

INJURY AND STRUCTURAL TRENDS DURING 12 YEARS OF NCAP FRONTAL OFFSET CRASH TESTS

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ABSTRACT

64km/h frontal offset crash tests are conducted by consumer crash test programs in Australia/New Zealand, Europe, the USA, Korea and Japan. Data from ANCAP and Euro NCAP crash tests are analysed and trends for head, chest and leg protection and structural performance are discussed.

Vehicle designs have evolved to provide better occupant protection in frontal offset crashes. Consumer crash test programs have accelerated this process.

INTRODUCTION

The Australasian New Car Assessment Program (ANCAP), US Insurance Institute for Highway Safety (IIHS) and Euro NCAP have conducted 64km/h offset crash tests since the mid 1990s. Japan NCAP and Korean NCAP also conduct this test. In 1999 ANCAP aligned its test and assessment protocols with Euro NCAP and began republishing applicable Euro NCAP results.

This paper sets out the results of an analysis of offset crash test results for 332 models of passenger vehicles. Results have been analysed by year model to check for trends over 12 years of testing (1996 to 2008).

DATA SOURCES

Crash tests conducted by Euro NCAP and ANCAP have been analysed. Table 1 sets out the number of models evaluated by year and vehicle category. Three categories have been used in the analysis:

- Cars - Passenger cars, multi-purpose passenger vans, sports cars
- SUVs - Sports Utility (four-wheel-drive) vehicles
- Commercial ("Comm") - Utilities ("pick-ups") and goods vans

Table 1. Sample Sizes

Year Model	Cars	Comm.	SUVs	All
1996	4			4
1997	9		3	12
1998	15		2	17
1999	17		1	18
2000	14			14
2001	17	5		22
2002	8		16	24
2003	26		3	29
2004	20		7	27
2005	26	11	8	45
2006	24	1	11	36
2007	28	5	5	38
2008	30	9	7	46
Total	238	31	63	332

Sample sizes in some cells are small, resulting in some uncertainty with derived trends. Also it should be noted that NCAP organisations sometimes conduct campaigns targeted at particular groups of vehicles and this can affect the derived trends.

All injury measurements are for Hybrid III 50%ile males.

RESULTS - INJURY MEASUREMENTS

Driver HIC

Figure 1 shows the trends for driver Head Injury Criterion (HIC36). There is a slight downward trend. It is rare to see HIC above 650 (the Euro NCAP lower limit) after 2001. The few cases above this value generally do not have a driver airbag. ANCAP is likely to have influenced the uptake of airbags, particularly with commercial vehicles that can meet Australian regulations without an airbag.

