation, depowered or advanced airbag systems in the Australian market has been made and except for limited cases identifying the type of airbag system a vehicle is equipped with is not possible without manufacturer cooperation.

3.3.6 Background for current recommendations and policy positions

It is likely that current recommendations and policy positions on child seating positions and restraint use are mostly based on studies of first generation airbags and little differentiation is made between earlier and later designs of airbags, despite some limited evidence that modern airbag designs pose less risk to child occupants in child safety seats.

One Australian test series conducted by the former NSW Roads and Traffic Authority (RTA) undertook a limited series of crash tests of child dummies in various restraint systems (rearward-facing restraints, forward-facing child restraints, booster seats and seatbelts) exposed to front passenger airbags, and reported that modern airbag designs did not systematically increase the recorded dummy dynamic responses (McIntosh, 2004 & Suratno et al., 2009). For frontal sled impact tests, the presence of an airbag reduced the recorded child dummy head accelerations even when the seat was in the fully forward position. For booster seats, the presence of an airbag reduced mean peak resultant head acceleration by more than 15%. For forward facing child restraints, mean peak resultant head acceleration was reduced by more than 18%. Similar results were observed for rearward facing restraints with mean peak resultant head acceleration reduced by almost 20% however concern was expressed over scenarios where the restraint abuts the airbag module.

The results from this work should be viewed with caution as the head kinematics along with airbag and restraint interactions were not reported. Furthermore there are no validated injury reference values available for the dummies used in that test series, limiting the ability to draw conclusions about absolute injury risk. While the authors conclude that the front passenger airbag has the potential to significantly reduce injury risks in some cases and at worst makes no difference to a child correctly and appropriately restrained in a forward facing restraint or booster, the reported head accelerations in the child dummies appear to be unacceptably high for both airbag and non-airbag cases. Importantly, whether or not the airbag makes contact with the restraint and the child dummy before it was fully deployed was not addressed. It is also unknown whether the test series included any larger rearward facing restraints (Type A2) that are becoming more common on the Australian market and sit closer to the dash.

This work is the only laboratory study of the interaction between second generation airbags and dummies restrained in child restraints. However, Menon et al. (2001) used sled testing and computer simulation to examine the interaction between three year old and six year old Hybrid III (HIII) dummies inappropriately restrained in lap-sash seatbelts. They found that in the presence of a second generation passenger airbag, the head injury risk (HIC) was lower for a three point seatbelted three year old HIII ATD when the seat track was positioned fully forward. There were no differences in HIC or other injury values when the seat track was in the fully rear position. The same study observed reduced HIC values for a six year old HIII ATD restrained by an adult three point seatbelt exposed to a deploying passenger frontal airbag when the seat track was in the mid position or fully rear position compared to scenarios where no passenger airbag was present.

Note that neither the three year old ATD nor the six year old ATD (or more precisely, the children they are representing in these tests) would be considered appropriately restrained, as they are too small to achieve good belt fit in an adult seatbelt. This is reflected in the recently introduced child restraint laws that require all children under seven years to use a size appropriate child restraint (NTC, 2007).

In the real world, recent evidence suggests that children are still safer in the rear seat, even though adults in modern vehicles may benefit from airbags and other front-seat safety technologies (Bilston et al., 2010; Lennon et al., 2008 & Winston et al., 2007). However these studies were not designed to look explicitly at the influence of airbags on injury risk to child occupants using dedicated child restraint systems. Arbogast et al. (2005) reported that children aged three to fifteen restrained using an adult seatbelt and exposed to second generation passenger airbags experienced a 41% reduction in the odds of serious injury compared to children exposed to first generation airbags.

There is therefore a paucity of data supporting the placement of children in dedicated restraints, particularly rearward facing restraints in front seating positions with passenger airbags if the rear seat is available. In theory, modern airbags may not significantly increase the risks for children in front seating positions compared to non-airbag equipped vehicles, and Arbogast (2005) suggests that changes in frontal passenger airbag design have been successful in lowering the risk of injury to restrained child occupants. However, this requires further validation to provide sufficient evidence to support the placement of older children in front seat airbag equipped positions, as that study highlighted the relative risks of airbag generations rather than assessing the absolute risk of injury for older children in front passenger positions.

3.3.7 Comparison of airbag designs

No reports of death or serious injury in child occupants from thorax side airbags have been identified in the literature, however concerns have been raised by some researchers particularly as injury caused by side airbags has been identified in adult occupants (Kirk & Morris, 2003) and cadaver testing has demonstrated the potential for injury (Duma et al., 2001 & Kallieris et al., 1997).

Gehre, Schäfer & Schindler (2001) identified upper neck axial rotation moments in excess of accepted injury reference values in full scale crash tests using a three year old HIII ATD restrained using a booster cushion with a lap-sash seatbelt. Injury reference values developed by a consortium of US organisations named the Side Airbag Out-of-Position Injury Technical Working Group (Side Airbag OOP TWG) (Lund, 2003) were used. The authors concluded that thorax airbags with a cylindrical profile generate higher neck axial rotation moments than thorax airbags with flatter profiles due to the shape of the airbag and the deployment direction towards the dummy were noted as the cause of the upper neck axial rotation moment. It may be that the greater lateral projection and deployment directly towards the dummy ribs tends to rotate the head via contact with the side of the face by the inflated forward portion of the airbag as the rearward portion is compressed.

The same study concluded that, for rearward facing child restraints, the side airbags are not dangerous due to the distance between the restraint and the point of airbag deployment.

