What should ANCAP be assessing in the rear seat?

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Abstract

The Australian New Car Assessment Program (ANCAP) currently includes two child crash test dummies restrained in child restraints in the rear of vehicles in frontal barrier testing and this is the only routine assessment of rear seat occupant in Australia. We are currently investigating the rear seat injury profile among injured car occupants in NSW, as well as studying specific rear seat injury mechanisms through in-depth crash investigation. This work indicates we need better assessment of rear seat safety in Australian vehicles. This paper explores the possibility of extending current ANCAP rear seat assessments and draws from our rear seat research program to examine what such an assessment might include.
Mass crash and hospital data, in depth investigations and laboratory testing of the rear seat in frontal impact and a recent analysis of the geometrical mismatch of rear seat occupants and the rear seat environment were reviewed. Relevant data was extracted and compiled to examine potential areas in which rear seat occupant protection could be adequately assessed. The data suggests that there is little to be gained through the current ANCAP inclusion of two child dummies in child restraints in the rear. Including a dummy representing a larger child would be more beneficial but there are a number of limitations to be addressed in the design of available dummies in order for them to provide meaningful performance assessment. In the short term more direct static assessment of the rear seat environment may be a solution.

Keywords

Rear seat occupants, ANCAP, crash testing, consumer programs

Introduction

Deaths and injuries due to road crashes have declined substantially over the last few decades. In 1980 there were 4.3 people killed and 42.3 people seriously injured for every 10,000 vehicles registered in Australia. By 2005 these figures had reduced to 1.2 and 22 people killed and injured per 100,000 vehicles (ATSB, 2007). For vehicle occupants, much of the casualty reduction can be attributed to the improved crash protection provided in modern vehicles. The United States Department of Transportation has estimated that from the time simple safety technologies like seat belts began to appear (1960) through to 2002 the increased availability and use of vehicle safety technologies have saved 328,551 lives (Kahane, 2004). The primary driver of vehicle safety design and occupant protection system improvements has been regulatory standards and the emergence of consumer information programs assessing these systems. However, almost all existing assessments based on crash tests are focussed on the performance of vehicles in protecting front seat occupants. The exceptions to this are EuroNCAP, where child occupant protection in child restraint systems in the rear are included in the rating system, and most recently Japan's NCAP where moves are being made to include a dummy representing a small adult female in the rear seat. In Australia, ANCAP tests currently include child restraint systems and child dummies as per the EuroNCAP protocols but these results are not used in the calculation of scores.

Beck et al (2009) demonstrated that over the last few decades, safety technologies have not been introduced into the rear seat of vehicles at the same rate as the front seat. This is a possible consequence of the lack of regulatory/consumer assessment of the rear seat environment and it follows that it might result in less casualty reductions in the rear seat than

in the front seat, if significant casualty reductions can be attributed to improved vehicle safety technologies. A recent matched-cohort analysis of North American crash data by Bilston et al (2010) has shown this to be the case. That analysis found that the relative risk of serious (AIS3+) injury for restrained rear seat occupants compared to restrained front seat occupants has declined in newer vehicles compared to older vehicles.

Historically, i.e. before the appearance of enhanced crashworthiness and safety technologies in the front seat, the rear seat was seen as being inherently 'safer', primarily because rear seat occupants are further away from intruding structures in the most common impacts i.e. frontal impacts. Furthermore, the rear seat is occupied much less often than the front seat, reducing the overall exposure to injury. These factors likely explain the lack of attention given to rear seat safety systems in the past. However, in the current environment where it is becoming increasingly difficult to find ways to further reduce casualties towards a 'Vision Zero' target, the rear seat may represent an area where potential gains might be realised without the need for the development of new technologies.

This paper uses data from our recent research program on rear seat occupant safety, to explore how ANCAP assessments could include rating of rear seat occupant protection.

Research Program
The program includes a multifaceted approach and encompasses a number of distinct but interrelated studies involving the analysis of mass crash and injury data, in-depth crash investigation, analysis of existing crash test data and laboratory crash sled testing.