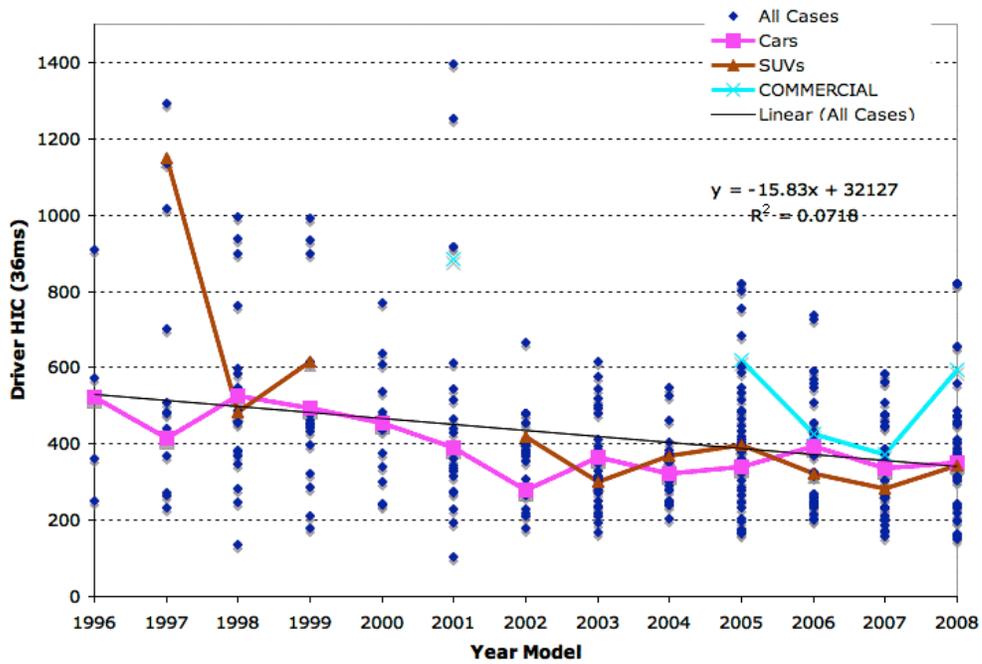


Figure 1. Trends in Driver HIC

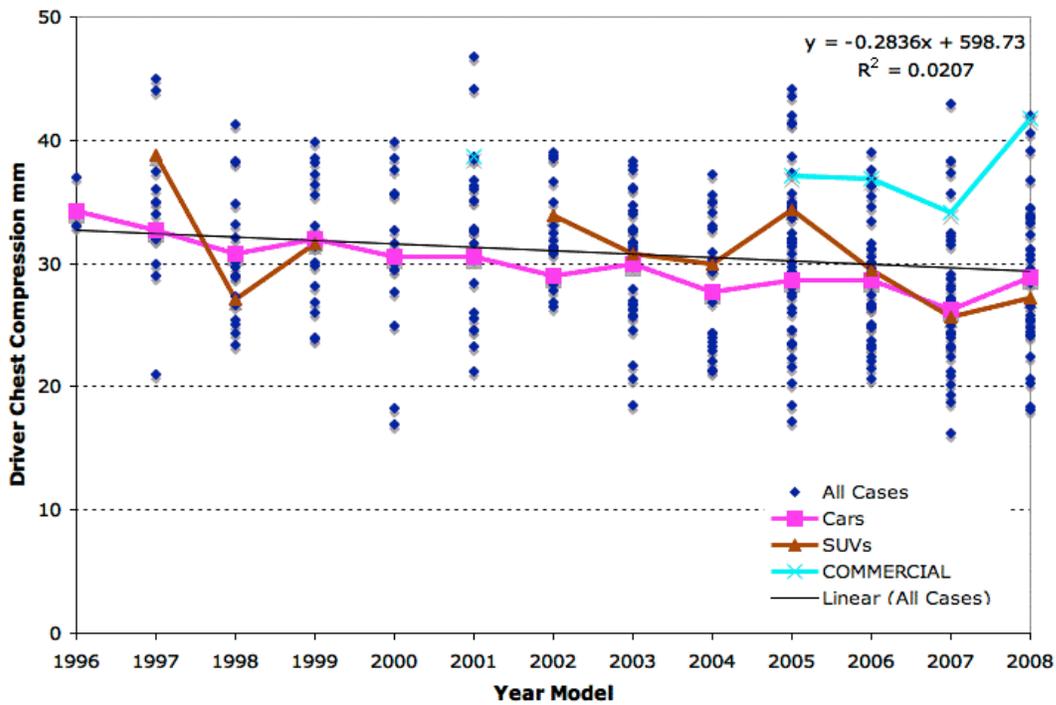


Figure 2. Trends in Driver Chest Compression

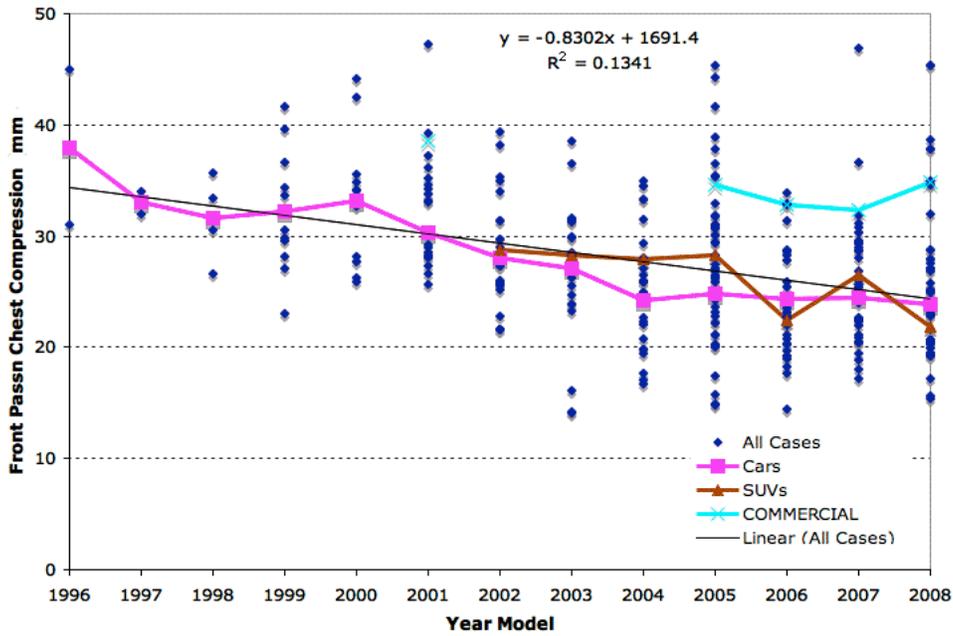


Figure 3. Trends in front passenger chest compression

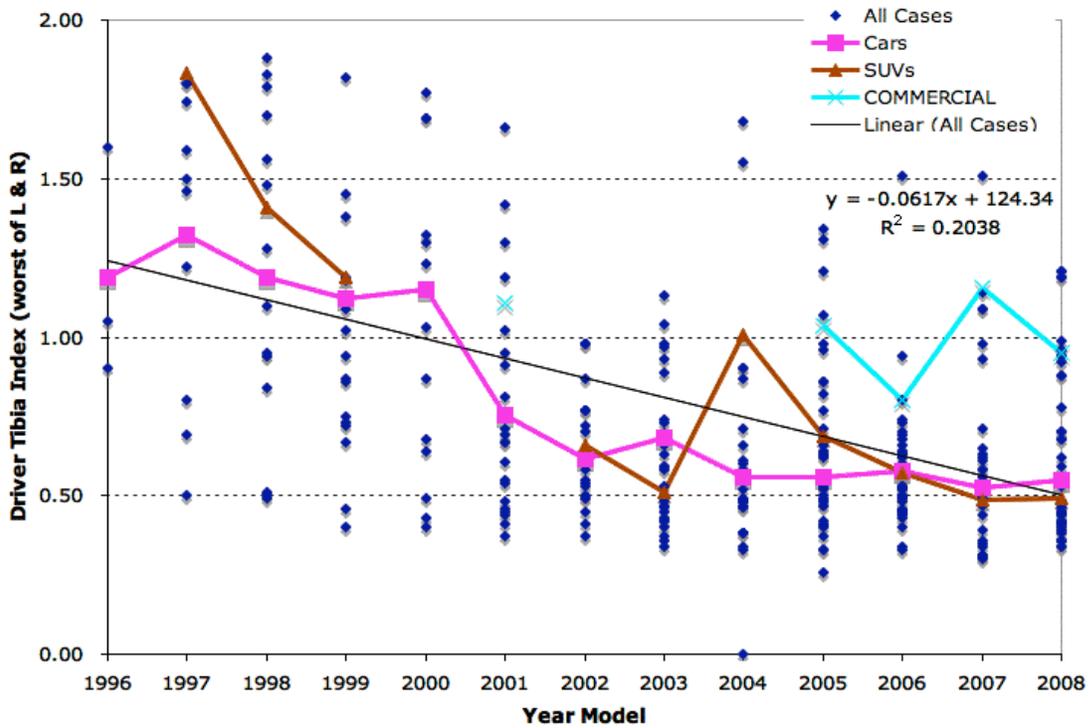


Figure 4. Trends in driver tibia index

Chest compression

Figures 2 and 3 show trends in driver and passenger chest compression. The Euro NCAP system assigns a good rating for compression of 22mm or less and a poor if more than 50mm.

There is a slight downward trend for car drivers but the average remains well above the desired 22mm level.

There is a slightly stronger downward trend with passenger chest compression, compared with drivers, but the averages remain well above 22mm.

For both the driver and passenger the average commercial vehicle values are substantially higher than for cars and SUVs.

Seat belt technologies such as pretensioners and load-limiters are usually fitted to models that achieve relatively low chest compression values.

Driver Tibia Index

Four separate tibia index values are measured. The worst of these four readings is used in the analysis (as it is for scoring under the Euro NCAP protocol). Results are plotted in Figure 4. The Euro NCAP

system assigns a good rating for a tibia index of 0.4 or less and poor for 1.3 or more.

The strong downward trend (that is, reduced risk of serious injury) that was evident in the 2001 analysis has continued (Paine 2001).

RESULTS - DEFORMATION MEASUREMENTS

A-Pillar Movement

Residual rearward displacement of the A-pillar (adjacent to the upper hinge of the front door) gives an indication of the integrity of the passenger compartment. Large displacements are usually associated with catastrophic collapse of the roof, driver's door and floorpan.

Euro NCAP applies a "chest score modifier" to A-pillar displacements greater than 100mm, scaling up to a 2 point penalty at 200mm displacement.

Results are plotted in Figure 5. A downward trend that was evident in 2001 has continued (Paine 2001). Commercial vehicles tend to have a larger displacement than cars or SUVs.

