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Bull bars and road trauma

This report investigates the positive and negative aspects of bull bars with regard to road trauma in Australia through assessment of the current literature and analysis of fatal road crash data. Quantification of risk is limited by a number of factors, including restricting the analysis to fatal crashes, incompleteness of data on the bull bar status of vehicles involved in crashes, lack of data on animal strikes and the difficulty of isolating effects of bull bars from other factors associated with injury outcomes, such as vehicle size and speed. Current improvements in bull bar design may offset the risks for pedestrians and other vulnerable road users predicted by experimental studies and the possible risks indicated in an analysis of side impact crashes.

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BULL BARS AND ROAD TRAUMA

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Abstract

This report investigates the positive and negative aspects of bull bars with regard to road trauma in Australia through assessment of the current literature and analysis of fatal road crash data. Quantification of risk is limited by a number of factors, including restricting the analysis to fatal crashes, incompleteness of data on the bull bar status of vehicles involved in crashes, lack of data on animal strikes and the difficulty of isolating effects of bull bars from other factors associated with injury outcomes, such as vehicle size and speed. Current improvements in bull bar design may offset the risks for pedestrians and other vulnerable road users predicted by experimental studies and the possible risks indicated in an analysis of side impact crashes.

Keywords

BULL BARS, ROAD TRAUMA, PEDESTRIANS, SIDE IMPACT CRASHES

NOTES:

(1) ATSB research reports are disseminated in the interests of information exchange.
(2) The views expressed are those of the author(s) and do not necessarily represent those of the Commonwealth Government.

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Executive summary

This report assesses the available evidence on the contribution of bull bars to road trauma in Australia. It consists of a literature review and an analysis of ATSB's national fatal road crash database.

There is a dearth of scientifically based studies of the effect of bull bars on road safety. Experimental research has concentrated on pedestrian effects, but largely ignored risk to occupants of vehicles involved in side impacts. The risk to the occupants of bull bar equipped vehicles themselves has only recently become a focus of research due to potential for bull bar interference with airbag triggering. No quantification of the positive aspects of bull bars in animal strikes was found in the literature.

Analysis of ATSB's national fatal road crash database

A number of factors greatly hampered the use of ATSB's national fatal road crash database in estimating the risk posed by presence of a bull bar.

Lack of accurate baseline data on the proportion of vehicles fitted with bull bars was an important limitation. Moreover, the crash data indicate that bull bars are more commonly fitted to large vehicles and vehicles driven on rural roads. This complicates the task of isolating any detrimental effect of the bull bar from the increased risk imposed by greater vehicle weight, height and speed.

Other factors included crude estimation of vehicle speed in the database, the non-recording of bull bar status in 40% of cases and the fact that bull bar recording rates are higher for vehicles such as cars which have a relatively low likelihood of bull bar fitment. Furthermore, the literature review suggests that risk would vary by bull bar style and composition. A risk assessment should accordingly take these factors into account, but this was not possible here.

Because of these limitations it was not possible to draw firm conclusions about the contribution of bull bars to road trauma in Australia.

The fatal crash data do, however, enable one to broadly specify a ceiling to the contribution of bull bars to road trauma in Australia. The data show that about 30 pedestrians, 10 bicyclists and motor cyclists and 50 occupants of side impacted vehicles are fatally injured each year in impacts with the front of a vehicle equipped with a bull bar.

These counts are potentially underestimated as a result of incomplete bull bar identification in the crash records. However, it is likely that many of these deaths would occur regardless of the presence of a bull bar due to the severity of the crash circumstances. On balance, the number of deaths attributable to bull bars is probably substantially less than the number identified as involving a bull bar-equipped vehicle.

Impact of a bull bar with a pedestrian

The experimental studies reviewed in this report provide some evidence that older-style bull bars present an additional risk to pedestrians and other vulnerable road users. However, while the effect of a bull bar is likened in these studies to an impact without a bull bar at a higher speed, this hypothesis could not be confirmed in the analysis of Australian fatality statistics.

The magnitude of any additional risk therefore remains undetermined.

The crash data analysis did, however, show that pedestrians killed in bull bar impacts have a unique injury profile. Whilst having the same high levels of head injury as pedestrians killed in non-bull bar impacts, they are more likely to sustain severe abdominal and chest injury as well.

Further research is warranted on this potentially important new finding in order to estimate the extra risk of death or serious injury imposed by the additional abdominal or chest injury in such collisions.

Impact of a bull bar with the side of a vehicle

No experimental studies were located on the risks associated with the impact of a bull bar with the side of a vehicle.

The significant limitations of the crash data analysis in the current study meant that it was not possible to do more than indicate that an extra risk may exist.

Recent developments

Recent improvements in the design and fitting of bull bars may have reduced the risk below that imposed by the older style bull bars used in the experimental studies and present in many of the crash records analysed here.

Issues concerned with air bag deployment and the proper operation of crumple zones in striking vehicles also appear to have been addressed by recent improvements in bull bar design.

No data are available on the current market share of these designs.

Protective effect of bull bars

There is no clear evidence that bull bars reduce injuries to occupants of bull bar-equipped vehicles. Analysis from first principles suggests that bull bars would not offer significant protection in most instances, though there may be some advantage to front seat occupants of forward control vehicles, by reducing the likelihood of intrusion into the cabin space. On the basis of broad assumptions concerning rural fitment rates and crash involvement, it is estimated that only a small number of fatal road crashes are forestalled by bull bars in animal strikes (up to nine per year). This estimate does not include lives that may be saved by preventing stranding of vehicle occupants in remote areas.

No attempt has been made to estimate the savings in property damage to bull bar-equipped vehicles. The aggregate savings might be quite large, though they could be offset by increased damage to other vehicles, and increased vehicle operating costs resulting from increased mass and aerodynamic drag.

Conclusions drawn

This report provides no conclusive basis for opposing the use of newer-style bull bars. The experimental findings reviewed here about impacts of bull bars with pedestrians and other unprotected road users do, however, provide some case for considering measures to phase out the use of older style, protruding, rigid bull bars, especially in urban areas.

This would not, however, provide a panacea for road safety, being unlikely to have more than a minor effect on the road toll as a whole.

Nevertheless, there is the potential to save some pedestrian lives and those of relatively unprotected road users, such as bicyclists, as well as reduce the incidence and severity of injury to both the occupants of other vehicles and to the occupants of bull bar-fitted vehicles themselves.

