Testing the pedestrian safety of bull bars: methods and results

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ABSTRACT

Thirteen bull bars and five models of vehicle were tested to measure their performance in pedestrian impact tests. Three types of test were selected for the assessment: two tests using an impactor representing the upper leg of an adult pedestrian and a test with an impactor representing the head of a child. The headform impact and one of the upper legform impacts were with the top rail of the bull bar and the second upper legform impact was with the bumper section of the bull bar. Equivalent locations on the vehicles to which the bull bars attach were also tested. The tests were conducted at 30 km/h. The tests showed that the steel bull bars tested presented the highest risk of injury of any configuration tested. Aluminium/alloy bull bars also performed worse than the vehicles tested, but to a lesser extent than the steel bull bars. Overall, the polymer bull bars tested performed best and slightly better than the front of the vehicles tested.

INTRODUCTION

Four-wheel-drive (4WD) vehicles are used by many motorists who do most of their driving in urban environments. Much has been spoken and written on the safety implications of these vehicles and the bull bars that are fitted to them. While bull bars are sometimes mounted on ‘recreational’ 4WDs, they are may also be installed on work vehicles, conventional passenger cars and derivatives and heavy vehicles.

The extent to which bull bars are involved in pedestrian collisions and injury is not clear from readily available data. In 1996, the Federal Office of Road Safety estimated that bull bars were certainly involved in 12% of fatal pedestrian collisions but may be involved in as many as 20% (FORS, 1996), although it is not clear how the latter estimate was arrived at, nor whether these figures represent an increased risk of death due to the presence of the bull bar. More recently Attewell and Glase (2000) used Australian crash data to try to estimate the effect of bull bars on fatality statistics. They could not draw firm conclusions due to the incompleteness on the bull bar status of vehicles in their fatality database. Furthermore, there were (and are) few data on bull bar fitment rates, so it was difficult to estimate risks associated with bull bar fitment. Attewell and Glase note that data on bull bar fitment rates would facilitate the estimation of relative risks of injury and death associated with bull bars.

Previous physical tests of the type to be reported in this paper have shown that bull bars can increase the severity of impacts with pedestrians but that not all bull bars are equally dangerous (Lawrence, Rodmell and Osborne, 2000; McLean, Anderson and Streeter, 1998). Attewell and Glase (2000) conclude that, on balance and given the results of such impact tests, bull bars are likely to increase the risk of injury to pedestrians.

For many vehicle owners who drive their vehicles in mainly urban environments, bull bars rarely perform their ostensible purpose – protecting the vehicle in the event of an animal strike. However, they are (with some exceptions) legal additions to vehicles. Despite discussion on the subject in the media, there is currently no readily available information in Australia on the aggressiveness of bull bars, and consumers and regulators have no information on how much more of a risk to other road users a bull bar will present.

AS 4876.1 2002 - Motor Vehicle Frontal Protection Systems

In 2002, Standards Australia issued Part 1 of a new Standard for frontal protection systems - AS 4876.1 2002 - Motor Vehicle Frontal Protection Systems. The term “Frontal Protection Systems” was used because it implies that there may be other ways to protect the front of a vehicle from disabling damage in the event of an animal strike than by fitting a conventional bull bar.

AS 4876 Part 1 deals with the protection of children who might be at some risk of injury if struck by a bull bar and specifies other design requirements of vehicle frontal protection systems. The design requirements cover matters pertaining to the geometry of the bull bar and of the sections used to construct the bar: essentially, bull bars should conform to the shape of the car and not have sharp edges. Two other parts (dealing with effects on airbag deployment and the effectiveness of a device in protecting the vehicle) have yet to be considered.

The test of impact performance is intended to simulate an impact with the head of a child pedestrian. It specifies the use of an EEVC WG17 compliant child headform (EEVC, 2002), which is spherical, weighs 2.5 kg, and is launched horizontally at 30 km/h at any part of the bar over 1000 mm from the ground. In practice, this means that many bull bars on the market designed for passenger vehicles will not require any testing at all, as only bull bars fitted to larger vehicles, such as tall 4WD vehicles, are higher than 1000 mm. Note that the Standard applies also to bull bars designed for small buses and light goods vehicles of a gross vehicle mass of less than 3500 kg, but not to heavy vehicles. There is no reason to expect that any safety problems for pedestrians would be less for bull bars fitted to heavy vehicles.