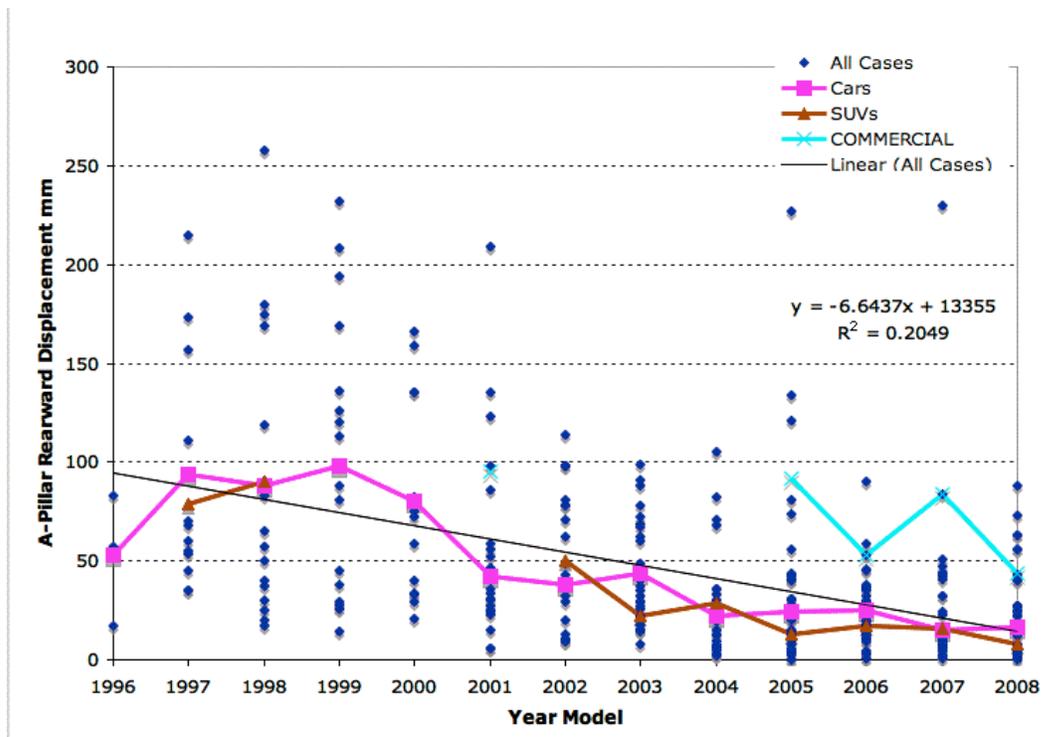


Figure 5. A-pillar rearward displacement (mm)

Brake Pedal Movement

Residual rearward displacement of the brake pedal gives an indication of potential injury to lower legs and feet. Breakaway pedal mounts are becoming common to eliminate rearward movement of pedals.

Under the Euro NCAP system a good result is obtained if the displacement is less than 100mm and a poor result is obtained if the displacement is 200mm or more. Results are plotted in Figure 6.

There is a downward trend for cars and SUVs. Commercial vehicles generally have much larger pedal displacement than cars and SUVs. In some cases it is possible that the groin of the dummy contacted a pedal that was displaced close to the front edge of the seat.

Offset score

The Euro NCAP system assigns a score out of four for each of four body regions: head/neck, chest, upper leg and lower leg. In some cases "modifiers" are applied to the scores - the scores are reduced to take into account the potential for further injury due to intrusion or stiff, sharp interior components. Figure 7 shows the trends for offset scores between 2000 and 2008.

The general trend is an improvement in offset score, indicating reduced risk of serious injury. However, there are still some cases with comparatively poor offset scores. The average for commercial vehicles remains well below that for cars and SUVs.

Vehicle body deceleration

Vehicle body decelerations were available from model year 2000 for ANCAP tests. After review of the data it was decided to use the peak b-pillar x-axis deceleration on the non-struck side because the struck side plots had some unrepresentative spikes. The non-struck side was therefore considered to be more appropriate for comparison purposes.

Figure 8 shows that there is no strong trend with peak vehicle deceleration over the eight years. This is despite the downward trend in a-pillar displacement over the same period (Figure 5). This result suggests that car designers are finding ways to manage vehicle decelerations at the same time that the cabin structural integrity is being improved.

There was no noticeable change in average kerb mass of cars over the study period (not graphed).