In addition, Insurance Institute for Highway Safety (2012) states that *the risk of injury from a side airbag in the rear seats is extremely low for properly restrained and positioned adults or children. Children shouldn't lean against doors because the initial deployment force may be harmful.*

Tylko (2000) raised similar safety concerns for out of position children interacting with thorax as well as thorax head protecting side airbags. This concern is based on static airbag deployment testing and full scale crash tests for restrained children in front and rear seat positions. The results of full scale crash testing showed large extension moments in the upper neck were observed in unrestrained six year old HIII ATDs seated on a booster cushion and positioned with the neck thorax junction in line with and in close proximity to the top margin of the side airbag module. The adult seatbelt was not used in order to examine the interaction of the child ATD and the airbag independent of any seatbelt effects. This 'out of position' test simulated a reclining, unrestrained child resting against the B pillar and door trim. Upon contact with the airbag (into the upper back of the dummy) the ATD's chest was thrust forward and the unsupported head lagged behind, resulting in neck moment values indicative of serious neck injury. A follow up study of correctly positioned child dummies in child restraints found that there was little risk posed to children in child restraints from side airbags (Tylko & Dalmotas, 2003).

3.3.8 Curtain airbag related fatalities and injuries

No literature reporting incidents of serious injury or death in children from curtain airbags, or relevant laboratory work was identified. Tylko and Dalmotas (2000) investigated the effects of curtain airbags in full scale crash tests, however due to limitations in dummy biofidelity and technical issues, the results were inconclusive and the authors recommended further testing.

A review of EuroNCAP crash tests where there was a curtain airbag deployment in proximity to a restrained child ATD occupant showed very little interaction between the child ATD and the curtain airbag during airbag deployment (Hobbs, 2007). Tests included 50km moving barrier tests and pole side impact test scenarios with child ATDs in rearward facing child seats occupying the second row left hand side position, on the struck side of the vehicle. This suggests that the risk to rearward facing child restraint occupants from deploying curtain airbags in side impacts is low.

While there may be some risk to child occupants who are in the path of a deploying curtain airbag, for example, where a curtain airbag deploys downwards onto the head or neck of a child leaning against the door or window sill, it is likely to be lower than the risks posed by interaction with rigid door surfaces or of an intruding vehicle. However this is based on assessment of theoretical risk as there have been no studies examining this issue and this assessment is not supported by any identified literature or real world cases. There is a need for investigation of this issue.

3.3.9 Knee airbag related fatalities and injuries

No literature on knee airbags and child occupants was found. The literature did not identify any incidents of serious injury or death in children from knee airbags.

In theory, there may be some risk of lower leg injuries to older children in forward facing restraints or boosters if the child's legs are projecting horizontally past the edge of the seat cushion. A preliminary review of images of deployed knee airbags from vehicle manufacturers and from ANCAP crash tests suggest that there would be no increased injury risk from knee airbags in the case of rearward facing child restraints. However this has also not been studied and so is not supported by any identified literature or real world cases, and requires further study.

3.4 Vehicle standards associated with child occupants and airbags

3.4.1 Frontal airbag standards

There appear to be no regulations, standards or guidelines that aim to minimise the risk of injury to children less than twelve years of age from frontal airbags, including front passenger airbags.

US regulation FMVSS 208 sets injury performance requirements for adult dummies in crash tests, including small adult females (HIII5F) which are equivalent in size to twelve year old children (Hollowell et al., 1999). However the standard does not set injury requirements for younger occupants. It requires vehicles with front passenger airbags to have a warning label such as in Figure 10 below. Optionally, the vehicle may have a Dynamic Automatic Suppression System (DASS) that automatically controls whether or not the airbag deploys during a crash by:

- (1) Sensing the location of an occupant, moving or still, in relation to the airbag
- (2) Interpreting occupant characteristics and location information to determine if the airbag should deploy
- (3) Activating or suppressing airbag system based on interpretation of occupant characteristics and location.

It should be noted that the (geometric) test procedures for DASS include three year old test dummies.



Figure 10 Airbag warning label⁸

Hobbs (2007) describes the “Hazardous Airbag Deployment Modifier” which is the EuroNCAP consumer rating program for new cars, a penalty to driver or front passenger airbags that deploy in a manner that might cause head or facial injury to the occupant during the 64km/h frontal offset crash test is applied. A penalty is applied if the airbag unfolds in a manner that sweeps across the face of the dummy (an eye injury risk) or deploys with a rearward velocity exceeding 90m/s within the head zone, defined as the area 150mm forward of the dummy's face (brain or neck injury risk). This modifier is assessed by video analysis of the crash test, where the dummy is a fiftieth percentile adult male. It is not intended for assessment of the risk to child occupants but it is considered that it could be adapted for this purpose.

3.4.2 Side and curtain ('rail-mounted') airbag standards

In July 2003, the Side Airbag OOP TWG published a set of recommended procedures for evaluating occupant injury risk from deploying side airbags that includes procedures for assessing risk to out of position child occupants in US vehicles (Lund, 2003)⁹. The purpose of the Side Impact OOP TWG is to develop a common understanding of the risks associated with side airbag deployments and ways to minimise those risks.

⁸ Image courtesy of Ford.

⁹ The Side Impact OOP TWG members include Alliance, AIAM, AORC, Autoliv, BMW, Bosch, Breed, DaimlerChrysler, Delphi, Ford, General Motors, George Washington University, Honda, Hyundai, IIHS, Dale Kardos and Associates, Mazda, Mitsubishi, Nationwide Insurance, NHTSA, Nissan, Porsche, Simula, Subaru, Takata, Toyota, Transport Canada, TRW and Volkswagen.

While these are voluntary guidelines, the Technical Working Group expects that vehicle manufacturers and their suppliers adopt the procedures and recommendations and it is understood that most manufacturers offering vehicles for sale on the US market currently use these guidelines in the development of side and curtain ('rail-mounted') airbag systems. It is likely that most cars offered for sale in Australia have side and curtain airbags developed in accordance with these guidelines, since they provide a degree of indemnity for the manufacturer, however since details of airbag design and performance are often commercial in confidence, compliance with non-mandatory guidelines is difficult to confirm conclusively. Comparison of local and overseas crash tests of the same vehicle model in NCAP tests support the case that Australian airbag systems are typically the same as those used overseas.

Importantly the Side Impact OOP TWG's procedures identify that:

Some level of inflation injury is inherent with any inflatable restraint system that reduces the risk of injury in side impacts. The group's work reflects the best current information on how to measure the risk of significant injury from the airbag inflation itself and assure that it is very small, but the risk cannot be made zero.