The size and nature of the rear seat occupant casualty problem in NSW
A profile of rear seat and front seat occupant injury for the years 2005-2007 in NSW was constructed from a linked hospital and police record data set. The data sources include the NSW Admitted Patient Data Collection (APDC) and the NSW Roads and Traffic Authority's Traffic Accident Database System (TADS), and NSW Roads and Traffic Authority's (Road Crash Analysis (RCA) data. The NSW Emergency Department Data Collection (EDDC) was also used in the linking process. A matched dataset was constructed by selecting all episodes of care with an external cause code of being involved in a motor vehicle accident and age of patient 9 years or older and linking these using probabilistic record linkage methods with the NSW RTA RCA data. In an attempt to increase linkage rates, deterministic linkage against residual RTA records was then undertaken. Finally all remaining unlinked APDC and RTA RCA records were again put through probabilistic linkage with an EDDC and APDC linked dataset. The proportion of APDC records unable to be linked was 29%.

Rear seat and restraint geometry
Outboard rear seat and seat belt geometry from 51 current vehicle models were measured using a customized measuring jig (Bilston & Sagar, 2007). Seat geometry measurements included seat cushion angle to the horizontal, seat back average angle to the vertical, seat cushion depth, seat back height and seat depression width. Seat belt measurements included the distance between lap belt anchorage points, position of upper (sash belt) anchorage point, angle of sash belt when fastened, location of the fastened seat belt and length of the buckle assembly. Seat and seat belt geometry was then compared with child and adult anthropometry. The anthropometry data was constructed from existing datasets (Snyder et al, 1975,1977). Anthropometric data used included buttock to popliteal length (femur or upper leg length), seated shoulder height, and shoulder and hip breadth. A symmetrical, upright seating position within the seat depression was assumed. Comparisons were made in terms of

buttock to popliteal length/seat cushion depth, and sash belt geometry/shoulder height and breadth for 5th to 95th percentile anthropometry bands for children aged 2 to 14 years.

In-depth crash investigation
Injury mechanisms among rear seat occupants aged 9 years and older have been investigated through a 3 year prospective in-depth crash investigation study. This includes vehicle and scene inspections, as well as a driver interviews, detailed medical record review, and crash severity estimation using the Crash 3 program, using the same protocols employed in the Australian National In-depth Crash Investigation Study (ANCIS). Prospective cases were collected through 6 major NSW trauma and paediatric hospitals – Prince of Wales Hospital, Sydney Children's Hospital Randwick, Westmead Hospital, Children's Hospital at Westmead, Liverpool Hospital and the John Hunter Hospital. The prospective sample is supplemented by existing rear seat occupant ANCIS cases.

Analysis of ANCAP child restraint data
Dynamic responses from the TNO P1.5 and P3 child dummies included in child restraint systems in the rear seat of ANCAP offset frontal impacts were examined to explore the usefulness of the data being collected (Bilston et al, 2011). The analysis used linear regression to examine the correlation between the two child dummies responses, correlation between the driver and front passenger dummy responses and relationship between the child dummy responses and vehicle type, mass and B Pillar accelerations.

Analysis of rear seat head injury sources in North American crash data and barrier tests
Cases involving rear seated children aged 7-12 years using adult seat belts in frontal crashes (12 o'clock) were identified and extracted from the NASS/CDS database for the years 1997-2008 inclusive (Brown et al, 2010). Details extracted included gender, age, height, weight, seating position; vehicle make, model and year of manufacture; impact direction, delta v, CDC and injury descriptions and severities of all occupants. Head injury sources from the real world cases were then compared to existing full-scale crash tests where child-sized dummies (HIII10 year old, or HIII 5th percentile) were positioned in the rear row of the vehicles. Finally MADYMO modelling was used to explore potential deficiencies in the ability of the crash test dummies to adequately represent head strikes with the front seat backs. The response of both HIII10 year old and 5th percentile dummies positioned in the rear seat of a 2004 Ford Taurus was modelled in 48 and 56km/h frontal impacts and compared to the response of same sized MADMYO Human Facet models under the same impact conditions.