Abbreviations/acronyms

ADR	Australian Design Rule
AIS	Abbreviated Injury Scale
ATSB	Australian Transport Safety Bureau
BAC	Blood Alcohol Content
FORS	Federal Office of Road Safety
NHMRC	National Health & Medical Research Council
NRMA	NSW Roads and Motorists Association
OR	Odds Ratio
RTA	Roads and Traffic Authority (NSW)
SAE	Society of Automotive Engineers
4WD	4 Wheel Drive

Background

Bull bars are traditionally sturdy structures attached to the front of vehicles in order to decrease vehicle damage in the event of minor impacts and to protect occupants against the more serious consequences of collisions with animals. They are generally more common in rural areas where there is a higher likelihood of collisions with animals. The increased popularity of 4WD and off road vehicles has led to an increase in the prevalence of vehicles fitted with bull bars in metropolitan areas.

There is no specific legislation regulating the use of bull bars in Australia. They are commonly fitted after a vehicle has been purchased.

It has been suggested that bull bars pose an additional threat to pedestrians and that bull bars increase the severity of injury outcomes in other vehicles when the bull bar strikes the side of such vehicles. Additionally, it has been claimed that bull bars pose a threat to the occupants of a bull bar-fitted vehicle themselves by decreasing the effectiveness of crumple zones and by interfering with the appropriate triggering of airbags. On the other hand, it is the widely held view, especially in the rural community, that bull bars mitigate the severity of crashes involving frontal impacts with animals.

Through assessment of the current literature and analysis of road crash data this report attempts to quantify the contribution, both positive and negative, of bull bars to road trauma in Australia.

Literature review

Over 30 articles were sourced in a literature search using the MEDLINE, ROAD, ROADRES and ENGINE databases[1]. The articles report on laboratory crash tests (Australia and Germany), simulations (Australia) and assessments of actual crashes (Australia and United Kingdom).

Since bull bars originated in Australia, it is not surprising that much of the research has been conducted in Australia. The literature available to date has been published as reports by road authorities or as conference proceedings. None was located in peer reviewed journals. A workshop on bull bar safety was held in Sydney in 1994, sponsored by the RTA, The Institution of Engineers and the NRMA. Participants included safety experts and industry and user group representatives. Some of these authors also contributed to the Staysafe 44 Parliament of NSW Joint Standing Committee on Road Safety (Developing Safer Motor Vehicles for Australia) in 1998. There has not been a large amount of work based on formal analysis of actual crash data. Several authors, such as Bowd (1995), Rechnitzer (1995) and Parker (1995),

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[1] ROAD provides information on roads and road related material, including vehicle design and safety, road safety and vehicle testing. Relevant Australian journal articles, reports, monographs, theses and conference papers are indexed (from 1978), as well as all Australian Road Research Board (ARRB) publications. Overseas literature is selectively included.
ROADRES contains current and completed Australian research projects (from 1978) on road related topics carried out by federal and state road and traffic authorities as well as other research organisations and local government.
ENGINE provides access to Australian engineering information, covering all branches of engineering. Conference papers, journal articles, technical papers and books are indexed from 1980.

cite the apparent conflict between the fitting of bull bars and the Australian Design Rules. Australian Design Rule (ADR) 42/02, clause 12.1.1 seeks to prohibit the equipping of a vehicle with 'any object or fitting' which is not 'technically essential' and is likely to increase the risk of bodily injury to any person. The ADR does not specifically prohibit bull bars on vehicles. More recently, the possible interference of bull bars with airbag triggering has meant that bull bar fitment also needs to be assessed with respect to ADR 69 regarding occupant injury risk - see Gardner (1994) and Taylor (1998).

The results of the literature review are summarised below under the following themes: prevalence; reasons for fitting bull bars; and the theoretical pros and cons of bull bar fitment. This is followed by sections on pedestrian injury, side impacts, frontal impacts, air bag deployment, trucks, evaluation of risk and benefit, and developments in bull bar design.

Prevalence

The data on bull bar prevalence are patchy. The fitment rate is clearly lower for passenger cars than larger vehicles. Chiam & Tomas (1980) report a prevalence of less than 1% in Melbourne in 1980 based on observation of 26,000 passenger cars. An estimate of 2% is quoted for Victoria in 1994 in Gardner (1994). Haley (1998) quotes 50% for 4WD vehicles, passenger vans and light commercial vehicles according to NRMA figures from 1994. These estimates are consistent with survey results by Zellmer and Otte (1995) who report 60% fitment rates for off road vehicles in Germany. Hardy (1996) also reports 60% prevalence amongst off road vehicles and 13% amongst light goods vehicles based on the survey of a small number of vehicles in Great Britain. However, these latter reports do not provide survey methodology or information on the number of vehicles surveyed.

Moore (1994) reports on a small survey of farmers from rural NSW (with a 58% response rate). A total of 33 out of 38 respondents (87%) reported fitting bull bars to their family cars.

No statistics were located on trends in fitment rates. However, Taylor (1994), an industry representative, reports consistent growth in local and export sales.

Reasons for fitting bull bars

The popularity of bull bars in the presence of alternatives to repel animals, such as the high frequency emitting device described by Gore (1994) and Parker (1995)[2], indicates that there are many reasons that bull bars are fitted. Higgins (1994) proposes that the common reasons for fitting bull bars are to protect the vehicle against damage and reduce occupant injury in the event of collision either with an animal or another vehicle. He also postulates that image and fashion are powerful motivators. This latter point is consistent with a much earlier report by Page et al (1984) on a survey of Melbourne city drivers. The three major reasons given for fitting bull bars to sedans were to protect against parking collisions, to make the vehicle more visually attractive and to allow more aggressive driving in peak hours.

[2] The efficacy of electronic devices under various conditions has been questioned. See Bollinger (1994).

In a report by Couter (1994), 4WD club members give more practical reasons for attaching bull bars; ie to give bodywork protection from scrub overgrowth and for mounting winches, driving lights and radio aerials. Moore (1994) and Keill (1994) report that rural motorists are particularly concerned with ensuring vehicle mobility after a collision with an animal, especially at night. Moore also reports that rural drivers felt it was safer to hit an animal with a bull bar rather than swerve and avoid one without a bull bar. Both Taylor (1998) and Sansome (1999) also cite reduced repair costs for bull bar impacts.

There are disadvantages of bull bars with respect to vehicle performance (Couter 1994). Many of the referenced papers report on the changed collision dynamics for vehicles with bull bars. These have specific consequences for pedestrians and other vulnerable road users, other vehicles (especially in side impacts) and the vehicle itself (with respect to the increased rigidity of the vehicle and effects on air bag deployment). Each of these topics is described in more detail below.

Pedestrian impacts
In an early report, Chiam and Tomas (1980) examine the effect of bull bars on the vehicle pedestrian collision dynamics. The experiments reproduced collisions between an adult male dummy and cars with and without bull bars and at impact speeds of 20km/h. The results show that impacts with bull bars result in a higher incidence of knee or ankle fractures and higher severity head injury than impacts with the front of the vehicle. It was concluded that this is due to higher and more concentrated impact points in the case of bull bars. This is also noted by Haley (1994).