It is conceivable that a manufacturer might claim Standards compliance because of the geometry of the bar without needing to meet any impact performance requirement. Other pedestrian testing protocols, such as those devised by the European Enhanced Vehicle-safety Committee (EEVC, 2002) and the European New Car Assessment Programme (Euro NCAP, 2004) uses 1000 mm ‘wrap-around-distance’ as the lower boundary for child headform tests and so it might be inconsistent to single out bull bars for special treatment in this respect. Yet, young adults and the elderly make up the largest proportion of pedestrian casualties in Australia (ATSB, 2005) and so there are sound reasons to require bull bars to offer some protection to pedestrians of adult stature too, though it is absent from AS 4876.1. The European Directive on vehicle frontal protection systems, 2005/66/EC, requires tests to measure the risk of injury to adult pedestrians in a collision with a vehicle fitted with a bull bar.

The performance requirement in AS 4876.1 is that the Head Injury Criterion (HIC) value (based on impact acceleration of the child headform) should be 1500 or less. In automotive safety testing, a HIC value of 1500 is not acceptable: a HIC value of 1000 is the normal limit. If a child’s head were struck at 30 km/h, a bull bar that complied with the Standard might still be likely to inflict a serious injury. Therefore, compliance with the Standard may not ensure that the bar is safe at impact speeds of 30 km/h.

Australian Standards are consensus documents requiring the agreement of the parties involved in their development including, in this case, the manufacturers of the bull bars. Consequently, as noted in the Preface to the Australian Standard, “Child head impact criteria have been included incorporating values that are considered achievable.” A European Union Directive on vehicle frontal protection systems (2005/66/EC) does not share the Australian Standard’s view of what is acceptable, and bull bars will be subjected to more comprehensive and demanding testing in Europe than in Australia. Furthermore, compliance with the Directive will become mandatory. No jurisdiction in Australia has yet mandated the testing of bull bars to the Australian Standard.

The aim of this project was to define a test method that will produce data on the risks to vulnerable road users associated with bull bars and to report on the results of testing on a range of bull bars currently available in Australia.

METHODS

The assessment procedure used for this study focuses on two body regions – the head of a child and the upper leg and pelvis of a pedestrian of adult stature. Each bull bar and vehicle front had three tests conducted on it: a child headform test, an upper legform to bumper test and an upper legform to upper rail/bonnet leading edge test. Each test was conducted at 30 km/h. Figure 1 summarises the types of tests used in this study and the procedures are further outlined in following sections.

A speed of 30 km/h was adopted rather than 40 km/h (as specified in EEVC/Euro NCAP protocols) because a) preliminary testing showed that many of the bull bars were too stiff to yield useful information from impacts conducted at the higher speed and b) it is the speed specified in the Australian Standard (AS 4876.1 2002 - Motor Vehicle Frontal Protection Systems). It is reasonable to assume that tests conducted at 40 km/h would produce more severe impacts than those reported here.

The performance requirements used are the same as those nominated by EEVC/Euro NCAP for pedestrian safety assessment. The European Directive 2005/66/EC nominates higher permissible loads in some tests, but the EEVC/Euro NCAP limits were chosen because:

- The tests were conducted at 30 km/h, rather than at the higher speeds of 35 or 40 km/h, specified by 2005/66/EC, and thus produced lower loads than would have been produced at the higher speeds;

- The chosen performance requirements are more closely aligned with internationally accepted injury tolerance limits.