The procedures also note that at the time of writing research into side airbag inflation injuries was ongoing and as such the recommendations may require future revision.

In Europe, there is an ISO technical report outlining draft procedures for assessing 'out of position' occupant airbag interactions for side impacts (N556 ISO/DTR 14933 - Road vehicles - Test procedures for evaluating occupant interactions with deploying side impact airbags). This includes three and six year old child dummies, and the fifth percentile female dummy, that are representative of a twelve year old child.

3.5 Airbag deactivation

In both North America and Europe, some vehicles have switches that allow front passenger airbags to be disabled when a child occupant is sitting in that seating position. Due to local regulations about child restraint usage this is mandatory in some countries. For example, in Sweden where children are required to be restrained in rear facing restraints up to three years of age, the front seat is often the only place where these large CRS can be accommodated. These switches can be manual or automatic, the latter being based on sensor systems that detect a child restraint in the front seat. Currently in Australia, there are very few vehicles that have switches to enable airbags to be switched off when a child occupant is in the front seat, as Australian regulations require that the vehicle must be able to meet the normal frontal crash tests under the Australian Design Rules 69 and 73 with the airbag deactivated if a switch is fitted (personal communication, T. Belcher).

There have been reports in the USA of 'misuse' of airbag switches resulting in injuries to both child and adult occupants. Two forms of misuse occur – where a child occupant is in the front passenger seat in a child restraint and the airbag is not switched off, and where an adult occupant is in the front passenger seat and the airbag has not been reactivated. Johanssen et al. (2009) examined both forms of misuse in Europe. In an observational study, 15% of children transported in the front seat did not have the airbag deactivated, largely in older vehicles. Conversely, approximately 10% of adult passengers were travelling in the front seat without reactivating the airbag. No misuse of either type was observed in automated sensor based systems.

It should be noted that although the design of the switches is covered in the relevant US regulation FMVSS208 there do not appear to be any regulations or laws that require drivers to use an airbag deactivation system when a child restraint is installed in the front passenger seat.

4 Consultation with experts

Twenty-three Australian and international experts were contacted and invited to make comment on any matters related to safety of restrained child occupants in seating positions where airbags are present. Responses were obtained from seven experts.

Expert responses indicated there was no existing data beyond what had already been published, however one respondent contacted the Queensland Injury Surveillance Unit (QISU). QISU conducted a search of their injury database where the term 'airbag' (including misspellings) was used at triage for injuries resulting from motor vehicle crashes in years 1999 to 2010, inclusive. QISU advised that as a result of their search a total of forty cases where an injury directly associated with an airbag may have occurred were identified, but that only three cases may be relevant to this project. A copy of the search results were obtained for review.

A preliminary review of the data did not conclusively identify cases where airbag induced injury had occurred. With the level of detail supplied it was not possible to confirm whether the child occupant was seated in proximity to a deploying airbag and no details of the type of restraint used were available. Given the nature of the database, it is unlikely that further examination of this data will provide additional information.

5 Review of US NASS injury database

A search of US National Automotive Sampling System (NASS) was undertaken to review incidents of airbag induced injuries and fatalities in restrained children from passenger frontal, side (both seat and door mounted) and curtain (rail mounted) airbags. Motor vehicle crashes within the system for years 1999-2009 were searched.

5.1 Search terms

Table 2 shows the terms that were used when searching the NASS database.

Table 2
NASS search terms

	Passenger frontal airbags	Curtain airbag (rail mounted)	Other side airbags (door, panel or seat mounted)
Mortality/injury severity	All	Fatality, serious injury	Fatality, serious injury
Age	0-12	0-12	0-12
Seating position	Front right	Front right	Front right
Airbag available	Yes	Yes	Yes
Airbag deployed	Deployed during crash (as a result of impact)	Deployed during crash (as a result of impact)	Deployed during crash (as a result of impact)
Airbag location	All	Roof side rail	Door panel seat back
Child seat used	Yes	Yes	Yes

Notes: The search generated results where at least one occupant of any vehicle involved in the incident has an occupant with injuries/fatality corresponding to the mortality or injury severity level selected. Restrained child occupants may not actually be the occupant of interest.

5.2 Summary of NASS search results

5.2.1 Passenger frontal airbags

From the twenty one relevant cases that were found, five incidents of minor airbag related injury were identified. There were no airbag related fatalities. Variations in crash type, crash severity, occupant age, airbag type and the limited sample size meant that no patterns in injury causation could be determined however the data shows that in rare cases both first generation and depowered airbags caused minor injuries.

5.2.2 Curtain airbags

From the ten relevant cases that were found, no incidents of airbag related injury or airbag related fatalities were identified.

5.2.3 Side airbags

No cases involving restrained child occupants exposed to side airbags were identified.

Appendix 1 shows the details of the individual relevant cases reviewed.

6 Review of ANCAP test results

6.1 ANCAP test footage and test conditions

ANCAP frontal offset crash tests include two adult dummies in the front and 1.5 year old and 3 year old P series anthropomorphic test dummies (ATDs) as outboard rear seat occupants. The P3 ATD is seated in the outboard position behind the driver and the P1.5 ATD is seated in the outboard position behind the front passenger. The P1.5 and P3 are restrained in forward facing child restraints, using top tether anchorages. The frontal offset test is conducted at an impact speed of 64km/h.

A review of ANCAP high speed crash test footage was undertaken to observe current generation passenger frontal airbag deployment characteristics, particularly deployment timing and maximum rearward projection. The video footage was also analysed to estimate maximum forward head excursion of the P1.5. The purpose for this analysis was to estimate whether the P1.5 would come into contact with the passenger frontal airbag if seated in the same forward facing child restraint in the front passenger position. Footage from a single 2009 ANCAP frontal offset crash test was analysed. The test footage selected was representative of a typical ANCAP test and typical airbag, vehicle and ATD behaviour was analysed.