Zellmer and Otte (1995) report on crash tests conducted in Germany at the Federal Highway Research Institute (BASt). They conclude that bull bars strongly increase the risk of injury in accidents with pedestrians or bicyclists. They state that injury risk for a child in an impact with a bull bar at 20 km/h is similar to an impact with an off road vehicle at 30 km/h and a regular car at 40 km/h. They also conclude that hip and lower limb fracture risk for an adult impacting a bull bar at 25 km/h is similar to impacting a car bonnet at 40 km/h.

More recent Australian crash testing programs are reported by Reilly-Jones and Griffiths (1996) and Anderson and McLean (1998) from the NHMRC Road Accident Research Unit. Both studies conclude that pedestrians suffer more severe injury in collisions with vehicles with bull bars compared with vehicles with no bull bars at low impact speeds. The results of the latter program also indicate the steel and aluminium bull bars had the worst performance, but that plastic bull bars performed similarly to or better than the unprotected vehicle in terms of injury to pedestrians.

Side impacts
Rechnitzer (1993) and McLean (1994) report on the extra hazard that bull bars pose in the event of side impact crashes. Both point to the extra risk of head injury due to the increased height of impact and intrusion of the bull bar into the cabin of the side impacted vehicle. However, the literature search did not produce any reports of side impact crash testing of bull bar equipped vehicles or any attempt to quantify the increased risk for different types of vehicles and impact speeds.

Frontal impacts
Purvis (1994) states that there is increased risk of injury to occupants of a vehicle with a bull bar in a frontal impact with a heavy object, due to the interference of a bull bar with the crumple characteristics of the front of the vehicle. No reports of impact test data supporting this statement were located in the literature search. In contrast, a 1986 FORS report showed improved occupant safety for a van with a steel bull bar compared with the same model without a bull bar in a frontal barrier test at 50 km/h. However, as Purvis (1994) and Bullen et al (1996) point out, the outcome in an impact depends on many factors including the type of bull bar and how it is mounted.

Frontal impacts and air bag deployment
Several authors comment on bull bars and air bag deployment (Gardner 1994 and Purvis 1994). Tomas (1994), Sullivan (1996) and Taylor (1998) suggest that fitment of bull bars potentially causes misfiring of air bags at low speed impacts. But Bullen et al (1996) did not find this to be the case in experimental data. Tomas (1994) also suggests that reduced deceleration could also delay deployment which could pose injury risk to occupants. Sansome (1999) and Taylor (1998) report that both vehicle manufacturers and aftermarket specialists are addressing the challenge of designing bull bars compatible with air bag triggering systems.

Trucks
As with smaller vehicles, there are arguments both for and against bull bars on trucks (Sweatman 1990, Rechnitzer 1993). The arguments in favour of bull bars on trucks include the prevention of under-run and smaller likelihood of steering loss after a frontal collision. The main argument against bull bars on trucks is the same as for other vehicles, namely, that the bull bars are not energy absorbing, and thus present extra hazard to both unprotected road users and occupants of another vehicle in the event of a collision. However, the effect may be magnified in the case of trucks due to the height of the bull bar and the type of material used. Chiam and Tomas (1980) comment that the heaviest types of bull bars are those usually found on trucks.

Estimation of extra risk
There have been several different approaches in the literature in estimating the contribution of bull bars to road casualty statistics. A short report by FORS (Monograph 7, 1996) examined Australian fatal crash data for pedestrians for the year 1992. It states that bull bars were involved in 12% of fatal pedestrian crashes in 1992, but it was estimated that bull bar involvement could be as high as 20%, due to the large amount of missing information on bull bar status in the Fatality Crash Database. Bowd (1997) conducted an analysis of a larger number of crashes including single and multiple vehicle fatal crashes, as well as pedestrian crashes, occurring in 1990 and 1992. He estimated that bull bars were associated with approximately 29% of road trauma fatalities. However, his calculations are based on a number of assumptions and extrapolations of incomplete data that are difficult to evaluate.

Bowd (1995) had earlier attempted to estimate the number of additional pedestrian fatalities based on detailed estimates of impact speeds for fatal pedestrian crashes in urban Adelaide in the period from 1983 to 1991 (reported by McLean et al, 1994). Bowd found that the mean fatal impact speed was only 30 km/h for cases involving bull bars (based on 5 crashes all involving either 4WD vehicles or vans) compared with a mean of 61 km/h for 7 equivalent cases (same vehicle type) not involving bull bars. Despite the small numbers, the results are statistically significant and consistent with the BASt crash test results reported by Zellmer and Otte (1995). Bowd applied this double speed estimate to a function relating probability of death with vehicle-pedestrian collision speed (obtained from the literature) and estimated the underlying baseline distribution of collision speeds from the Adelaide data. He estimated that the rate of pedestrian fatalities would be increased by 274% if all vehicles in urban Adelaide had been fitted with bull bars or 27% if only 10% of vehicles had been fitted with bull bars. Bowd extrapolated this result to the national road toll. He estimated that a 10% fitment rate would have contributed to 57 fatalities (95% confidence interval between 42 and 72) annually out of an estimated total of 264 urban pedestrian fatalities from frontal collisions with bull bar eligible vehicles. This corresponds to 15% of total pedestrian fatalities (57/391).

Hardy (1996) attempted to estimate the number of additional casualties and injuries resulting from vehicles being fitted with bull bars using a different approach. His analysis was based on a case by case evaluation of a stratified sample of approximately 250 fatal, serious or slight injury crashes involving at least one bull bar equipped vehicle which occurred in Great Britain during 1994. Pedestrian crashes and crashes involving bicycles and motor cycles were oversampled and the estimates are restricted to pedestrian and two wheeler rider casualties. He estimated that in approximately 6% of fatal and 21% of serious injury impacts, the bull bar contributed to the higher severity level of injury to the pedestrian or rider. These figures were extrapolated to estimate the total number of casualties which were attributable to bull bars after incorporating estimates of fitment rates for different vehicle types from a small survey conducted in 1996. It was concluded that only approximately 2 to 3 fatalities out of an estimated total of 35 fatalities which had occurred in impacts with bull bar equipped vehicles and 40 serious injuries out of a total of 316 casualties could be attributed to bull bars in 1994. The author cautions against a wide generalisation of these results, since they are based on a relatively small sample of crashes and that the bull bars involved may be quite different from those used in Australia.