Analysis of seat cushion properties and risk of submarining
A series of 12 frontal sled tests were conducted to examine the effects of seating posture and seat cushion properties on submarining risk among rear seat child occupants using lap sash belts. A secondary aim was to investigate the utility of pelvic gyroscopes for assessing submarining. Seat cushion parameters and dummy seating posture were varied during the test, including cushion depth, cushion stiffness and simulated slouching in the dummy. Pelvic rotation (measured using gyroscopes) and femur displacement were collected from the dummy in addition to anterior/posterior head acceleration and displacement, chest compression and seat belt loads.

Findings
Rear seat occupant casualties
Almost one in every three passengers 9 years and older, admitted to hospital in NSW following a motor vehicle crash during the three years 2005-2007, was a rear seat occupant.

While rear seat occupants accounted for only 8% of all people aged >9 years injured as car occupants, they account for 30% of all passengers i.e. non-drivers. The age distribution and injury patterns for these rear seat occupants are illustrated in Figures 1 and 2. In Figure 1, three age groups have been used to discriminate between pre-adult anthropometry and physiology (children) (9-<16 years), adult (16-<55 years) and the ageing adult (55+ years). In terms of absolute frequency, adults dominate followed by ageing adults and then children. Note the age groups are not equal in terms of years per category. In Figure 2, the distribution of injury to various body regions demonstrate that the thorax, followed by the abdomen and spine region are the most commonly injured among rear seat occupants. However, as shown in Figure 3, this pattern varies substantially by age group. Head injuries occur most commonly among the children (9-16 years) group, thorax injuries occur most commonly among the oldest (55+ years group) and abdominal/spinal injuries occur relatively equally among all groups.
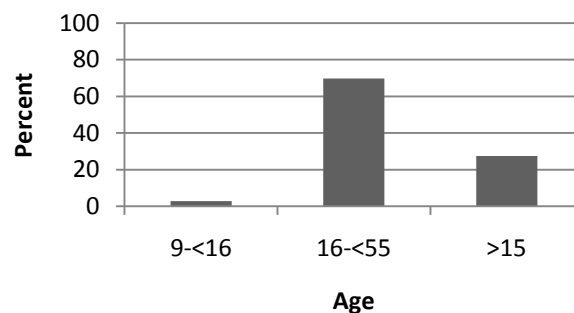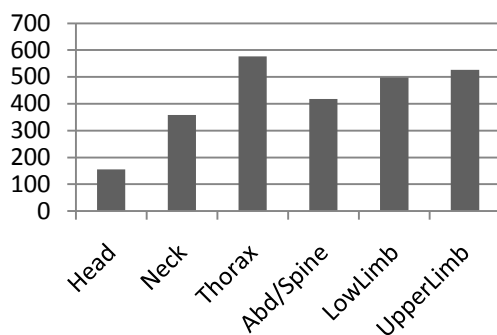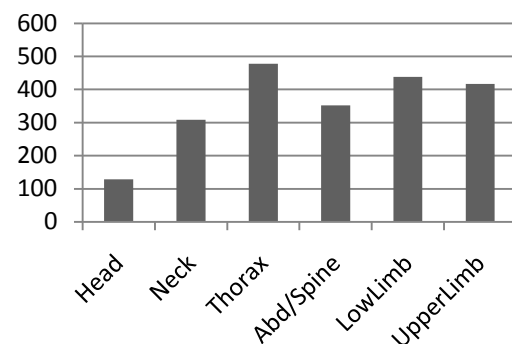

Figure 1: Age distribution of rear seat occupants admitted to hospital in NSW (2005-2007)

(a) All   (b) Recorded as restrained only

Figure 2: Injuries by body region among rear seat occupants admitted to hospital in NSW (2005-2007)

There was less recorded restraint use among the rear seat passengers in this sample with only 83% coded as using a restraint compared 90% restraint use among the front seat passengers. However, the recorded non-use of restraints was similar (3% rear and 2% front). There was more unknown restraint use in the rear (14% compared with 8%). Ignoring those cases with unconfirmed restraint use made little difference to the patterns of injury (See Figure 2 & 3(b)).