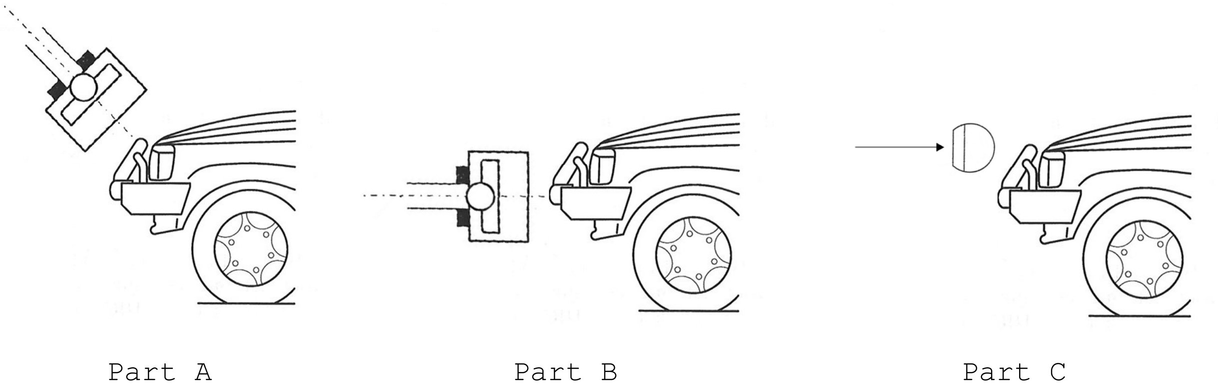

Figure 1 Schematic of Part A, Part B and Part C tests, using the EEVC WG17 impactors

Part A tests – top of bull bar and bonnet leading edge

An EEVC WG17 upper legform (EEVC, 2002) was used to test the top bar of each bull bar and the vehicle bonnet leading edge (Figure 1, Part A), in a similar way to the test specified by Euro NCAP Pedestrian Testing Protocol version 4.1, but at a lower test speed. The legform consists of a simply supported beam that represents an adult femur. The beam is covered in flesh-like foam. The legform is constrained to move in one axis, normal to the orientation of the beam. The legform measures impact forces and the bending moment across the beam. The force is measured at two points: at each of the beam's supports. The total force is given by the sum of the two support forces. The bending moment is measured by strain gauges placed at three points along the beam. The largest value measured by the three strain gauges is used to characterise the bending moment produced in the impact.

For the upper legform test of the top rail of the bull bar and for the comparison test of the bonnet leading edge:

- The geometry of the vehicle and bull bar was measured;
- The angle of the impactor was calculated using the procedure specified in Euro NCAP Pedestrian Testing Protocol version 4.1;
- The centre of the impactor was aligned with of the top rail of the bull bar or the bonnet leading edge of the vehicle and the test was conducted at 30 km/h; and
- The performance requirements were that the peak impact force on the impactor should be less than 5 kN and the peak bending moment below 300 Nm. (Note that these performance requirements are specified by Euro NCAP for impact speeds of 40 km/h.)

Part B tests – bumper section of bull bar and vehicle's standard bumper

An EEVC WG17 upper legform was used to test the bumper section of each bull bar and the vehicle's standard bumper (Figure 1, Part B) in a similar way to the Euro NCAP Pedestrian Testing Protocol version 4.1 testing procedure for a high bumper, but at a lower test speed. It was envisaged that the Part B test would be applied only if the bull bar had significant structural components at bumper height but our assessment was that all bull bars tested had such structures and consequently the test was applied to all bull bars:

- The centre of the upper legform impactor was raised to 500 mm from the ground and aligned with the bumper;
- The impactor speed was 30 km/h and the impact angle was horizontal;
- The performance requirements were that the peak impact force should be less than 5 kN and the peak bending moment below 300 Nm.

Part C tests – bull bar or vehicle leading edge > 1000 mm high

The EEVC WG17 child headform test (EEVC, 2002) was applied at the impact speed specified in the Australian Standard AS 4876.1 and an identical comparison test was applied to the car itself. The headform consists of a 2.5 kg sphere, with a triaxial accelerometer mounted at the centre of gravity. The headform measures the impact deceleration, which is then analysed to produce the Head Injury Criterion value for the impact.

Only sections of the bar or leading edge above 1000 mm were subjected to testing, in accordance with AS 4876.1. The centre of the headform was aligned with the centre of the top rail of the bull bar or leading edge of the vehicle. If the centre of the top rail was below 1000 mm from the ground, then the centre of the headform was aligned with the part of the top rail at 1000 mm from the ground (note that the vehicle ride heights were as specified by the vehicle manufacturer).

The test was conducted at 30 km/h and the performance requirements were that the Head Injury Criterion value should be 1000 or less.