The disparity in these estimates cannot be ignored, despite the cautions of both authors concerning the underlying assumptions. In terms of fatalities, Bowd's Australian estimate is over 50 and the Hardy's UK estimate is under 10, even though in the latter, Hardy includes bicyclists as well as pedestrians. The major problems with these studies (which are acknowledged by the authors) are that they are based on a small number of crashes and both require fitment rate data that are not available. It is concluded that the Bowd's higher estimate comes from a higher risk estimation in a single crash compared with Hardy's estimates.

Evaluation of benefits

There was no quantification in the literature of the benefits of bull bars. The difficulties of assessing benefits were highlighted by Bollinger (1994) who pointed out that official crash statistics refer to lives lost, not those saved. Some indication of magnitude is given by the frequency of animal strikes, but very little data were located in the literature and the reports that were found varied greatly. The estimates ranged from 1600 animal collisions a year in NSW based on NRMA insurance statistics (Purvis 1994) to an average of three large animal impacts per year per vehicle reported in a small survey of NSW farmers by Moore (1994). Sparke (1994) reported 20,000 kangaroo collisions per year nationally estimated by a Melbourne based zoologist. As with the estimation of risk, fitment rates would be required in any extrapolation of animal strikes to lives saved by bull bars in animal strikes.

Developments in bull bar design

Although suggestions have been made in the literature as to how bull bar construction could be improved (eg Zellmer & Friedel 1994); most experimental data published to date are based on old style bull bars.

There have, however, been many recent developments in the design and construction of bull bars. Sansome (1999) and Taylor (1998) (who are both linked to industry) refer to the improved, rounded design of bull bars as well as the availability of different bull bar styles for city and country regions. Small bull bars of minimal design, referred to as "nudge" bars, are suggested for city driving. Sansome and Taylor also indicate that extensive industry research is being carried out in many aspects of bull bar design including air bag compatibility. Both advocate the setting of industry standards.

Bull bars are available in many different materials. Chiam & Tomas (1980) list thermoplastic, aluminium and steel as most common in 1980. Sansome (1999) indicates that aluminium alloy is most common for bull bars fitted to passenger vehicles and is desirable in terms of its flexibility and weight. Haley (1998) and Anderson & McLean (1998) advocate plastic bull bars. No data was located on the relative frequency in the existing vehicle fleet or current market share of the different designs.

Other authors, related to both the car manufacturing industry (Sparke, 1994 and Sansome, 1999) and the after market industry (Taylor 1998), indicate that the mounting system used for a bull bar also plays a large role in the result of a collision. Bullen et al (1996) emphasised that the bull bar and its mounting system must be considered as a single integrated system. Taylor (1998) reported that the mounting system is a critical element in the current research and testing. Tomas (1994) mentions the type of mounting in discussing the possible dangers to van occupants if a bull bar on their vehicle is pushed up in an impact encroaching the cabin. Purvis (1994) suggests that bull bars should not be fitted to vans for this reason.

Literature review summary

The literature review confirmed that bull bars are commonly fitted primarily for safety and economic reasons, but that aesthetics and style also play a role. Although it is clear that bull bars are more commonly fitted to larger vehicles and more common in rural areas, no published figures were found on the current fitment rates for different types of vehicles in different regions.

The experimental data showed that bull bars pose a greater risk in the event of low speed impacts with unprotected road users such as pedestrians. The estimation that the effect on a pedestrian of an impact with a bull bar fitted to a passenger vehicle is roughly equivalent to a doubling of the impact speed was consistent with data from a small number of actual pedestrian crashes involving vans and 4WD vehicles. No reports were found describing experimental or simulation studies of the effect of bull bars in side impacts.

Only a small number of reports attempted to quantify the additional risk posed by bull bars in terms of casualties attributable to bull bar impacts. The results of those that did were restricted to unprotected road users and were quite divergent. The reasons for this include the small number of cases on which the results were based, the lack of reliable estimates of underlying fitment rates and relevant collision frequencies, and the lack of information on other factors that may determine the outcome in a collision.

Finally, despite the fact that safety appears to be a major reason for fitting bull bars, no results were found which attempted to quantify the safety benefits of bull bars.

The following analysis attempts to address some of these issues by accessing the Australian national road crash data which includes comprehensive crash details (including bull bar status if recorded) for not only pedestrian crashes, but for all types of fatal crashes.

Methods

The Road Fatality Crash Database compiled by ATSB is the only national set of Australian data on bull bar involvement in road crashes. Data were available for the years 1990, 1992, 1994, 1996 and 1997. No data were available for the intervening years due to the biennial collection, which was replaced by an annual collection process in 1996.

In order for bull bar status to be coded present or absent in the database, there must be evidence as to whether a bull bar is present or not (eg in the vehicle report, photo, or specifically mentioned in the police report). Otherwise bull bar status is recorded as unknown. The presence of significant numbers of vehicles with 'unknown' bull bar status results in a potential underestimation of prevalence, particularly for vehicles only peripherally involved in the crash. On the other hand, the inclusion of bull bar records for vehicles that were only marginally involved in the crash could lead to an overestimation of the contribution of bull bars to crash outcomes.

The study first examined the prevalence of bull bars for different types of vehicles involved in fatal crashes. This is not necessarily generalisable, however, to the vehicle fleet at large, since the cross-section of vehicles involved in fatal crashes is a possibly biased selection of vehicles.

The study then examined the role of the bull bar in crash outcomes. Because the role of the bull bar varies according to the type of crash, the following crash classes were separately analysed: pedestrian crashes, multiple vehicle side impact collisions and single vehicle frontal impact collisions. The characteristics of these crashes (the crash conditions, location and configuration), the persons killed and their injury profile were summarised. In addition, the number of fatal crashes in which vehicles hit animals was investigated.

Results

Overview

Figure 1 gives a breakdown of fatal crashes involving vehicles with bull bars in the five separate years under study.

The top level of Figure 1 indicates bull bar status. Ten percent of vehicles involved in fatal crashes were reported to have bull bars fitted. For over one third of vehicles (36%), there was no indication in the crash documentation of whether bull bars were fitted or not. The remaining vehicles did not have bull bars fitted and these are broken down into vehicles which were eligible for bull bar fitment (43%) and those for which bull bars are not applicable (11%) (ie bicycles, motorcycles and other non-motorised conveyances).

The percentage of vehicles with unknown bull bar status has decreased markedly with time, with a corresponding increase in the percentage of vehicles recorded as having no bull bar and a marginal increase in the percentage of vehicles with bull bars. This is examined further in a later section of this report.

The second level of Figure 1 gives a breakdown by impact location for the vehicles known to have bull bars fitted. This is the impact that resulted in a fatality, if there was a fatality associated with this vehicle (either one of the vehicle's occupants or an external road user such as a pedestrian or occupant of another vehicle involved in the collision)[3]. A total of 58% of impacts were with the front of the vehicle (ie involving the bull bar). This percentage is relatively consistent over time. It should be noted that even though these frontal impacts are with the bull bar, this doesn't necessarily imply that the fatality was directly attributable to the bull bar. The conditions may have been such that the impact with the front of the vehicle would have been fatal without the bull bar.