Comparison of the seat cushion length and the buttock to popliteal length (or femur length) across children of various ages and adults within the 50th percentile range revealed that the minimum age at which a child in this anthropometric band could find a seat cushion of suitable depth was approximately 11.5 years and the average seat cushion is not suitable until

approximately 14 years. For the children within the 95th percentile, the minimum age at which a child within this band could find a suitable seat cushion is just after 9 year, and the average seat is suitable after 11 years of age. For the smallest size for age children, i.e. within the 5th percentile, no seat cushion is suitable until 14 years of age. Furthermore, the deepest cushions would likely be problematic for up to 25% of adult occupants (Figure 4). See Bilston & Sagar (2007) for a more detailed analysis

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Rear seat and restraint geometry
Comparison of the seat cushion length and the buttock to popliteal length (or femur length) across children of various ages and adults within the 50th percentile range revealed that the minimum age at which a child in this anthropometric band could find a seat cushion of suitable depth was approximately 11.5 years and the average seat cushion is not suitable until approximately 14 years. For the children within the 95th percentile, the minimum age at which a child within this band could find a suitable seat cushion is just after 9 year, and the average seat is suitable after 11 years of age. For the smallest size for age children, i.e. within the 5th percentile, no seat cushion is suitable until 14 years of age. Furthermore, the deepest cushions would likely be problematic for up to 25% of adult occupants (Figure 4). See Bilston & Sagar (2007) for a more detailed analysis.

For shoulder belt fit, many children 9-16 would have difficulty achieving good static positioning of the sash belt in most cars. Figure 5 illustrates the percentage of vehicles measured that would provide an adequate shoulder belt position for age and percentile band of children. This also shows that there is a wide variety of sash belt geometries present in vehicles meeting current Australian Design Rules regulating the provision and location of lap sash belts in rear outboard positions of cars on the Australian market. See Bilston & Sagar (2007) for complete and detailed results.
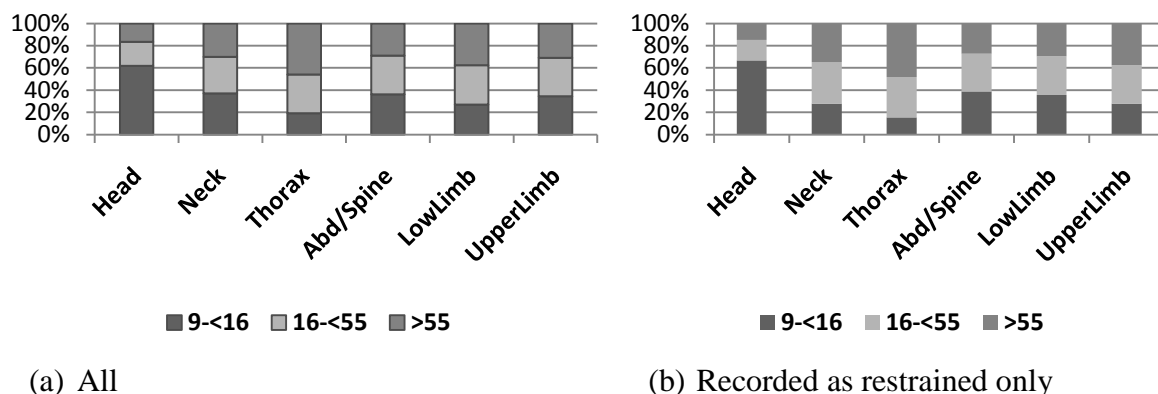

(a) All   (b) Recorded as restrained only

Figure 3: Injuries by body region among rear seat occupants of different ages admitted to hospital in NSW (2005-2007).