6.2 Assessing the likelihood interaction with a passenger frontal airbag

The method used involved determining the points of maximum rearward airbag projection, P1.5 maximum forward head excursion and the distance between adult head initial position and airbag maximum forward projection¹⁰. Timings of various events as displayed on the test video were also noted. Using vehicle decals as reference points, an approximate estimate of the rearward projection of the passenger frontal airbags and the P1.5 dummy head forward excursion can be measured. Test set-up notes and pre-test still images were used to determine how much further rearward the seat could be positioned.

6.2.1 Method

The analysis used the following method:

1. Determine P1.5 head initial position. Take snapshot and place reference point. Note time.
2. Determine point of P1.5 maximum head excursion. Take snapshot and place reference point. Note time.
3. Determine adult head initial position. Take snapshot and place reference point. Note time.
4. Determine time at which airbag reached full deployment. Take snapshot and place reference point. Note time.
5. Determine point at which adult head contacts airbag. Take snapshot and place reference point. Note time.
6. Determine child forward head excursion by measuring distance between initial head position and point of maximum excursion.
7. Determine distance between adult head initial position and point of contact with airbag.
8. Determine time taken from first forward movement of the P1.5 head until the point of maximum forward excursion
9. Compensation factor for P1.5 head compared to adult. Note that for this analysis a compensation factor of 'Omm'. It was assumed that there is no significant difference between child ATD head and adult ATD head initial position. Further work is required to make an accurate measurement.
10. Obtain seat track positions. Determine distance between mid and rearmost position.

¹⁰ The method used here differs to the method used in CREP dynamic assessments to calculate maximum forward head excursion. CREP measures head excursion relative to a point on the CRS, here the movement is relative to the seatback.

6.3 Assessment results from ANCAP testing

An example of an ANCAP crash test is shown in Figures 11 - 14 below.

6.3.1 Child ATD maximum forward head excursion

Figures 12 and 13 show P1.5 dummy head initial position and maximum forward excursion respectively. The blue vertical lines show the forward most position of the child head.



Figure 11 P1.5 Initial head position



Figure 12 P1.5 Maximum head excursion

Measurement determined that the maximum forward head excursion of the P1.5 head was approximately 275mm.

6.3.2 Distance between adult ATD initial position and maximum forward head excursion

Figures 13 and 14 show front passenger ATD's initial head position and airbag contact. The blue vertical lines show the forward most position of the adult head. Note that in this case head contact with the airbag coincides with full inflation of the airbag.

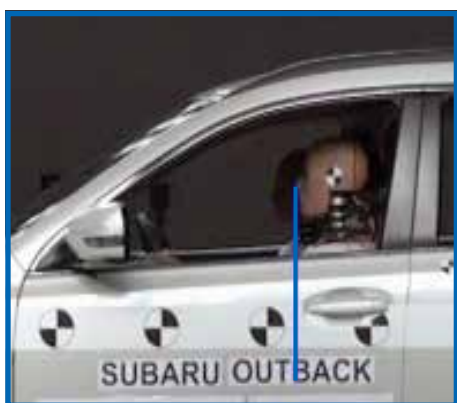


Figure 13 Adult ATD initial head position



Figure 14 Adult ATD contact with airbag

The distance between the adult passenger ATD face and maximum rearward airbag projection was measured to be 62.5mm. The passenger airbag was found to be fully inflated at 72ms from time of first vehicle contact with barrier.

6.3.3 Time to reach maximum forward head excursion

The P1.5 ATD head began to move forward at 51ms. The time between this initial head movement and maximum forward head excursion was 106ms. The adult front passenger ATD head began to move forward at 40ms. The time between this initial movement to airbag contact was 32ms. Note that the adult dummy makes contact with the passenger airbag at the time when the airbag reaches full inflation.

6.3.4 Likelihood of child's head making contact with deploying airbag

The passenger airbag was found to be fully inflated at 72ms from time of first vehicle contact with the barrier. Projecting the P1.5 dummy head movement into the front seat position we find that 32ms after first movement, the child ATD head had moved approximately 60mm forwards, slightly less than the 62.5 mm than the adult head had travelled. In this case the child head would be expected to contact the passenger frontal airbag at a time just after the airbag has fully inflated.

6.3.5 Likelihood of child's head making contact with a fully deployed airbag with a seat in the mid track position

With the seat in mid-position (as per the ANCAP test) the P1.5 head is estimated to penetrate a maximum of 212.5mm into the fully inflated airbag (note that no judgement on whether the airbag would be beneficial or pose injury risk are made here). Thus airbag contact is judged to be certain with the seat in mid position.

6.3.6 Likelihood of child's head making contact with a fully deployed airbag with a seat in the rearmost track position

If the front passenger seat track were in the rearmost setting the seat would be positioned a further 130mm rearward. If the front passenger seat were positioned in the rearmost position the child head would penetrate at most only 82.5mm into the passenger airbag, thus even in the rearmost position it is considered highly likely that head contact with the airbag would still occur.

6.3.7 Further discussion

The scenario where the front passenger seat is positioned fully rearward was included in order to achieve a position where the child would be furthest from the deploying airbag, thus minimising the interaction between the child head and the airbag and also to ensure maximum time was available for the airbag to reach full deployment, however a number of issues became apparent.

Firstly, while positioning the front seat fully rearward may reduce risks to a restrained child occupant with regards to airbags it may increase risks due to other factors, such as interaction with the B pillar during side impact crashes or poor belt geometry, particularly if the child's shoulder is located further rearward than the seatbelt top mount. Poor belt geometry could allow further forward excursion in some cases and may increase chest loads if there is a substantial gap between the belt and the child's chest for children in booster seats. For children in rearward or forward facing restraints it may not be possible to securely install the restraint or the restraint may sit skewed on the seat cushion. Further research to examine the effects of poor belt geometry caused by seat position is recommended.