The third level of Figure 1 indicates what the bull bars came into contact with. The most common impact was with another motor vehicle (64%), followed by pedestrians (19%) and other relatively unprotected road users including motor cyclists, bicyclists and animal riders (10%). The remaining collisions (7%) were with other objects.

The fourth level further disaggregates vehicles or objects struck by the bull bar. Of the 485 bull bar to vehicle impacts over the time period studied, 194 (40%) were with the side of another vehicle. There were two cases where a fatality resulted from an impact with an animal and 54 where the fatality resulted from an impact with another object (such as a pole, tree or embankment).

Across the five separate years, there were in total 750 fatalities external to the bull bar fitted vehicle and 128 fatalities among occupants of bull bar fitted vehicles (internal) resulting from collisions involving the bull bars (Table 1). The corresponding totals for the most recent year available (1997 which also has the least amount of missing information) are 126 external fatalities and 19 internal occupant fatalities.

[3] Vehicles not involved in fatal impacts are included with "other impacts". Seven cases (0.5%) for which the impact point was not specified are also included with 'other impacts'.)

It should be stressed that bull bars alone are not necessarily causing all of these fatalities, although they do provide an upper limit. It is important to realise that many other factors are relevant to the outcome of a collision. Clearly the speed and the mass of the involved vehicles play major roles. Additional factors include the age and sex of the persons involved, and, in the case of vehicle occupants, their use of seat belts and seating position relative to the impact point. In the case of bicycle riders, helmet status is also important. The bull bar contribution to these outcomes is examined below for each major crash type. This is preceded by an assessment of the prevalence of bull bars among vehicles involved in fatal crashes is examined.

Prevalence of bull bars in fatal crashes

Assessment of bias in reporting

Out of a total of 12,524 vehicles involved in fatal crashes in the 5 years under study, 11,105 (89%) were classified as suitable or 'eligible' for bull bar fitment (ie essentially excluding motor cycles and bicycles). Bull bar status was able to be determined from the crash documents for only 60% of bull bar eligible vehicles. In the other 40% of cases there was no mention of bull bars in the crash records and no relevant photos, but this does not necessarily mean that no bull bar was fitted. Given the large amount of missing information, it is advisable to investigate possible bias in the data collection, especially since these data will be used to estimate prevalence rates. It has already been shown that the unknown percentage is decreasing over time (Figure 1), but it is necessary to investigate other factors. In particular we are interested in crash features which are probably related to fitment rates, such as vehicle type and location (State/Territory, metropolitan/urban/rural), as well as factors which may be linked to the likelihood of reporting (for example post-crash vehicle defects testing and crash type).

Table 2 shows the percentage of vehicles with and without bull bar information by each of these factors. There is considerable fluctuation, but also some clear patterns. As noted earlier the amount of missing information is decreasing over time (from 48% in 1990 down to 24% in 1997). Cars and buses are the vehicles with the most information. Not unexpectedly, the vehicles that did not undergo a vehicle test had a higher level of missing data than those that did (52% vs 21%). There is also variation by location with Queensland and the Northern Territory having the highest levels of missing data.

In order to adjust for the possible confounding (or mixing) between these various effects and also to quantify the contribution of random fluctuations, a logistic regression model was fitted including all these factors as explanatory variables for known bull bar status. This is essentially modelling the probability of having bull bar information available and coded in the database. All of the factors included in the model were statistically significantly associated with bull bar status. The directions and magnitudes of the associations generally mirror those of the crude percentage distributions in Table 2 (see Table A1 which lists the adjusted odds ratios). Cars, buses and trucks were the vehicles most likely, and vans and light trucks, the least likely, to have the information coded. Tasmania and South Australia were the States with the most complete information and the ACT, Queensland and the Northern Territory were the jurisdictions with the least information. There was less information for vehicles involved in crashes outside capital city metropolitan areas compared with urban areas. Bull bar status was also more likely to be coded for pedestrian crashes compared with other types of crashes.

These results indicate that there are many potential biases in the information collected, making it difficult to assess the validity of an estimate of bull bar prevalence and whether there are changes over time. The net effect of these biases is unclear. The vehicle type and location biases could contribute to an underestimation of bull bar prevalence since the literature search suggests that bull bar fitment rates are higher for larger vehicles and for rural locations.

Prevalence

If the vehicles with no information are assumed not to have bull bars fitted, this results in an overall minimum prevalence of approximately 12%. Excluding these vehicles from the calculation of the percentage gives a larger estimate of 20%. This effectively assumes that these vehicles are a random sample of all vehicles involved in fatal crashes. This is undoubtedly not the case and is likely to be an overestimate of the underlying prevalence. The true figure is probably somewhere in between[4].

Factors related to bull bar fitment

Despite the incomplete data, further analysis was undertaken to investigate which crash and vehicle characteristics were associated with bull bar status. These factors are then interpreted in the light of the previous analysis on possible reporting biases. Table 3 shows the percentage of vehicles involved in fatal crashes with bull bars, with no bull bars and with no information. The percentage of vehicles with bull bars varies according to the size and type of vehicle, the vehicle testing and the location of the crash.

As in the previous section, in order to distinguish between relationships between these factors (for example, vehicle type and crash location) and in order to account for random variations, a logistic regression model was fitted including all of these factors. In this case, however, the outcome was bull bar presence versus no evidence of presence (ie either no bull bar or no information).

The logistic regression confirmed the statistical significance of the associations for each of the factors except metro/urban/rural status, although this was marginally significant (Table A2). The direction of each of the associations was the same as the crude percentages in Table 3. All the larger vehicles had higher bull bar percentages than cars, with articulated trucks and 4WD vehicles the highest. The Northern Territory and Western Australia had the highest figures and the ACT and Queensland had the lowest. This is interesting since the Northern Territory, ACT and Queensland had the largest amounts of missing data. So, it is possible that the figures for Queensland and the ACT are underestimates. Although the bull bar prevalence in crashes in other urban areas was not statistically significantly different from those for capital cities, statistically significantly higher prevalence was observed in rural

[4] Prevalence was also estimated at the crash level instead of the vehicle level. In 1997, 233 out of 1,585 fatal crashes involved at least one vehicle with a bull bar. This corresponds to 15% of fatal crashes. The figures in the earlier years are 12%, 13%, 16% and 16%, for 1990, 1992, 1994 and 1996, respectively. Again, it should be pointed out that these figures assume that the vehicles with no information about bull bars were assumed not to have bull bars and so these are probably underestimates of prevalence due to underreporting.

regions, even after adjusting for vehicle type and State. Finally, higher prevalence was observed in pedestrian crashes and multiple vehicle crashes compared with single vehicle crashes. However, since the information levels were higher for these types of crashes, this may be due to reporting bias.