Bull bar mounting

Two methods were used to mount the bull bars for testing. In most cases the bull bar was attached to the corresponding vehicle, according to the manufacturer's instructions. However, in some cases, mounting the bull bar to the vehicle would have required modification to the vehicle chassis rails. As the vehicles were to be (separately) crash tested by ANCAP after these pedestrian impact tests, the modifications could not be made, as the subsequent crash test might have been compromised. Instead, a universal chassis rail rig was used.

The chassis rail rig was checked to ensure that the results of the tests would be a valid representation of the bull bar as it would be on the vehicle: this was checked by testing a bull bar on the rig and again on the vehicle. The results from each test (headform and upper legform) were almost identical (within a few percent) and the standard chassis rails were deemed to be an accurate replacement to a vehicle chassis.

Bull bar and vehicle selection

The selection of vehicles was determined by ANCAP's program as this study was coordinated with ANCAP testing. ANCAP choose vehicles according the largest volume selling vehicles in the particular market segment. The vehicles in this study came from a 4WD testing program and work utility testing program. The vehicles tested were:

- Toyota Landcruiser (100 Series, manufactured Oct 2004);
- Nissan Patrol (manufactured Oct 2004);
- Ford Courier 4WD crew cab (manufactured July 2005);
- Toyota Hilux 4WD crew cab (manufactured Oct 2005);
- Holden Rodeo 4WD crew cab (manufactured Oct 2005).

It was not possible to test every type, material and brand of bull bar available in Australia. The choices were guided by the following criteria:

- For every vehicle, up to three bull bars would be tested;
- One of the bull bars fitted to each vehicle should be an Original Equipment Supplied (OES) product;
- For each vehicle, a steel bull bar would be tested, an aluminium or alloy bull bar and a polymer bull bar;
- Where bull bars of the same brand and material were very similar between two vehicle models that were being tested, results from a single bull bar were used for both vehicle bull bar models.

The bull bars selected for testing are described in Table 1. The brand of each bull bar is not identified, but bull bars were selected from popular brands with national distribution.

Table 1 Bull bar descriptions

Vehicle	Steel bull bar	Aluminium/alloy bull bar	Polymer bull bar
Toyota Landcruiser	Aftermarket bumper replacement	OES bumper replacement	Not available at the time of testing
Nissan Patrol	OES bumper replacement	Aftermarket alloy nudge-bar	Aftermarket bumper replacement
Ford Courier	Aftermarket bumper replacement	OES bumper replacement	Aftermarket bumper replacement
Holden Rodeo	Aftermarket bumper replacement (note 1)	OES bumper replacement	Aftermarket bumper replacement
Toyota Hilux	OES bumper replacement	Aftermarket over-bumper style (note 2)	Not available at the time of testing

Notes:
1. The Holden Rodeo aftermarket steel bull bar was the same brand as, and was almost identical to, the Toyota Landcruiser aftermarket steel bull bar. Tests were performed on the Landcruiser bull bar and the results were used for both bull bars.
2. The Toyota Hilux aftermarket alloy bull bar was almost identical to the Nissan Patrol aftermarket alloy nudge bar, except for the addition of wing sections. Tests were performed on the Patrol nudge bar and the results were used for both bull bars.

The test locations were chosen to reflect moderate to severe impact locations on the bull bars:

- The Part A upper legform impact locations were a mixture of top-rail impacts mid-way between and also closer to the bull bar uprights;
- The Part B impact locations were chosen where the bull bars appeared to be structurally stiff, or where there was a significant mass of material surrounding the impact location;
- For the Part C child headform impacts, locations on the top rail were chosen, either close to or on the main bull bar uprights, subject to the test locations being at least 1000 mm above the ground. For very stiff bull bars, the test was carried out in the centre of the top rail, away from the stiffest part of the bar, to prevent damage to the headform.

For the vehicle comparison tests, locations that were not necessarily directly behind the bull bar test locations were selected but were likely to produce the most severe impact. This was done on the reasoning that any point along the vehicle is equally as likely to be struck as any other point.