Potential increased risks for rear occupants due to rearmost front seat position were also identified. If the front seat is positioned fully rearward it increases the likelihood that a rear seat occupant will interact with the seat, particularly in frontal crashes. Further research is needed to identify the real risk to rear seated occupants, particularly properly restrained child occupants, in cases where the front passenger seat has been moved rearwards.

6.3.8 Conclusion of analysis

From the above analysis it was concluded that:

- The airbag would be fully inflated before contact between the child head and the airbag occurred.
- With the seat in mid-position contact between the fully inflated airbag and child head would have occurred.
- With the seat in rearmost position contact between the fully inflated airbag and child head would likely have occurred.
- There is no data to indicate whether contact between a young child's head and a fully inflated airbag is associated with an increased risk of head or neck injury, as there are no reliable neck injury criteria for young children.

6.4 Limitations of method

While this method provides an approximate estimate of the maximum forward head excursion of the P1.5 ATD and assesses whether interaction with the passenger frontal airbag is likely, the measurement error may be significant due to factors including parallax error, poor reference increments and errors due to footage resolution. Some compensation may also need to be made for differences in adult dummy versus child dummy initial head position. In this case it has been estimated that the child head and adult head are approximately an equal distance from the seatback, however this is an approximate estimation only and may not be the case in all ANCAP tests.

Moreover, the rear seat occupant excursion measurements are only an indirect proxy for actual child dummy excursions that would occur in the front seat, as the tests analysed use forward facing child restraints anchored with a top tether. Top tether anchorages are not typically available in front seating positions of Australian vehicles with two rows of seats. In vehicles with a single row of seats where top tether anchorages are present, the location of the tether anchor typically differs from that in the analysed tests, which will affect forward excursion of the child restraint and its occupant. Therefore, these data may underestimate the head excursion of child restraint occupants in the front seat. Head excursions of older children, including those using booster seats and seatbelts have not been estimated and are likely to be larger. There is also likely to be significant variation between specific models of child restraint.

Further adjustments in calculations may need to be made for differences in seat back angle, seat construction, seat cushioning, airbag profile, differences in kinematics between seating positions and parallax error for still image analysis. Furthermore a method to improve accuracy of measurement would be highly desirable.

It may be possible to extend this method to measure and assess injury risk for the P3 dummy however some adjustments may be required to compensate for differences in vehicle and dummy response due to the nature of the offset impact. For example, occupants on the struck side of the vehicle experience higher peak deceleration than on the non-struck side. Furthermore the P3 ATD has a greater seated height than the P1.5 and would therefore be expected to have increased head excursion.

This method could be further developed to remove measurement errors and/or ANCAP could be approached to provide further camera angles, higher resolution images, measurement reference decals, pre/post test dummy/seat measurements or dummy instrument readings for use in measuring airbag deployment and child ATD movement. Note that obtaining such data would require equipment in addition that that used in standard ANCAP crash tests. The ideal method would test child dummies in child restraints in the front seat under realistic conditions, such as in utilities where child restraint anchorages are available for front passenger seating positions. This is, however, expensive.

7 Key findings

The following key findings were found from a study of the literature and crash databases:

- While there were incidents of first generation frontal airbags causing serious and fatal injury to front seated child occupants using child restraints in North America, there is no evidence of any such injuries occurring in Australia.
- Airbags in Australian vehicles have always been supplementary systems and are likely to have been less aggressive than first generation airbags seen commonly in North America prior to 1998, even when first introduced.
- In 1998, depowered second generation airbags were brought onto the global market. These airbags are less aggressive and inflate to a lower volume than first generation airbags. Since the introduction of depowered passenger frontal airbags the risk to restrained children in the front passenger location has decreased and there is some suggestion in the literature that frontal airbags may reduce the risk of injury for older child occupants. For younger children in dedicated child restraints, particularly rearward facing restraints the evidence is less clear.
- A review of the US NASS database found only minor injuries in restrained younger children.
- Data from QISU does not identify any serious injuries or fatalities to restrained Australian child occupants from any type of airbag. More comprehensive Australian data is not available.
- The limited laboratory based research conducted in Australia appears to support the field data that the presence of frontal passenger airbags results in reduced risk of head injury for appropriately restrained children in forward facing restraints and booster seats in comparison to no airbags (Suratno et al., 2009). However the laboratory work indicated the absolute head injury risk is high in both airbag and non-airbag tests, and is limited by the biofidelity of the child dummies used in these tests and the lack of analysis of kinematic data.
- Despite limitations, analysis of ANCAP crash test footage supports field data that current airbag designs are less aggressive than early designs of airbags.
- The majority of reported fatalities and injuries to child occupants due to airbag interaction occur when the child is not restrained or improperly restrained. These reports relate to first generation airbags in North America.
- Generalisations about child seating position and airbags cannot be made when there is such a wide range of airbag performance in the fleet. In particular, to be confident about recommending that children in a forward facing child seat may be restrained in the front seat, each vehicle model will need to be assessed for the manner in which the passenger airbag deploys. In practice, this is likely to be impractical at a population level, but could possibly be undertaken in association with ANCAP crash tests.
- Recommendations on the age at which children may be restrained by an adult seatbelt only are appropriate.
- No fatalities or serious injuries were identified for appropriately restrained children from either side thorax or curtain airbags.
- Even in newer vehicles, children up to the age of sixteen are safer seated in the rear seat compared to children seated in the front seat. Indeed, based on robust mass data analysis, children of all ages continue to be at a lower risk of injury in the rear seat regardless of whether or not airbags are present. Theoretically, children aged twelve and older could be provided the same level of protection by frontal airbags as small adults, but the field experience does not confirm this. For younger children too big for booster seats but not yet of adult stature it appears likely that improper seatbelt fit may be a bigger issue than injury risk from airbags.