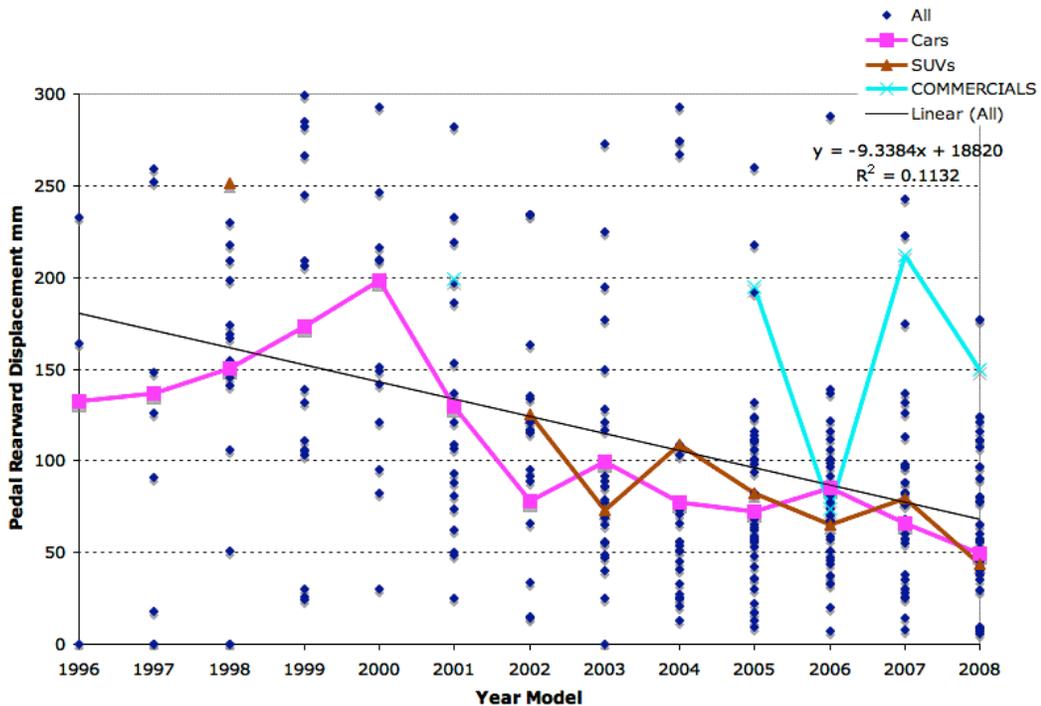


Figure 6. Pedal rearward displacement (mm)

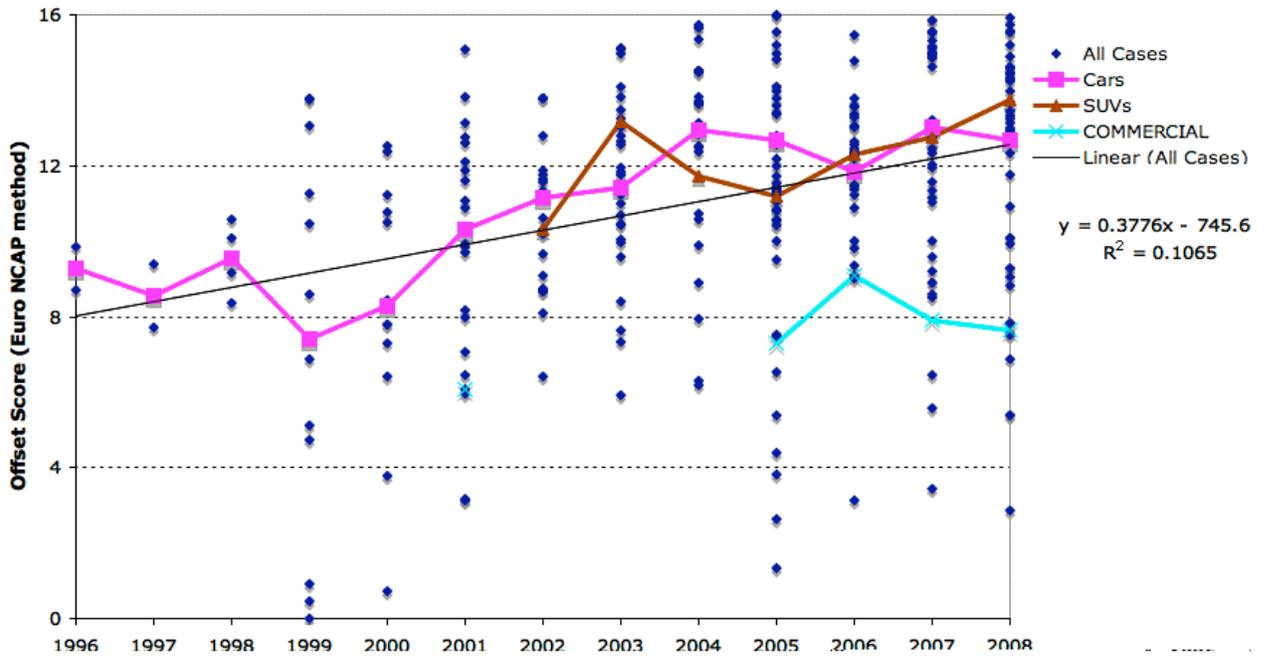


Figure 7. Trends in offset test score (with modifiers)