RESULTS

Part A test results – top of bull bar and bonnet leading edge

The results (Table 2) show that, by the measure of peak force generated in the test, the polymer bull bars tested produced the lowest force and that the results were at or under the Euro NCAP injury threshold value of 5.0 kN. It should be noted though that the test speed used in this study was 30 km/h and that typical test speeds in Euro NCAP tests are generally higher; so it should not be concluded that the polymer bull bars comply with Euro NCAP testing requirements. Yet, the polymer bull bars tested appeared to be safer than the leading edges of the vehicles that they were mounted to. The results of the bull bar tests were significantly associated with the bull bar material (Kruskal-Wallis test, $n=11$, $P < 0.05$).

The alloy bull bars tested performed similarly to the bonnet leading edge of the vehicles tested, but slightly worse overall. In contrast, steel bull bars produced about twice the impact force as the leading edges of the vehicles.

Note that the similarity between three of the results does not reflect any "clipping" of the data that occurred in other tests on the steel bull bars, but indicates very similar performance across the bull bars tested.

Table 2 Results of upper legform impact (Part A) tests by individual vehicle: peak force (kN)

Vehicle	Bonnet leading edge	Steel bull bar	Aluminium/alloy bull bar	Polymer bull bar
Toyota Landcruiser	7.7	12.4	**6.3** [3]	Not available
Nissan Patrol	6.0	12.4 [3]	7.4	**4.2**
Ford Courier	5.7	12.4	8.5 [3]	**5.0**
Holden Rodeo	8.4	12.4 [2]	6.3 [3]	**4.4**
Toyota HiLux	**4.5**	13.3 [3]	7.4 [2]	Not available

Notes:
1. Bold figures denote best result
2. Denotes default result taken from another test on an equivalent bar (see Section 3)
3. Denotes results for tests on bull bars that are optionally factory fitted (OES)

The upper legform test also produced measures of the bending moment across the legform. The Euro NCAP limit for bending is 300 Nm. The bending moment results of the upper legform tests are shown in Table 3. Of all bull bars tested, the polymer bull bars produced the lowest bending moments and were, on average, better performing that the front of the vehicle. Two of the three tests on the polymer bull bars satisfied the performance requirements of the test. As with the peak force, the bending moment results of the bull bar tests were significantly associated with the bull bar material (Kruskal-Wallis test, $n = 11$, $P < 0.05$).

The alloy bull bar test results were generally similar to or worse than those for the fronts of vehicle, and the steel bull bars were much worse. In tests on the steel bull bars, the severity of the impact was so great that the measuring capability of the instrumentation was exceeded in every test.

The polymer bull bars produced, on average, bending moments less than the Euro NCAP injury threshold, but (as noted previously) at a lower impact speed than that which would be specified by the Euro NCAP protocol.

Table 3 Results of upper legform impact (Part A) tests by individual vehicle: peak bending moment (Nm)

Vehicle	Leading edge	Steel bull bar	Aluminium/alloy bull bar	Polymer bull bar
Toyota Landcruiser	**469**	>1025 [4]	541 [3]	Not available
Nissan Patrol	364	>1022 [3, 4]	635	**156**
Ford Courier	**372**	>1018 [4]	732 [3]	423
Holden Rodeo	608	>1025 [2, 4]	538 [3]	**299**
Toyota HiLux	**362**	>1007 [3, 4]	635 [2]	Not available

Notes:
1. Bold figures denote best result
2. Denotes default result taken from another test on an equivalent bar (see Section 3)
3. Denotes results for tests on bull bars that are optionally factory fitted
4. Over-range result. Peak bending moment clipped to this value

Part B test results – bumper section of bull bar and vehicle's standard bumper

Part B tests consisted of an upper legform impact on the bumper section of the bull bar. The measures of impact severity and the threshold values for injury were identical to the part A tests.

The impact force results of the tests are given in Table 4, by vehicle and bull bar (material) type. The results of tests with the vehicle bumper are also given. These latter tests show the performance of the vehicles without the bull bar. The bending moment results of the upper legform tests are shown in Table 5.

It may be noted that, according to the bending moment produced in these tests, the bull bars performed similarly to or often only slightly worse than the vehicle itself. However, the peak impact force produced by the bumper sections of the steel bull bars and two of the aluminium/alloy bars was considerably higher than that for the vehicle bumper. The bumper section of the bull bar presents a broad, flat surface to the impactor and hence bending across the impactor is not as pronounced as in tests with the top rail of the bull bar. However, the stiffness and mass of the bumper sections is such that the impact force produced is higher than in the tests of the top rails of the bull bars.