In-depth crash investigation
To date, our dataset contains details for 34 rear seat occupants (14 from the prospective study and 20 retrospectively extracted from the ANCIS dataset) Injury Severity Score (ISS) range from 2 to 19 for these occupants. The two most commonly injured body regions have been the thorax and abdomen. Injury mechanisms for injuries to the thoracic region have primarily related to belt loads. Belt loading has also been a predominate mechanism among the abdominal injuries and have been observed in combination with lumbar spine injuries as a result of submarining (the process of the lap belt sliding up over the iliac crests of the pelvis

and subsequently loading the abdomen). Both minor and major head injuries have also been observed . Head injuries have primarily been associated with contact with intruding side structures in side impact but have also occurred in frontal impacts in combination with seat belt misuse. The data set is still too small to see significant variations in injury sources by age, but thoracic injury due to belt loading due appear to be more often associated with older occupants.
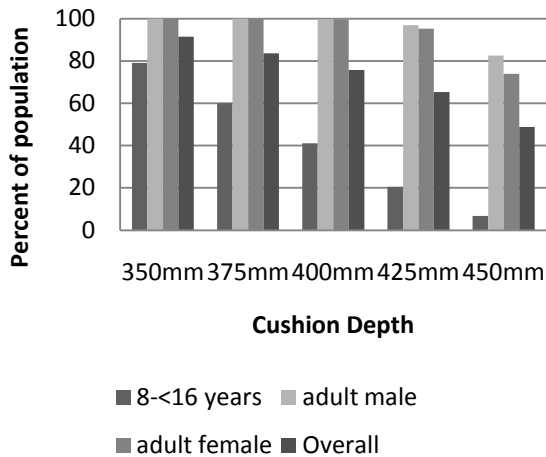

Figure 4: Percent of children, adult males and adult females that would be provided with adequate seat cushion depth (based on a recommended depth of 95% popliteal to buttock length) across the range of cushion depths observed in sample vehicles
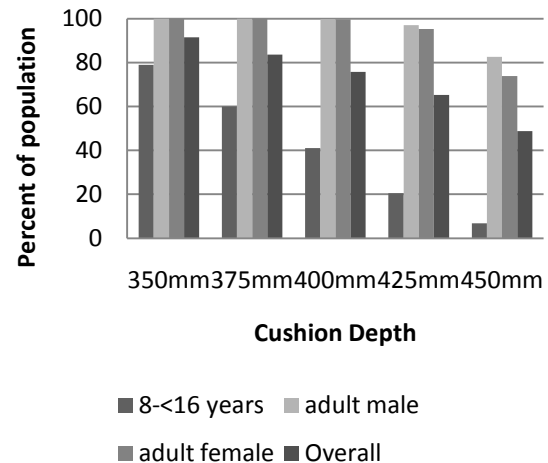
Figure 5: Percent of vehicles measured that would provide adequate static sash belt positioning for children aged from 6-16 within 5th, 50th and 95th percentile bands.

Analysis of ANCAP child restraint data
The dynamic responses (HIC, head acceleration, chest acceleration, neck forces) of the two child dummies in the rear seat of ANCAP frontal offset tests are highly correlated with each other (accounting for ~70% of the variation). These responses are also correlated with the b-pillar accelerations, although less strongly (b-pillar acceleration accounts for approximately 20% of the variation). This suggests that the two child dummies do not provide independent information about vehicle safety performance. In contrast, the driver and passenger dummies are not significantly correlated, and thus these two dummies provide independent information on vehicle safety system performance (Bilston et al, 2011).

Rear seat head injury sources in North American crash data and barrier tests
Of the 245 rear seated children aged 7-12 years identified in the 1997-2008 NASS/CDS data with an injury to the head, face or neck in a frontal crash and using an adult seat belt, two-thirds were in purely frontal crashes (i.e. PDOF 12 o'clock). All neck injury among these children was minor (AIS 1), as was most injury to the head and face. However, 12 cases were identified with AIS 2+ head/face injury. The primary reported source of injury was contact with the seat back (8/12 cases). Other sources included contact with the rear seat head restraint, side door and unspecified areas of the vehicle interior. While all occupants were reported to have been using a three point belt, it was not possible to ascertain whether the restraint was being used correctly in all cases. However, in at least three cases, superficial injuries may have been indicative of correct belt use, while in at least two cases the pattern of concomitant abdominal and spinal injury may have been indicative of incorrect restraint use.