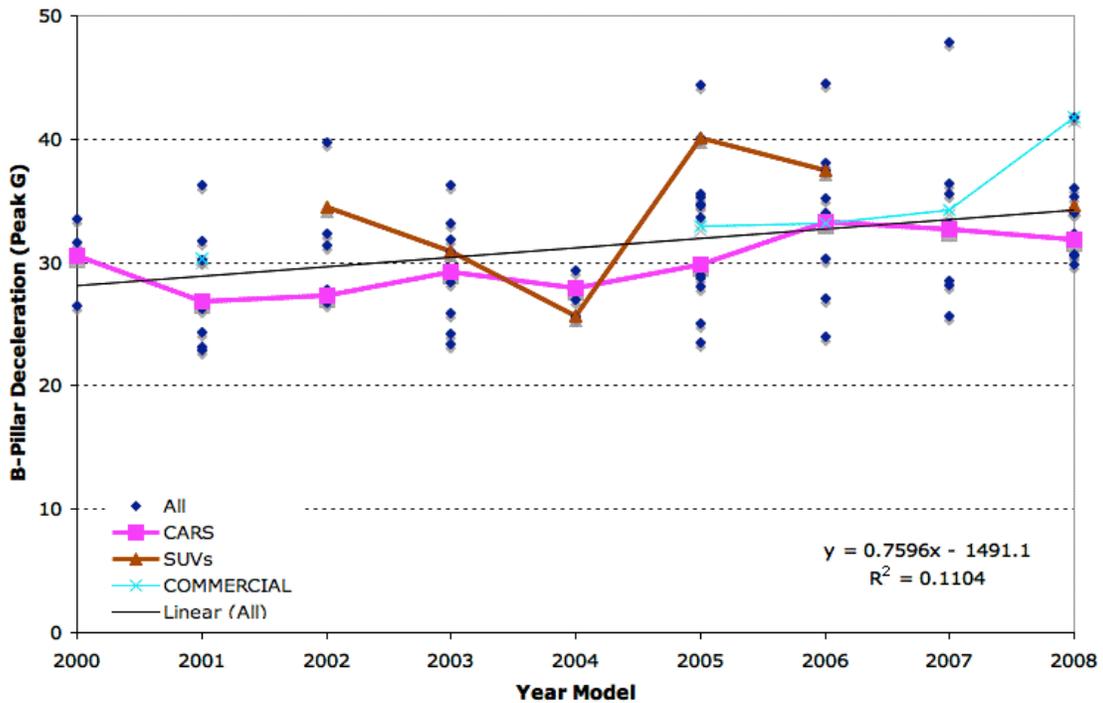


Figure 8. Trends in B-pillar deceleration (peak G, non-struck side)

TRENDS WITH TWO AUSTRALIAN CARS

ANCAP began 64km/h offset crash tests of Australian cars in 1995. The trends with two popular large cars - the Holden Commodore and Ford Falcon - are analysed below. Both models reached an ANCAP 5-star occupant protection rating for the first time in 2008 (the Commodore offset test injury scores are based on the 2006 year model).

ANCAP began assigning star ratings, based on Euro NCAP protocols, in 1999. ANCAP introduced more stringent requirements for a 5 star rating in 2004 when it required a score of at least one point in the side pole test. This effectively required head-protecting side airbags. In 2008 ANCAP added electronic stability control as a requirement for 5 stars.

Deformation trends

Figure 9 shows the trends with A-pillar displacement and pedal displacement for both models.

The Falcon pedal displacement measurements are not available for pre 2000 models but were large.

There has been strong improvement in both deformation measurements over the decade. This is also evident in the images from the peak of the crashes (see Appendix 1).

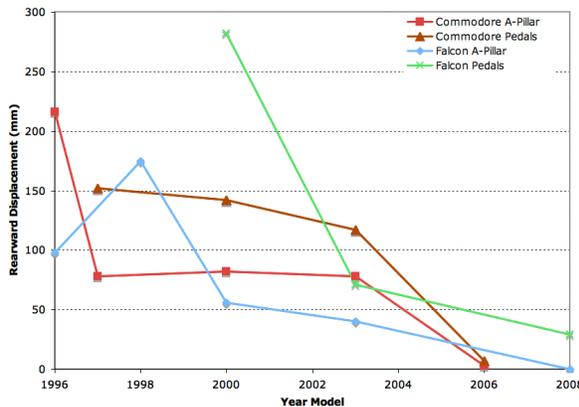


Figure 9. Deformation trends with Commodore & Falcon

Injury Trends

Driver injury measurements have been normalised using the Euro NCAP limit and the results are presented in Figures 10 & 11. The lower limit is used for HIC, chest compression and femur compression. The upper limit (1.3) is used for tibia index due to the very high values in the initial years. The Euro NCAP lower limit for tibia index is 0.4.

The Commodore shows a strong improvement in driver HIC between 1996 and 1997. Chest compression and femur compression improved gradually. Tibia index improved strongly between 1996 and 2003.