8 Limitations

The following limitations of the study were identified:

- Much of the available literature refers to pre-1999 vehicles equipped with first generation airbags in overseas vehicle models and therefore does not examine the effect changes in airbag design have had in reducing risks to child occupants.
- Some of the literature does not distinguish between seatbelted children and children restrained in child safety seats. In both scenarios children are considered to be 'restrained'.
- Fleets are made up of vehicles that differ in make, model and year of manufacture resulting in vehicles with different structural design, airbag design, number of airbags, seat track length, seatbelt pre-tensioner availability and seat width. Each of these factors can affect how occupants will interact with airbag systems. Furthermore, impact conditions, occupant pre-crash position, pre-impact braking and use/misuse of restraints will also influence how an occupant interacts with airbags. The literature generally does not take these factors into account, therefore separating out the relative effect of each of the factors above is not possible.
- At least one study considers any child restraint in the front seat of an airbag equipped vehicle to be improperly restrained and therefore such occupants are included in statistics with restraints that are not installed or inappropriately restrained children.
- There are differences between Australian and US airbags such as volume, rate of deployment and venting characteristics. These differences occur because US airbags are designed to provide greater protection to unrestrained adult occupants. This must be considered when reviewing data from the US.
- Consequences of child passenger safety initiatives must be considered when reviewing rates of child fatalities and injuries over time. Since 1999, there are very few child fatalities due to passenger airbags, however this may be partially due to successful initiatives to have children sitting in the rear seat rather than changes to airbag design. For example, Kindelberger (2003) reports that declines in child deaths per million vehicles may have been due to a combination of public education programs, such as moving children to the rear seat, and redesigned airbags.
- The data used in published studies and in NASS may be biased by misreporting of whether the child was appropriately restrained. This can occur for a variety of factors:
 - Data entry error
 - Documenting authority not wishing to cause any further trauma to family of deceased or injured child
 - If proper use of restraint is unknown, the documenting authority gives benefit of doubt to parent or carer
 - Parent or carer incorrectly reporting that child was properly restrained
 - Parent or carer falsely reporting that child was properly restrained to avoid consequences
- It is possible that the fatality rates for unrestrained or improperly restrained children are higher than have been reported and that some airbag fatalities were incorrectly attributed to properly restrained children.
- Many studies comment that pre-impact braking places children in a more forward position leading to more adverse airbag interactions. However the Australian practice of using top tethers to anchor the child restraint and having the child in a six point harness may minimise forward excursion under heavy braking. For this reason, overseas studies (where top tethers were not used) may provide estimates of forward excursion greater than expected in Australian crashes, or may overestimate the severity of injuries caused by forward excursion.
- The effects of pre-impact braking and pre-impact manoeuvres have not been examined in detail in the literature therefore the extent to which they influence child occupant interaction with airbags is not well understood.
- No data on risk of middle front row restrained child occupants in vehicles with three frontal seating positions was available.

- Reliable injury criteria for the child dummies used in many of the testing studies are not available. In particular, there are no well accepted neck injury criteria, and no accepted injury reference values for the P1.5 and P3 series dummies used in ANCAP and some other test series. Moreover, the recorded head accelerations and neck forces and moments do not assess the entire spectrum of injury mechanisms possible in child occupants.
- Child dummy biofidelity is limited due to the lack of robust data for dummy validation and thus conclusions drawn from testing studies need to be viewed with caution, particularly when there are unrealistic contacts (e.g. head to leg) where the recorded accelerations do not reflect real world accelerations or injury risks.
- Some studies reviewed restraints secured using LATCH systems, which differ from the Australian restraints to date. There may be some Australian differences, particularly in restraint movement during impact which may affect an occupant's potential to sustain injury.

9 Conclusions

The risk of injuries and fatalities from deploying airbags can be minimised by properly restraining children in an age appropriate child restraint in the rear seat. Cases of serious injury or death among properly restrained front seated child occupants in forward facing restraints and booster seats are scant, suggesting that the risk of injury from a passenger frontal airbag in these cases is low.

The evidence is less clear for the youngest children in rear facing restraints and the practice of discouraging rearward facing restraints in front seats with active frontal airbags is justified. However, variations in individual vehicles and restraints make it impossible to ascertain the population level risks with any degree of certainty. For this reason further exploration of ways to control this risk across the fleet should be considered.

Unrestrained and improperly restrained children are more likely to be out of position and out of position children are at the highest risk of injury from deploying airbags. It should be noted that conclusions about the risk to out of position children are based on sled testing and full scale crash testing. There is limited real world data to confirm the conclusion that out of position children are particularly at risk.

Although changes in design to passenger frontal airbags in recent airbag designs have reduced the risk of serious injury and death for properly restrained child occupants compared to early airbags, the risk of serious injury and death from passenger frontal airbags has not been eliminated. However, it is important to note that the rate at which airbags deploy in Australia is slower and the risk of injury from depowered second generation airbags is comparatively lower than first generation airbags.

10 Recommendations

10.1 General recommendations

To minimise the risk of injury or death to restrained children from airbags, it is recommended that:

- children aged twelve or younger should not be in a seating position with a front passenger airbag if there is an available rear seat position
- rear facing child restraints should not be used in a seating position with a front passenger airbag as children are always safer in the rear seat when using dedicated child restraint systems
- front passenger seats should be moved to their rearmost position when children are restrained in proximity to a frontal airbag and discouraged from leaning forward
- risks associated with children travelling unrestrained or improperly restrained should be emphasised in material communicating recommendations for use of the front seat and other positions fitted with airbags, since the greatest risks for child occupants from airbags occur when children are unrestrained or not using restraints properly
- children may sit adjacent to rear seat curtain airbags however they should not sit with their head directly in line with the curtain airbag deployment path. There is no real world evidence of increased injury risk from rear curtain airbags or rear side thorax airbags but a theoretical risk from direct deployment injury exists
- the risk of injury from a side airbag in the rear seat is extremely low for properly restrained and positioned children.

10.2 Recommended further research

The current research identified a number of significant gaps in the evidence that was available and the following research is recommended to better understand the real risks posed to restrained children by airbags in Australian vehicles in order to inform future policy decisions.

Such research would require real world crash investigation of airbag deployment cases involving child occupants together with simulated crashes, including full scale crash tests and sled tests where direct comparisons of airbag systems can be made.