Of the 39 barrier test crashes identified in the NHTSA crash test database that included rear seated dummies restrained by three point belts, 6 included the Hybrid III 10 years dummy, and 33 included the Hybrid III 5th percentile dummy (with anthropometry approaching that of a 12 year old). With one exception, no head contact with the back of the front seat occurred. The exception involved the Hybrid III 10 year old in a vehicle with a shortened rear seat compartment. Head strikes with the rear seat head restraint, rear seat back and C Pillar in rebound were recorded in a number of tests (17/39 tests). Review of video footage revealed no tests (except that with the shortened rear seat compartment) where the dummy head came close to striking the rear seat back. A head strike with the front seat back could also not be achieved in MADYMO modelling using models of the Hybrid III dummies nor a human facet model with inherently increased and more realistic spinal flexibility, even thought the human facet model did marginally increase the amount of forward head excursion (see Figure 6).

Assessing submarining risk with variations in seat cushion properties
Variations in seat cushion properties that allowed the front edge of the seat cushion to collapse under the dynamic load of the dummy resulted in visually obvious submarining, i.e. the lap part of the seat belt was clearly seen to move up into the abdomen (Beck et al, 2011). However this motion was not associated with clear differences in more objective measures such as femur displacement and pelvic rotation (See Figure 7). The most severe submarining occurred when the dummy was placed in a slouched position prior to the impact, a common seating position chosen by children who are too small for the standard rear seat environment. However, shortening the cushion and reducing the stiffness of the cushion resulted in submarining due to the edge of the cushion collapsing under the load of the dummy.
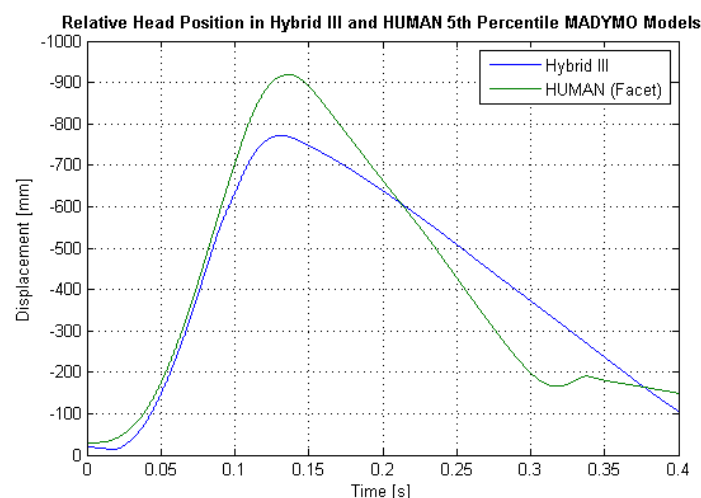

Figure 6: Comparison of forward head displacement in rear seated, 3 point belt restrained Hybrid III and Human facet 5th percentile MADYMO models in a modelled 2004 Ford Taurus in a 56km/h frontal impact.