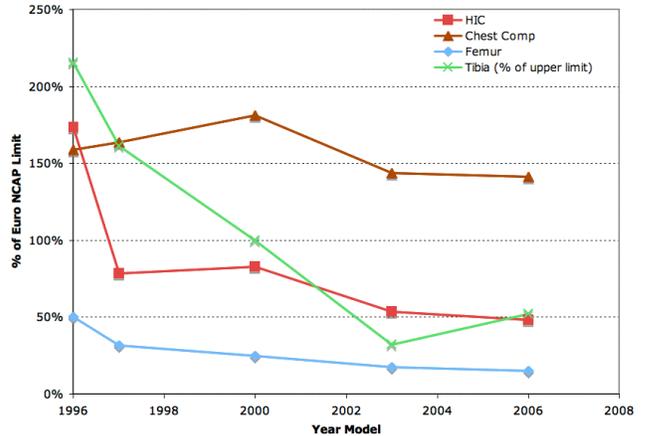


Figure 10. Commodore injury trends

For the Falcon the driver HIC, femur compression and tibia index improved strongly. Chest compression changed little.

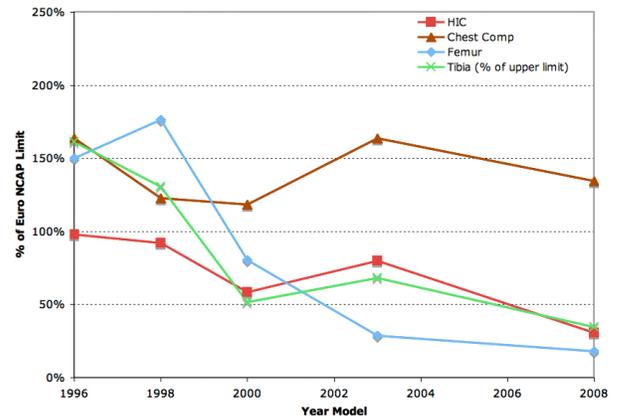


Figure 11. Falcon injury trends

DISCUSSION

The average values for HIC and chest compression for the driver, as measured in the 64km/h frontal offset crash test have reduced gradually over the 12 years of analysis. As observed in 2001 (Paine & Griffiths), some vehicles already had a driver airbag and advanced designs of seat belt by the mid 1990s.

The main effect of NCAP programs has been to influence the models that do not have these technologies and this appeared to be the case in Europe when Euro NCAP commenced. By the late 1990s, however, Australia and New Zealand were noticeably lagging in the uptake of these features, which were not essential for meeting regulations. ANCAP is therefore likely to have resulted in accelerated introduction of these features (Fildes and others 2000).

The risk of lower leg and foot injury has reduced substantially over the period of analysis. Footwell, pedal and underfloor designs continue to improve. This can be attributed, in part, to the consumer offset crash tests which can be very demanding on the vehicle structure in this region. Structures that channel crash forces around the vulnerable footwell area are evident in recent designs (Paine and others 1998). An increasing number of models have pedals with breakaway mounts or designs that move the pedal forward in the event of relative movement between the firewall and pedal mounting bracket.

Commercial vehicles

Unfortunately there remain on the Australian and New Zealand markets many models of commercial vehicle that have much lower performance than typical cars. This is a concern because these vehicles are usually used for work purposes, the drivers may have little say in the selection of these vehicles at the time of purchase and may travel many more kilometres per year than the average, increasing their crash exposure.

There are now several ANCAP 4-star commercial vehicles for sale in Australia and New Zealand. A few commercial utilities and vans have head-protecting side airbags as an option and these may achieve a 5-star rating during 2009.

Structural performance

The analysis of vehicle body deceleration indicates a slight increase in the average of the peak B-pillar deceleration of tested models between 2000 and 2008 (Figure 8: 28g to 34g). This slight increase contrasts with major improvements in lower leg protection (Figure 4) and suggests that footwell design improvements not been at the expense of substantially higher vehicle body deceleration.

Prior to 2000 many models experienced excessive collapse of the front occupant compartment (see Figure 5 and examples in the appendix). It is likely that vehicle body decelerations did increase during this period, when cabins were strengthened and more crash energy was absorbed by the front structure.

Figures 1 and 2 indicate that front occupant restraint systems evolved to cope with these increased vehicle body decelerations. For example, seat belt pretensioners and load limiters allow the occupant to ride down the crash while controlling the loading on the human body.

Digges and Dalmotas (2007) have proposed that US NCAP introduces a 40km/h full-frontal crash test using 5%ile adult female dummies in both front seats. They note a rise in chest injuries suffered by frailer occupants in crashes of relatively low severity and suggest that occupant restraint systems appear to be optimised for the 50%ile adult male used in the 56km/h US NCAP full frontal crash test. They also note that chest compression may be more relevant for frailer occupants than the chest deceleration that is rated by US NCAP.