10.2.1 Australian crash testing

Research should be conducted into the following areas by conducting sled tests, full scale crash tests and/or reviewing available reports of real world Australian crashes to:

- examine the effects of rear seat torso/thorax bag deployment on CRS and booster kinematics. This should include rotation and possible interaction with other occupants of the rear seat to identify potential risks
- investigate the risk of head and neck injury to restrained children contacting a fully inflated passenger frontal airbag
- identify and examine other front seat hazards that may be specific to restrained children such as injuries due to structural intrusion or glass injuries
- examine the difference in risk of injury or death for restrained child occupants in front seat compared to rear seat positions in Australian vehicles and restraints including a range of ages and type of impact
- examine differences in injury risk for restrained children seated in rear seats in vehicles with less rear passenger room compared to restrained children in front passenger seat exposed to airbags
- examine the effect that poor belt geometry caused by changes in seat track position has on forward excursion for child occupants in rearward facing, forward facing and booster restraints. In particular, examine cases of children restrained in all types of restraints where the child's shoulder is further rearward than the seatbelt top mount
- examine the differences in risk and injury mechanisms for restrained child occupants between airbags designed for the US and Australian markets to better understand whether risks identified in the US fleet are directly applicable to the Australian fleet
- conduct sled tests at typical heavy braking decelerations to estimate typical forward head excursion in pre-impact braking scenarios.

10.2.2 Australian real world cases

Examine incidents of airbag related injuries and fatalities from real world cases in Australia in order to:

- investigate real world outcomes in modern vehicles, including whether a reduction in observed injuries are solely due to improved airbags, or largely due to reduced exposure to airbags such as children being rear seated
- identify the risks to properly and improperly restrained child occupants.

10.2.3 Australian crash data in comparison to worldwide data

Monitor the prevalence of the Australian safety systems for vehicles in Australia and any differences to overseas systems by investigating:

- advanced airbag systems that change deployment characteristics based on occupant position, occupant height, occupant weight, child restraint use or crash severity and evaluate their performance
- rear thorax airbags, in particular monitor whether such airbags on Australian vehicle are designed for restrained or unrestrained occupants
- passenger knee airbags
- airbags designed to prevent interactions between occupants
- the number of first generation airbags remaining in the Australian fleet.

10.2.4 Collate and compare historical ANCAP data

Obtain and review a sample of archival ANCAP data to examine:

- the likelihood of contact with a deploying passenger airbag by restrained forward facing child occupants in child restraints, booster seats and seatbelts.
- the likelihood of contact with a deploying side or curtain airbag by restrained child occupants in relevant seating positions
- whether side airbags (thorax and head) in Australian vehicles meet the out of position occupant guidelines as set out by the Side Impact Out-of-Position Injury Technical Working Group
- the feasibility of a protocol for the assessment of ANCAP data to rate airbag performance for restrained child occupants in future ANCAP crash tests.

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A APPENDIX 1

NAAS case search results

Note: Some cases appear multiple times below as the occupant was exposed to multiple airbags.

A.1 Results of passenger frontal airbag search

The search generated 26 results, 18 of which were deemed relevant. Five cases were deemed not relevant as the airbag did not deploy for the seating position of interest. Two cases were deemed not relevant as the child occupants were unrestrained. Five cases involved injuries linked to contact of an airbag. None of the cases reviewed included an incidence of a child fatality of a restrained child. There were no vehicles noted to have passenger airbags disabled using a switch in the search.

1. Case ID: 151007205 - Frontal, moderate severity

The 9 month old male front passenger in a rear facing child seat was exposed to a deploying first generation passenger frontal airbag. The airbag was not associated with any injury.

2. Case ID: 157008722 - Frontal, moderate severity

The 20 month old right side passenger, restrained in a child safety seat, was treated and released with minor contusion. The first generation passenger frontal airbag deployed but was not associated with any injury.

3. Case ID: 613009770 - Frontal, moderate severity

The 22 month old right front passenger who was restrained in a child safety seat was exposed to a deployed second generation depowered passenger frontal airbag but sustained no injuries.

4. Case ID: 151009041 - Frontal, severe crash

The 24 month old front passenger was exposed to a deploying second generation depowered airbag mounted in the top instrument panel. They received a non-incapacitating unspecified injury (unknown cause).

5. Case ID: 158009149 - Frontal, moderate severity

The 5 year old, male front passenger restrained in booster seat was exposed to a deploying second generation depowered passenger frontal airbag. The occupant sustained no reported injury.

6. Case ID: 158010072 - Frontal, moderate severity

The 3 year old female front passenger restrained in an Evenflo Generations booster seat was exposed to a deploying first generation passenger frontal airbag. The occupant sustained no reported injuries.

7. Case ID: 150009347 - Frontal oblique, low to moderate severity

The 9 year old front passenger restrained in an Evenflo Right Fit booster seat was exposed to a deploying second generation depowered passenger frontal airbag. The occupant sustained no reported injuries.

8. Case ID: 766011069 - Side impact, low to moderate severity

The 4 year old female front passenger restrained in an Evenflo booster seat (unknown model) was exposed to a deploying first generation passenger frontal airbag. The occupant sustained left forearm fracture from an unknown cause that required 3 days hospitalisation. Blood was observed on the passenger frontal airbag (in proximity to the airbag cover).

9. Case ID: 769012798 - Frontal, moderate to high severity

The 3 year old front passenger restrained in a Graco TurboBooster booster seat was exposed to a deploying first generation passenger frontal airbag. Contact with the airbag caused facial and scalp abrasions.

10. Case ID: 241001726 - Multiple impacts, minor severity

The 4 year old right front passenger who was restrained by a forward facing tray-shield child safety seat (Evenflo Ultara I) and exposed to a deploying second generation depowered passenger frontal airbag, sustained bruises to his neck from the safety harnesses on his child seat. He did not receive treatment.