In conclusion, even in the presence of the higher amounts of missing data, statistically significantly higher prevalence rates are observed for larger vehicles and for vehicles involved in crashes in rural regions.

Based on the 1997 figures (for which the coverage is most complete) (Table 4), the ranking from lowest prevalence to highest prevalence is from cars (2%), buses (9%), light trucks (28%), heavy rigid trucks (30%), articulated trucks (35%), passenger vans (37%) and 4WD vehicles (47%). Again, it should be pointed out that these figures are potential underestimates through under-reporting and they may not reflect the underlying prevalence rates for Australia, since they are based on the subset of vehicles that have been involved in fatal crashes.

The prevalence estimates are increasing and unknowns are decreasing over time for cars, passenger vans, 4WDs, light and heavy rigid trucks (Table 4, Figure 2). This was confirmed by chi-squared tests for trend for all vehicle types except buses, but this category had a small number of cases.

Bull bars and fatal pedestrian crashes

In the period under study, pedestrians comprised approximately 18% of the road toll. (In 1997, 325 pedestrians were killed in impacts with 317 vehicles.) Attention is now restricted to bull bar eligible vehicles (ie essentially excluding motor cycles and bicycles that accounted for 3% of pedestrian deaths). The fatal point of impact is recorded as the front of the vehicle for 75% of pedestrian crashes and the undercarriage for 10%. Side impacts account for 4%, other impacts for 5%, and in 6% the impact point was not recorded. These percentages are based on aggregate counts over the total period under study.

In the period under study, 140 fatal frontal pedestrian impacts were with bull bars (11%), 707 were with vehicles without bull bars (56%) and bull bar status was not recorded in the remaining 423 cases (33%) (Figure 1 and Table 5). This corresponds to 145 pedestrian fatalities in frontal impacts with bull bars[5] and averages out to at least 29 per year (Table 1). There were 29 of these fatalities in 1997 (Table 1).

As was seen with the prevalence estimates over all fatal crashes, the percentage of vehicles with bull bars varies by vehicle type and crash location for fatal frontal pedestrian crashes as well (Table 5). Amongst the vehicles involved in these crashes, a higher percentage of the larger vehicles had bull bars (highest for 4WD vehicles). Bull bars were also more prevalent in the crashes in rural regions.

Cars are the most common vehicle type involved in fatal frontal impacts with pedestrians. They represented 967 of 1270 bull bar eligible vehicles (ie 76% of total) involved the crashes studied. (Table 5). Heavy vehicles, such as trucks and buses, are the next most common (9% of total). Four wheel drive vehicles account for 5%.

[5] Some crashes resulted in more than one pedestrian death.

Only 11% of fatal frontal pedestrian impact crashes occurred in rural regions. Almost 70% of fatal pedestrian crashes occurred in areas with speed limits of 60 km/h or less. Approximately half occurred at night.

An attempt was made to compare speeds for bull bar impacts and non-bull bar impacts to follow up the work of Bowd (1995) who found that fatal bull bar impacts were, on average, at lower speeds than fatal non-bull bar impacts in urban areas. Unfortunately, vehicle speed estimates were available for only 56% of the fatal frontal pedestrian impacts with bull bar eligible vehicles. The subset of fatal frontal pedestrian impacts occurring in low speed zones (≤ 60 km/h) was extracted (487 crashes). The average estimated vehicle speed prior to impact for the 42 vehicles with bull bars (53 km/h) is similar to the average for the 317 vehicles without bull bars (54 km/h) (Table 6). However, the average speed for the other vehicles, for which bull bar status was not recorded, is statistically significantly lower (47 km/h). To investigate whether this pattern is due to other factors related to speed, mass or bull bar status, a multiple regression model for the average speed of the vehicle before impact was fitted incorporating terms for bull bar status (yes, no, unknown), type of vehicle (car, van, 4WD, light truck, heavy truck/bus), age group of pedestrian killed (<16, 16-59, 60+), sex of pedestrian killed, crash time (night vs day), evidence of braking before impact (yes vs no) and year of the crash.

The regression coefficients are listed in Appendix Table A3. After adjustment for these other factors, the mean impact speed was 3 km/h higher for the vehicles with bull bars compared with those without, but this difference was not statistically significant ($p = 0.3$). The adjustment did not affect the statistically significantly low impact speed lower for the unknown group which was estimated to be 5 km/h less than that for vehicles without bull bars ($p = 0.002$).

Statistically significantly higher impact speeds were observed for night-time crashes compared with daytime crashes ($p = 0.0004$). Statistically significantly lower impact speeds were observed for older pedestrians ($p = 0.001$) and light trucks ($p = 0.004$) and heavy trucks ($p = 0.003$) in comparison with cars. Vans and 4WD vehicles also had lower average impact speeds compared with cars, but the differences were not statistically significant ($p = 0.5$ and $p = 0.4$ respectively).

The analysis was repeated on the subset of vans and 4WD vehicles which included 17 vehicles with bull bars, 7 vehicles without bull bars and 11 vehicles where bull bar status was not recorded (Table 6). The crude average impact speed was higher for the 17 bull bar equipped vehicles (mean 56 km/h) compared with the 7 vehicles without bull bars (mean 43 km/h), but the difference was not statistically significant ($p = 0.06$, t-test). The 11 vehicles with unknown bull bar status had an intermediate mean impact speed of 50 km/h.

So Bowd's lower fatal pedestrian impact speeds for bull bar equipped vans and 4WDs could not be replicated in these data. This is perhaps not surprising since the subset analysis of vans and 4WDs and the South Australian data were both based on very small samples (24 vehicles and 12 vehicles respectively). However, the analysis including all vehicle types did not even produce a result in the same direction. It is possible that this may be due to inaccuracy in the estimated speed of the vehicle or biases in the subset of crashes where speed estimates were available. In the Fatality

Crash Database, the estimation is based on police and independent witness observation, and does not appear to be as sophisticated as that used for the South Australian data. However, the general magnitude of speeds estimated in the Fatality Crash Database is compatible with the South Australian data since 78% were greater than 40 km/h, compared with 80% quoted by McLean in a summary of the same data in a later report (1996). It is also reassuring that the results for factors other than bull bar status were consistent with expectation (ie. lower speeds for crashes involving the more vulnerable pedestrians and lower impact speeds for crashes involving larger vehicles).