While some of the aluminium/alloy bars and the polymer bars performed similarly to the vehicle bumpers, all results, with the exception of one test, exceeded the injury threshold value of 5 kN / 300 Nm. Overall, the results of the bull bar tests were not significantly associated with the bull bar material (Kruskal-Wallis test, $n = 11$, $P > 0.05$).

Table 4 Results of upper legform impact (Part B) tests by individual vehicle: peak force (kN)

Vehicle	Vehicle bumper	Steel bull bar	Aluminium/alloy bull bar	Polymer bull bar
Toyota Landcruiser	**6.9**	12.0	12.2 [3]	Not available
Nissan Patrol	11.7	13.6 [3]	7.3	**7.1**
Ford Courier	11.0	17.1	16.2 [3]	**6.8**
Holden Rodeo	**4.1**	12.0 [2]	9.4 [3]	11.9
Toyota HiLux	**7.2**	17.3 [3]	7.3 [2]	Not available

Notes:
1. Bold figures denote best result
2. Denotes default result taken from another test on an equivalent bar (see Section 3)
3. Denotes results for tests on bull bars that are optionally factory fitted

Table 5 Results of upper legform impact (Part B) tests by individual vehicle: peak bending moment (Nm)

Vehicle	Vehicle bumper	Steel bull bar	Aluminium/alloy bull bar	Polymer bull bar
Toyota Landcruiser	**406**	412	791 [3]	Not available
Nissan Patrol	726	**362** [3]	674	426
Ford Courier	693	982	>1034 [3, 4]	**535**
Holden Rodeo	**88**	412 [2]	640 [3]	660
Toyota HiLux	**378**	740 [3]	674 [2]	Not available
Average	458	582	763	540

Notes:
1. Bold figures denote best result
2. Denotes default result taken from another test on an equivalent bar (see Section 3)
3. Denotes results for tests on bull bars that are optionally factory fitted
4. Over-range result. Peak bending moment clipped to this value

Part C test results – bull bar or vehicle leading edge > 1000 mm high

The results of the Part C tests are given in Table 6. The results show that the polymer bull bars produced the least severe headform impacts on average, but were more severe than the results of the tests on the corresponding vehicles in two of the three tests (Patrol and Rodeo). The steel and aluminium/alloy bull bars produced more severe impacts than either the polymer bull bars or the leading edge of the vehicle. In several of the tests of steel bull bars the HIC values listed are artificially low, as the acceleration exceeded the measurement range of the instrumentation. The results of the bull bar tests were significantly associated with the bull bar material (Kruskal-Wallis test, $n = 11$, $P < 0.05$).

Table 6 Results of headform impact (Part C) tests by individual vehicle: HIC value

Vehicle	Bonnet leading edge	Steel bull bar	Aluminium/alloy bull bar	Polymer bull bar
Toyota Landcruiser	**1524** [1]	>4749 [4]	2514 [3]	Not available
Nissan Patrol	**837**	>5817 [3, 4]	2048	1162
Ford Courier	2156	5255	3092 [3]	**612**
Holden Rodeo	**1160**	>4749 [2, 4]	1246 [3]	1232
Toyota HiLux	**1698**	>6384 [3, 4]	2048 [2]	Not available

Notes:
1. Bold figures denote best result
2. Denotes default result taken from another test on an equivalent bar (see Section 3)
3. Denotes results for tests on bull bars that are optionally factory fitted
4. Acceleration was clipped. Actual HIC result higher than this value.

DISCUSSION

The results of the tests performed in this study support the view that bull bars increase the risk of injury to pedestrians. However, it is evident from these results that some bull bars are less aggressive to pedestrians than others. The vehicles itself may present a risk to a pedestrian in a crash and hence some bull bars may be less aggressive that the front of the vehicle that they are designed to protect.

Upper legform impact results

The Australian Standard AS 4876.1 does not include an impact that measures injury risk to adult pedestrians. In this study the EEVC WG17 upper legform impactor was used to examine the risk of upper leg injury to an adult pedestrian posed by a vehicle and a bull bar. As in the headform tests, the bull bars were tested at 30 km/h, rather than the 40 km/h nominated by the related EU Directive 2005/66/EC, because the metal bull bars and most of the original equipment bumpers were very stiff. There was concern that the tests at 40 km/h would have produced impacts beyond the range of instrumentation available, which would have meant that a useful comparison between the performance of the bull bars would not have been able to be made.