11. Case ID: 166005156 - Frontal, moderate to high severity

The seven week old front passenger in an incorrectly installed rear facing safety seat (Evenflo Discovery), in the right front seat was transported to the hospital but was uninjured. The second generation depowered frontal passenger airbag deployed.

12. Case ID: 166001931 - Frontal oblique, moderate severity

The 4 year old child front passenger contacted the first generation passenger frontal airbag, which caused a minor facial abrasion, minor tongue laceration, minor facial skin contusion and minor eyelid contusion.

13. Case ID: 183001873 - Frontal oblique, moderate severity

The 16 month old front passenger restrained in a rear facing child safety seat was exposed to a deploying first generation passenger frontal airbag. No injuries requiring treatment were sustained.

14. Case ID: 161003722 - Frontal, low to moderate severity

The 16 month old male front passenger restrained in a forward facing child safety seat was exposed to a deploying second generation depowered passenger frontal airbag. A facial skin contusion was attributed to the airbag and other minor contusions and lacerations were attributed to loose objects and the child restraint.

15. Case ID: 862004628 - Frontal oblique, low to moderate severity

The 3 year old front passenger restrained in a forward facing child safety seat suffered facial skin contusions from probable contact with the second generation depowered passenger frontal airbag, and a neck strain not associated with the airbag.

16. Case ID: 170002168 - Frontal, low to moderate severity

The 2 year old front passenger restrained in a forward facing child seat (Evenflo, unknown model) sustained lower extremity and facial skin abrasions from probable contact with the second generation depowered passenger frontal airbag.

17. Case ID: 161005224 - Frontal oblique, low severity

The 4 month old male front passenger restrained in a rear facing child safety seat (Cosco/Peterson First Ride) was exposed to a deploying second generation depowered passenger frontal airbag. The occupant was transported to hospital and released with no injuries noted.

18. Case ID: 881004183 – Sideswipe, frontal

The 3 year old front passenger restrained in a forward facing child safety seat was exposed to a deploying first generation front passenger airbag. The child sustained an upper extremity skin contusion, facial skin abrasion, neck/throat abrasion from probable contact with the passenger frontal airbag, and a finger fracture attributed to contact with the centre instrument panel. There were other minor injuries not associated with the airbag.

A.2 Results of curtain airbag search

The search generated 21 results, 10 were deemed relevant. Of the cases deemed not relevant four involved child occupants not exposed to deployed airbags, in three cases airbag availability/function was not indicated and in three cases an airbag was not available for the child occupant's seating position. Occupant details were not listed for one case.

1. Case ID: 771013195 - Frontal, high severity

The 1 month old male occupant seated in the second row right position, restrained in a rearward facing child safety seat (Chicco KeyFit) was exposed to a deploying curtain airbag. No injuries were sustained from the airbag, but the child sustained serious head, brain, and thoracic injuries attributed to interactions with the restraint and seat back.

2. Case ID: 141013562 - Oblique frontal, low to moderate severity

The 2 year old female occupant seated in the second row left position, restrained in a forward facing child safety seat (Cosco/Dorel Alpha Omega Elite) was exposed to a deploying curtain airbag. No injuries were sustained from the deployed airbag, and a neck strain was attributed to interaction with the child restraint. The 3 year old male occupant seated in the second row RHS position, restrained in a booster seat was exposed to a deployed curtain airbag. No injuries were sustained.

3. Case ID: 762013304 - Frontal, low severity

The 22 month old male occupant seated in the second row right position, restrained in an incorrectly installed forward facing child safety seat (Britax Marathon) was exposed to a deploying curtain airbag. No injuries were sustained from the airbag, and a skin contusion was sustained from the harness webbing.

4. Case ID: 663014182 - Oblique, low to moderate severity

The 2 year old female occupant seated in the second row right position, restrained in a forward facing child safety seat (Graco, unknown model) was exposed to a deploying curtain airbag. No injuries were sustained from the airbag, and the child had other minor injuries from self-contact and flying glass.

5. Case ID: 770013732 - Rollover, severe

The 3 year old male occupant in second row right seating position restrained in forward facing child restraint (Cosco/ Dorel Summit) was exposed to a deploying curtain airbag. While the child sustained minor head contusions injuries from the child restraint shell in the crash, no injuries were attributed to the airbag.

6. Case ID: 249013284 - Oblique, moderate severity

The 3 year old male occupant in second row right restrained in a forward facing child safety seat (Britax Roundabout) was exposed to a deploying curtain airbag. No injuries were sustained from the airbag, and the child sustained a leg contusion from interaction with the seat back.

7. Case ID: 877012870 - Frontal, severe crash

The 4 year old female front passenger restrained in a Graco TurboBooster booster seat was exposed to a deploying rail mounted curtain airbag. The front passenger airbag and thorax airbag mounted to the seat did not deploy for reasons unknown, but there was no airbag switch present. The occupant sustained contusions and abrasions to multiple body regions thought to be due to the booster seat shell and belt webbing. The airbag was not associated with any injury.

8. Case ID: 157007242 - Side impact, low to moderate severity

The 1 year old female occupant restrained on the left hand side in the second row in a forward facing child safety seat (Cosco/Dorel unknown model) was exposed to a deploying curtain airbag and panel mounted thorax airbag. No injuries were sustained.

9. Case ID: 909001865 - Rear impact, moderate severity

The 2 year old female occupant in restrained in the second row on the left hand side in a forward-facing child safety seat (Britax Husky) was exposed to a deploying curtain airbag. No injuries were sustained from the airbag, and an eyelid contusion was attributed to loose object contact.

10. Case ID: 155007307 - Frontal oblique, moderate severity

The 5 month old female occupant restrained in the second row on the right hand side in a rearward facing child safety seat (Graco unknown model) was exposed to a deploying curtain airbag. No injuries were sustained.

A.3 Results of side (door/panel or seat back) airbag search for 2004-2009 NASS cases

The search generated 32 results, none of which were found to be relevant after review. In 30 cases there was no deployed side airbag for the restrained child occupants. In 1 case the side airbag did not deploy and in one case occupant details were not listed.

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