Bull bars and injury profile of pedestrians killed

The characteristics and injury profile of the pedestrians fatally injured in frontal impacts are shown in Table 7 by bull bar status of the vehicle that hit them. Simple chi-squared tests indicate that bull bar status is statistically significantly associated with age group ($p = 0.02$), alcohol status ($p = 0.04$) and severe chest ($p = 0.0002$) and abdominal injuries ($p < 0.0001$) and marginally associated ($p=0.08$) with lower extremity injury. There was a lower percentage of older persons (60 years and older) and higher percentage of persons with high blood alcohol content (BAC) among those hit by bull bars. This may be related to a higher incidence of alcohol-related pedestrian crashes in rural regions, where bull bars are more common[6].

Although the occurrence of severe head injuries was not associated with bull bar status, a higher percentage of pedestrians killed in frontal impacts with bull bars had severe chest and abdominal injuries. The frequency distribution of the mix of these injuries is also presented in Table 7. A combination of severe injuries to the head, chest and abdomen was more common in bull bar impacts (21%) compared with non-bull bar impacts (6%), whereas severe head injury in the absence of severe chest and abdominal injury was less common in bull bar impacts (16%) compared with non-bull bar impacts (32%).

This was investigated further by fitting three separate logistic regression models to the probability of sustaining at least one severe injury to the head, chest and abdomen. In these models, the association between bull bar presence and occurrence of severe head, chest and abdominal injuries amongst the fatalities is estimated by odds ratios (OR). A value greater than one indicates greater risk. In addition to bull bar status, vehicle type, broad age group and speed zone were included in the models to adjust for possible confounding with bull bar status. For example, it may not be the bull bar, but the different shape, height or mass of vehicles most likely to have bull bars which is contributing to the results seen in the crude analysis. These regression analyses were based on 1165 pedestrians killed in frontal impact crashes.

No statistically significant results were found for head injury, except that the older pedestrians were least likely to sustain severe head injury (Table A4). This is probably due to their greater risk of death from complications of other types of injury.

The patterns for chest and abdominal injury observed in the crude analysis were also evident in the adjusted analysis. The pedestrians hit by bull bars had the highest

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[6] In 1996 and 1997, pedestrian alcohol intoxication was a major contributing factor in 40% of pedestrian crashes in rural areas compared with 24% of pedestrian crashes in urban areas.

likelihood of chest injury although this was not statistically significant (OR = 1.40 for bull bar yes vs no, p = 0.2) and the pedestrians hit by vehicles for which bull bar status was unknown had the lowest likelihood of chest injury (OR = 0.65 for bull bar unknown vs no p = 0.002). A similar pattern is apparent for abdominal and pelvic contents injury (OR yes vs no = 1.79, p = 0.04; OR unknown vs no = 0.69, p = 0.06). Restriction to the 802 fatalities that occurred in 60 km/h speed zones produced similar, though not statistically significant, results (Table A5). Restriction to 1,024 fatally injured pedestrians aged 16 years or older, not tabulated in this report, gave slightly larger odds ratios for presence of bull bars versus absence for both chest injury (OR = 1.51 for bull bar yes vs no, p = 0.1) and abdominal injury (OR = 1.94, p = 0.02).

The lack of association between bull bar status and presence of severe head injury may be considered surprising in the light of experimental results. However, it should be noted that this analysis is constrained to the subset of fatally injured pedestrians, for whom the incidence of severe head injury is high in any event (71%). The higher likelihood of chest and abdominal injury in bull bar impacts is interesting, since this has not been previously reported and these types of injuries have not been the subject of detailed experimental study. The results warrant further investigation, especially since it is difficult to interpret the lower incidence of these injuries for the vehicles with unknown bull bar status.

Bull bars and side impact crashes

Bull bars have been implicated as posing additional risk in side impact crashes. This section investigates the scale of the problem and attempts to estimate this extra risk based on ATSB's Fatality Crash Database.

Figure 1 and Table 8 show that there were 194 fatal side impact crashes involving bull bars in the five years under study. These represent 20% of the 960 fatal crashes in which the front of one vehicle impacted the side of another vehicle. In an additional 34% of side impact crashes, it was not recorded whether a bull bar was present or not on the striking vehicle[7]. So these figures suggest that there are at least 40 fatal crashes annually in which the front of a vehicle equipped with a bull bar hits the side of another vehicle.

Investigation of risk requires an analysis of the resultant fatalities. Since we only have data on fatal crashes, by definition, there will be at least one fatality resulting from each crash. The fatalities may occur in one or both vehicles. Given the smaller amount of protection afforded by the side of a vehicle compared with the front, it is expected that a greater number of fatalities will occur in the struck vehicle than the striking vehicle. This is borne out in Table 8. In 89% of the 960 side impact crashes, the fatalities occurred in the struck vehicle, compared with only 13% where fatalities

[7] It is interesting to compare the bull bar prevalence on the striking vehicle with that of the vehicle which was struck on the side, since it provides a relevant comparison group in terms of the location and time of the crash. The prevalence is, in fact, much lower, only 5%, with 31% unknown. There could be many reasons for this. It could be that a bull bar on the striking vehicle increases its aggressivity or that bull bar prevalence is less likely to be reported for a vehicle struck on the side. It appears, however, that it is probably related to vehicle size. An investigation of the relative distribution of vehicle types shows that the striking vehicle is more likely to be a larger vehicle than the struck vehicle. Thus the striking vehicle is more likely to have a bull bar fitted.

occurred in the striking vehicle. These figures also depend on many factors, such as the relative sizes and speeds of the vehicles and the number, age and restraint use of the vehicle occupants. The important question for this study is whether there is an additional effect of bull bars over and above vehicle size and these other factors.

Comparison of crash outcomes in Table 8, unadjusted for the different types of vehicles involved, suggests a greater risk of occupant fatality in the struck vehicle when the striking vehicle is fitted with a bull bar compared with the non-bull bar impacts. A total of 95% of the 194 bull bar impacts resulted in fatalities in the struck vehicle, compared with a lower 86% of 438 non-bull bar impacts. An intermediate figure of 90% was observed for the vehicles with unknown bull bar status. It needs to be borne in mind, however, that these results could be linked to the greater likelihood of a larger vehicle having a bull bar fitted. An examination of the subset of 474 car-car impacts indicates 100% fatalities with bull bar impacts (out of only 7 cases), compared with 92% for non-bull bar impacts (299 cases) and 95% for unknown bull bar status (168 cases).

Further analysis was undertaken adjusting for the different types of vehicles involved in the collision. This was done by fitting a series of logistic regression models where the outcome is whether or not at least one fatality occurred in the struck vehicle (ie the one sustaining the side impact). The first model fitted (the unadjusted model) contains a single explanatory variable which is the presence/absence of a bull bar on the striking vehicle. The other models (the adjusted models) additionally include the following potential confounding variables (the type of striking and struck vehicle and number of occupants in each vehicle, the speed zone of the crash site and the year of the crash).