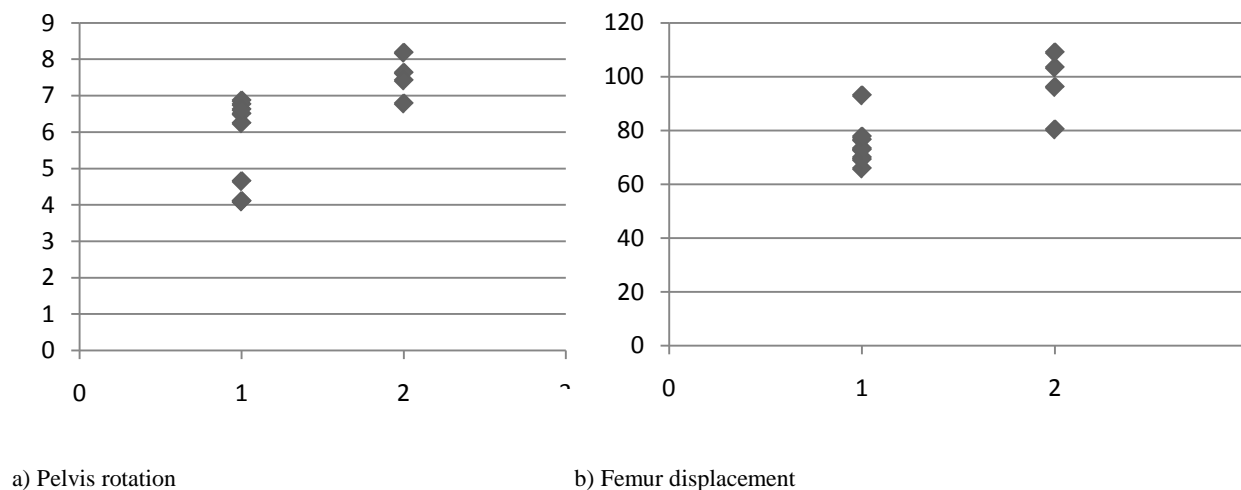a) Pelvis rotation   b) Femur displacement

Figure 7: Measure femur displacement and pelvic rotation in the Hybrid III 6 year old when there is no evidence of submarining (1) and when there is clear visual evidence of the lap belt riding up into the abdomen of the dummy (2).

Implications

Approximately one in three passengers aged over 9 years admitted to hospital following a motor vehicle crash is a rear seat occupant. Currently there is no regulatory or other routine assessment of a vehicle and its safety systems capacity to mitigate injury to rear seat occupants. The rear seat is the universally recommended seating position for all children at least until the age of about 12. Children too big for dedicated child restraints systems rely on the rear seat environment for crash protection. Unlike children who use child restraints systems that are subjected to stringent regulatory assessments and a consumer information program, there is no routine assessment of a vehicle's ability to protect older children who comply with recommendations and occupy the rear seat.

Bilston and Sagar (2007) have demonstrated that many children aged between 9 and 16 years and possibly a substantial number of adults will have difficulty in achieving a good seating posture in many current model vehicles, due to either thigh length and seat cushion mismatch or sash belt geometry (or both). Poor sash belt fit may lead to shoulder roll out during a crash, allowing greater motion of the upper torso and increased risk of head and neck injury. Poor sash belt fit may also increase discomfort and be a motivator for misuse of the sash belt. This would also lead to an increased risk of head and neck injury. Poor positioning of the sash belt, shoulder roll out, or misuse of the sash part of the seat belt may also increase the risk of deleterious loading of the torso in a crash, increasing the potential for thoracic, abdominal and spinal injuries.

The mass crash data profile of the types of injuries being sustained by rear seat occupants has revealed that for occupants of all ages, the thorax and abdominal/spinal regions are the most commonly injured. However, the pattern of injury appears to vary across different aged occupants. Head injuries are common among 9-16 year olds, and thoracic injuries are common among the oldest occupants. Abdominal/spinal injuries occur across all age groups in relatively equal proportions. These patterns of injury are unsurprising given the evidence from the work of Bilston and Sagar (2007) and Huang and Reed (2006).

Early indications from our in-depth crash investigations are that the thoracic, abdominal and spinal injuries are likely to largely be related to belt loading and possibly submarining. Our preliminary evidence is still less clear on the most important sources of head injury, primarily

due to small numbers at this stage. However, protecting the head from injury due to contact with the vehicle interior should obviously always be a priority.

The data presented here suggests a need for assessing head injury risk for younger occupants (i.e. the largest children); and thoracic, abdominal/spinal injury risk for all occupants. All of these could usefully be assessed by including a 5th percentile dummy as a rear seat passenger in ANCAP tests. In the current protocols used by ANCAP, there is no room left in the rear seat as both outboard positions are occupied by child restraint systems. Since the analysis above suggests that these two dummies are not providing substantially different information about vehicle performance, one of these dummies could be omitted without much loss of information (especially since the data is not currently being used for the ANCAP ratings) and replaced by the 5th% female dummy. This would be likely to have little if any effect on test cost.