In tests with the top rail of the bull bars (Part A tests), only the polymer bull bars displayed acceptable impact performance, producing bending moments less than 300 Nm and forces less than 5 kN at 30 km/h. The polymer bull bars were mostly less aggressive in this regard than the leading edge of the vehicles that they were attached to.

Steel bars were very aggressive in Part A tests and an equivalent impact with a pedestrian's upper leg would almost certainly have resulted in severe pelvic and/or femoral injuries.

Part B tests of the bumper sections of bull bars and vehicles were almost uniformly poor, with the steel bars producing the highest impact forces and aluminium/alloy bars the highest bending moments. The original bumper of one vehicle (Holden Rodeo) performed very well in this test. While all polymer bull bars also performed poorly in Part B tests, they were less aggressive than the bumpers they replaced in two of three tests.

Headform impact results

While many of the bull bars performed poorly in the headform tests, it is also clear that the bonnet leading edge of most of the tested vehicles also performed poorly (Table 6). While the leading edges were, in many cases, less rigid than the steel bull bars and some of the aluminium/alloy bull bars, they too have not been designed to be safe in impacts with child or adult pedestrians and in many cases pose a high risk of injury in pedestrian collisions.

Nevertheless, the results demonstrate that the metal bull bars that we tested had a significantly worse impact performance than the bonnet leading edge of the vehicles. In two out of three headform tests, the polymer bull bars also performed worse than the vehicle but to a much lesser degree than the metal bars. However, it should be borne in mind that the vehicles performed fairly, or marginally in two tests and the polymer bull bar performed marginally in both of these cases. Furthermore, unlike the tests on the metal bars, the polymer bull bars were tested directly on the top of the bull bar stanchion, which was probably the stiffest location, making the comparisons less than favourable to the polymer bars.

OES bull bars and aftermarket bars

All of the original equipment supplied (OES) bull bars tested in this study were metal bars. They performed poorly in all tests and, with the exception of one Part A test, they performed worse than the front of the vehicle.

It appears from the results of the tests conducted that OES bull bar manufacturers and most aftermarket suppliers are not designing bull bars with pedestrian safety in mind, nor are the vehicle manufacturers requiring safe designs from OES bull bar suppliers. We would encourage vehicle manufacturers to specify that OES bull bars are tested and, at least, comply with the Australian Standard AS 4876.1 and that the manufacturers of aftermarket bull bars do likewise. Even though the Standard has limitations, compliance with the Standard would represent some improvement on the current situation.

Validity of the results

The primary aim of this study was to define a test method to measure the pedestrian impact injury risk posed by bull bars mounted to vehicles sold in Australia. To illustrate the usefulness of the method, we tested a selection of vehicles and bull bars made of a range of materials. The results appear to show that there are marked differences in performance between bull bars. While we tested as many bull bars as was feasible, the tests were too few and the bull bars were not selected in a manner to unequivocally generalise the differences between bull bars by the material from which they are constructed. We cannot conclude that all steel bull bars on the market are unacceptable, or that all polymer bull bars on the market are acceptable. However, we selected current generation bull bars that that are readily available to consumers, and within the range tested, material type was predictive of relative performance in Part A and Part C tests. There are plausible physical mechanisms that explain the relative performance of the bull bars in these tests, such as the density and stiffness of the materials and bull bar structures, and it is our opinion that thrust of the results might be somewhat generalisable to bull bars manufactured for passenger vehicles, and possibly for larger vehicles as well. It is our opinion that, should a method of evaluating bull bars be widely adopted, there would be changes in design and an improvement in the safety of these devices, whatever material is used.

It might be asked how well do the tests reflect what would happen to actual pedestrians. The chief justification for our choice of methods are: (i) the test tools, methods, and injury criteria are based on internationally recognised protocols that have undergone much development and the results are of a form that can be compared to other areas of crash testing; (ii) the measurements do reflect aspects of an impact that have physical meaning and are plausibly related to physical stresses that would be placed on the body in an impact. Therefore, the relative results of different tests should at least reflect a ranking of injury risk. Also, a study that used an EEVC headform test to reconstruct real crashes showed that the results of the headform tests do relate to actual injury severity (Anderson et al., 2003). It is less clear how the actual values of bending moment and impact force in the upper legform relate to real injury risk.