While comparison data was not available at the time of writing, it is possible that the Euro NCAP/ANCAP 64km/h offset test (that already rates chest compression) would provide similar incentives to the proposed 40km/h full frontal test to address the protection of frailer occupants. In particular, car designers are known to have experienced challenges in getting front occupant chest compression below the 22mm lower limit that is a "good" rating under Euro NCAP/ANCAP protocols.

Consideration could be given to replacing the 50%ile adult male dummy in the front passenger seat with a 5%ile adult female to further address the concerns about frail occupants.

Rear seat occupants

Rear seat restraint systems tend to be much less sophisticated than the front seat systems. There are no dynamic performance requirements for rear seat belts in Australian regulations. Recent analysis by Esfahani and Digges (2009) found concerns about rear seat occupant protection, compared with front seats.

Brown and Bilston (2007) found that older children could be better protected in rear seats. Seat belt geometry and dynamic performance deserved greater attention.

Mizuno and others (2007) conducted a series of full-frontal crash tests with the intention of showing the hazards of not using seat belts in rear seats. An unexpected result was that the injury measurements for a restrained 5%ile adult female dummy indicated a high risk of head and thorax injury. As a result of follow-up research it is likely that Japan NCAP will add this dummy to the rear seat for its full frontal and frontal offset crash test protocols.

Timing of introduction of vehicle safety initiatives

The table in Appendix 2 gives a timeline for introduction of various vehicle safety initiatives, such as the frontal offset crash test. This illustrates that NCAPs frequently introduce new requirements well ahead of the regulations and, in many cases, sets tougher requirements than subsequent regulations.

These demanding NCAP tests are likely to have been a key factor in the improvements to occupant protection evident over the twelve years analysed for this paper.

CONCLUSIONS

Analysis of vehicle deformation and front occupant injury trends for NCAP frontal offset crash tests conducted between 1996 and 2008 indicated a gradual reduction in the risk of serious head and thorax injury and a strong reduction in the risk of serious lower leg injury.

NCAP programs have likely had an influence on the models that did not perform well and many of these have dropped out of the Australasian market.

Now that there is an ample choice in most vehicle segments, fleet purchasers are increasingly demanding a minimum 4 star ANCAP performance and this appears to have triggered some manufacturers into taking more notice of the ANCAP ratings. There have even been cases of retests of improved models in order to gain a better rating.

Concerns remain about the dismal offset crash performance of many models of commercial vehicle. NCAPs should focus more attention on testing this group and draw attention to the large differences in performance.

There are also concerns about the protection of rear seat occupants and it is clear that most rear seat restraint systems are not keeping pace with the design of front seat restraints. NCAPs should consider adding a small adult female dummy to the rear seat for the offset crash test.

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APPENDIX 1 - IMAGES FROM CRASH TEST VIDEOS

The following images illustrate the improvements in structural performance evident from 12 years of ANCAP offset crash tests. ANCAP began the Euro NCAP-style star rating in 1999.

Year Model	Holden Commodore	Ford Falcon
1994-6		
1997-8		
2000 ★★☆☆☆		
2003 ★★☆☆☆		
2008 ★★★★★		

Commercial utility vehicles - 64km/h offset crash tests conducted by ANCAP

Vehicle Model	1995	2005-8
Holden Rodeo		
Mazda Bravo/ BT50 & Ford Courier		
Mitsubishi Triton		
Toyota Hilux		

APPENDIX 2 - TIMING OF INTRODUCTION OF ROAD USER PROTECTION INITIATIVES

Table A2. Timing of Road User Protection Initiatives

Test Procedure	Procedures Developed	Consumer Tests	Regulation (cars)
Full frontal crash test	USA: late 70s	US NCAP: 1979 ANCAP: 1992 (56 km/h)	FMVSS 208: late 1970s (48km/h) FMVSS 2008: 2007 (56km/h) ADR 69/00 1995 (48km/h)
Offset crash test (40% frontal)	EEVC: early 90s	ANCAP: 1993 (60km/h) IIHS: 1995 (64km/h) ANCAP 1995 (64km/h) EuroNCAP: 1996 (64km/h)	ECE R94: 1998 (56km/h) ADR73/00: 2000 for new models, 2004 for existing models (56km/h)
Side Impact (Moving barrier, perpendicular impact)	EEVC: early 90s	EuroNCAP: 1996 (50km/h) ANCAP: 1999 (50km/h)	ECE R95: 1998 (50km/h) ADR72/00: 2000 for new models, 2004 for existing models (50km/h)
Side Pole Impact (29km/h perpendicular or 32km/h oblique)	EEVC: mid 90s	Euro NCAP: 1999 ANCAP: 2000 US NCAP: 2010	US FMVSS 214: 2010 ECE ? ADRs ?
Pedestrian Protection	EEVC: early 90s	EuroNCAP 1996 (40km/h) ANCAP: 2000 (40km/h)	ECE 2005 (first phase) ECE 2010 (second phase) ADRs ?