The question remains as to how performance would best be assessed if a 5th percentile dummy was included in the rear seat of ANCAP tests. Japan NCAP have introduced the Hybrid III 5th percentile dummy (which approximates the anthropometry of an 'average' 12 year old child) in its offset frontal test and uses performance criteria based on FMVSS 208 and the new US NCAP assessment procedure (Ikari & Kawahara, 2009). These performance criteria include the Head Injury Criteria (HIC), neck tensile loads, chest deflection, pelvis acceleration and femoral load. From our early evidence, it appears this may not be sufficient to adequately minimise risk of injury to rear seat occupants. Chest deflection is related to thoracic injury risk but the apparent higher incidence of thoracic injury among the more elderly of rear seat occupants might suggest a need to rethink the performance limits used. Moreover, there is no assessment being made of abdominal or spinal injury risk and this appears to be a common region of the body injured among rear seat occupants.

Currently there are however a number of possible barriers to being able to adequately assess the risk of abdominal and spinal injury using current generation dummies. Our work examining submarining risk presented here and in Beck et al (2010) demonstrates the lack of sensitivity in objective measures like femur displacement and pelvic rotation in assessing submarining risk. While this work used the 6 year old dummy, the lack of pelvic rotation in this dummy due to the non-biofidelic stiffness of the spine is also a problem in larger dummies ((Klinich et al., 2010; Couturier et al., 2007).

From our collaborative work with researchers from George Washington University (Brown et al., 2010), and more recent similar work by others (Bohman et al., 2011) indicates the lack of spinal biofidelity in the dummies may be an issue for adequate assessment of head contact in the rear seat. However this issues requires further study to determine with more confidence what are the most important sources of head contact in frontal impact. It is possible for example that contact during rebound may be the greatest priority. It is also possible that head injury attributed to contact with the seat back is more often associated with seat belt misuse than thought or even pre-impact manoeuvres (Bohman et al, 2011).

The implications of this are that we may not be able to completely and confidently assess real world head injury risk for rear seat occupants in frontal crashes using current crash test dummies. However, in reality any assessment would be better than nothing. At the very least, as assessment program as being used by JNCAP would allow for some comparison of the loads felt by occupants in the rear seats of different model vehicles, and encourage vehicle manufacturers to begin to pay attention to the protective systems provided to rear seat occupants.

In the interim and even in addition to any dynamic assessment, there is potential for including static assessments of the rear seat environment. The deficiencies in the match between seat and seat belt geometry and occupant anthropometry that we have observed in current vehicles could be assessed by measuring the static seat and seat belt geometry. There would also clearly be some usefulness in rating vehicles in terms of the safety technologies they provide as standard in the rear seat. JNCAP have recently introduced a "Rear Seat Passenger's Seat Belt Usability Evaluation Test" that aims to rate the usability of the rear seat, but also includes criteria for whether a seat belt reminder system is installed. This type of evaluation might also be useful in an Australian context, given the findings emerging from our body of research in this area.

Finally, there are a number of limitations to be kept in mind when reviewing the results of each of the studies presented here. For the work from published studies these are discussed in detail in Bilston and Sagar, 2007, Brown et al, 2010, Beck et al 2011 and Bilston et al 2011. For the data extracted from ongoing studies, the most important point to make is that the results presented here are from preliminary analysis. For the rear seat injury profiles the number presented here are absolute numbers and do not take in account rear seat occupancy. There are also inherent limitations in the linked mass data. Finally the data presented here does not include occupants who died at the scene. The most important limitation from the in depth investigation is the small sample size. Others to keep in mind are the convenience sample, and the current lack of inclusion of crashes involving rear seat occupant fatalities.

Conclusion

The data suggests that there is little to be gained through the current ANCAP inclusion of two child dummies in child restraints in the rear. Including a dummy representing a larger child would be more beneficial but there are a number of limitations to be addressed in the design of available dummies in order for them to provide meaningful data performance assessment. In the short term more direct static assessment of the rear seat environment may be a solution.

Acknowledgements

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