One other aspect of the tests should be mentioned: The impactor measurements (with the possible exception of bending in the upper legform) do not necessarily distinguish between concentrated loading and distributed loading. For example, two tests with the same head impact result may not indicate differences in risk if one test were of a structure that caused highly concentrated loading and the other test was of a structure that distributed the loading during the impact. The stresses on the skull are higher in concentrated loading and hence we would expect more harmful consequences from such an impact. It is therefore also important to emphasise the geometry of bull bars as an important consideration in bull bar design from a pedestrian-protection point of view.

CONCLUSIONS

This paper has proposed a testing protocol for bull bars that goes further than the Australian Standard AS 4876.1 by including tests that represent an impact with the lower extremities of an adult pedestrian. Furthermore, a method is proposed in which performance is appraised against generally recognised injury risk thresholds. The method appears to differentiate the performance of the bull bars in the tests and so may be able to form the basis of a rating system for bull bars.

The tests showed that the steel bull bars tested pose significant risks to pedestrians in the event of a collision. Bull bars constructed of lighter metals (aluminium/alloy) performed better but were still slightly worse than the fronts of the vehicles to which they attach. The polymer bull bars improved same aspects the pedestrian impact performance of the vehicles and may prove to be an acceptable way of protecting the front of the vehicle without causing increased risk of injury to pedestrians.

It should be noted that the vehicles themselves performed poorly, highlighting the lack of any vehicle safety standard in Australia for the protection of pedestrians.

ACKNOWLDGEMENTS

This study was funded by the South Australian Motor Accident Commission (MAC) through a Project Grant to the Centre for Automotive Safety Research. The MAC Project Manager was Ross McColl. We are grateful for the in-kind support from the Australian New Car Assessment Program (ANCAP). ANCAP provided the vehicles for the comparison tests.

The Centre for Automotive Safety Research receives core funding from both MAC and the Department for Transport, Energy and Infrastructure.

The views expressed in this paper are those of the authors and do not necessarily represent those of the University of Adelaide, the sponsoring organisations or other supporting organisations.

REFERENCES

2005/66/EC Directive number 66 of 2005, Official Journal of the European Union, 25 November 2005, L 309, pp 37 - 54

Anderson, R.W.G., Streeter, L.D., Ponte, G., Van de Griend, M., Lindsay, T., McLean, A.J. 2003, 'Pedestrian subsystem head impact results reflect the severity of pedestrian head injuries', International Journal of Vehicle Design, vol. 31, no. 1/2, pp. 1-15.

AS 4876.1-2002 Motor vehicle frontal protection systems, Part1: Road user protection, 17 September 2002, Standards Australia, Sydney, Australia, 24 p.

ATSB 2005, Road deaths Australia: 2005 statistical summary, Australian Transport Safety Bureau, Australian Government, Canberra, Australia, 55 p.

Attewell R. and Glase K. 2000. Bull bars and trauma, Consultant Report 200, Australian Transport Safety Bureau, Australian Government, Canberra, Australia, 54 p.

EEVC 2002, EEVC Working Group 17 Report, Improved test methods to evaluate pedestrian protection afforded by passenger cars, December 1988 with September 2002 updates

Euro NCAP 2004, European New Car Assessment Programme (Euro NCAP) pedestrian testing protocol, version 4.1, March 2004, 51 p.

FORS 1996, Pedestrian fatalities in Australia, Monograph 7, Federal Office of Road Safety, Canberra, Australia, 4 p.

Lawrence G., Rodmell C., Osborne A. 2000. Assessment and test procedures for bull bars, TRL report 460, Transport Research Laboratories, Crowthorne, Berkshire, United Kingdom, 50 p.

McLean A.J., Anderson, R.W.G., Streeter, L.D. 1998, Aggressiveness of bull-bars in the event of a collision with a child pedestrian: Head-form test results for three bull-bar products, Road Accident Research Unit, University of Adelaide, Australia, 12 p.