The unadjusted OR for bull bar presence vs absence is 3.0, p = 0.002 (Table A6). However, the effect of adjusting for vehicle type and the other factors is that the estimate is decreased and the statistical significance disappears. The fully adjusted OR is 1.9 (p = 0.4, 95% confidence interval 0.4, 8.6). In this analysis the vehicles with bull bar status unknown have been kept as a separate group. The corresponding estimates for bull bar status unknown vs absence are intermediate with an unadjusted OR of 1.5 (p = 0.08) and an adjusted OR of 1.5 (p = 0.3). A conservative assumption would be to assume all of these vehicles did not have bull bars. This further reduces the risk estimate. The adjusted OR (not shown in the table) then becomes 1.5 (p = 0.6, 95% confidence interval 0.3, 6.4).

It cannot be concluded from this analysis that bull bars pose additional risk in side collisions. The lack of statistical significance may be due to a lack of 'power' (ie detection capability). Despite the inclusion of over 600 cases, the analysis only had a power of 66% to detect an odds ratio of 2[8]. If complete bull bar information had been available in all 960 cases the power would have been acceptable (84%). It is also possible that there is still residual confounding with respect to vehicle size and the odds ratio of 2 is still an overestimate. There is still a substantial range in size among passenger vehicles, which make up a majority of the struck vehicles. Other possible risk factors that were not taken into account include seat belt use, age and seating

[8] With a 5% significance level and 30% vs 70% split for bull bar presence vs absence for vehicles with known bull bar status (632 vehicles) and an underlying 86% fatality rate for the reference group (bull bar absent).

position of the occupants. Additionally, it should be considered that this is a biased subset of severe crashes in which at least one person is killed. Obviously, the inclusion of lower severity crashes would provide additional pertinent information for risk estimation.

Bull bars and single vehicle frontal collisions
Since bull bars potentially interfere with the crash dynamics in a frontal impact collision with a solid object, it is possible that vehicle occupants are at extra risk when bull bar equipped vehicles are involved in single vehicle frontal impacts. This section attempts to estimate the frequency of this type of collision and evaluates the possibility of risk assessment using the information in the Fatality Crash Database.

Single vehicle crashes account for approximately half of non-pedestrian fatal crashes. Approximately 3,000 bull bar eligible vehicles were involved in fatal single vehicle crashes in the period under study (approximately 600 in each year). The fatal impact occurred at the front of the vehicle in 23% of cases and the side of the vehicle in 25% of cases. A further 36% were overturns. A total of 708 vehicles were involved in fatal single vehicle frontal impacts during this period (Table 9). Of these, only 56 vehicles (8%) were recorded as having bull bars. Bull bar status was not recorded for 255 vehicles (36%). As seen in the third level of Figure 1, there are at least 12 fatal crashes annually in which an occupant of a bull bar equipped vehicle is killed after a frontal collision with an object. Not all of these are fixed objects, although the majority of these are poles or trees (Table 9).

The relatively low bull bar presence in these crashes (8%) is probably due to the high involvement rate of cars in these types of crashes. Passenger cars make up 80% of vehicles in these crashes (568/708) and traditionally these vehicles have low fitment rates. Also, only half of these crashes occur in rural areas (54% = 388/708).

No attempt was made to quantify bull bar attributable risk for these crashes. In theory, an impact speed comparison between bull bar equipped and non-bull bar equipped vehicles might have provided some evidence that bull bar collisions are more likely to be fatal at lower impact speeds than the equivalent vehicle without a bull bar. Accurate independent vehicle speed estimates are, however, highly unlikely in the case of single vehicle fatal crashes. The small number of cases with useable speed estimates would have precluded adjustments for other important risk factors such as seat belt status, age of occupant, type of vehicle and type of object hit.

Bull bars and crashes involving animals
Analysis of extra risk to external road users and occupants in the event of collisions with bull bars should include an assessment of the reduced injury risk in the event of collisions with animals, for example an estimate of the number of lives saved if an animal hits a bull bar instead the front of an ‘unprotected’ vehicle. Ideally, this estimate would be compared with an estimate of lives lost to assess the net position. (It is beyond the scope of this report to evaluate the practical and financial benefits from reduced vehicle damage in the event of minor impacts.)

As identified in the literature review, the main obstacle in quantifying the benefits of bull bars is the lack of data on the frequency and the characteristics of animal strikes.

The Fatality Crash Database is the only national data source with information on both bull bar status and animal involvement in the crash. The Casualty Crash Database is a separate national crash database also compiled by ATSB. It includes serious injury crashes (ie resulting in hospitalisation), as well as fatal crashes, and is collected on an annual basis. Animal involvement can also be determined in this database based on the crash type coding, but bull bar status is not one of the data items collected. The information in these two databases is discussed below.

Frequency of crashes involving animals

For the eight year period (1990 to 1997) there were 1392 crashes resulting in hospitalisation after animals were hit (Table 10). This represents 1.0% of all hospitalisation crashes, nationally, in this time period. A total of 85% of these animal strike crashes occurred outside the metropolitan areas of capital cities. However, they still comprise only 1.7% of crashes in these non-metropolitan areas.

The corresponding percentages for fatal crashes are slightly lower; 0.7% of all fatal crashes and 0.9% of non-metropolitan fatal crashes.

At current crash levels, these figures correspond to approximately 150 serious injury crashes and 10 fatal crashes per year involving animal strikes.

Characteristics of fatal crashes involving animals

What extra information does the Fatality Crash Database provide? Across the five separate database years, there were 52 fatal crashes that involved impacts with animals and 38 additional fatal crashes where an avoidance manoeuvre around an animal led to a fatal crash. These 90 crashes represent 1.0% of all fatal crashes that occurred in that period.

The type of animal hit was recorded as stock (24 cases, 46%), horse/large animal (13, 25%), kangaroo/wallaby/emu (11, 21%), small animal (3, 6%) and was not specified in one case (2%).

The majority of fatal animal strike crashes (85%, 44/52) and fatal avoidance manoeuvre crashes (74%, 28/38) occurred in rural regions. The bull bar fitment rates were 19% (10/52) for the fatal animal strike crashes and 13% (5/38) for fatal avoidance manoeuvre crashes. All of the fatal crashes involving vehicles with bull bars and animals occurred in rural regions (Table 11).

The exact involvement or non-involvement of bull bars in the fatal animal strike crashes is hard to assess, since in a substantial number of cases (38%, 20/52), the vehicle hit the animal and then overturned or hit something else (eg another vehicle or a tree). In these multi-impact cases, it is most likely that the first impact with the animal was at the front of the vehicle. However, only one impact location is recorded for any single vehicle in the database and this is generally the final point of impact.

Among the other 32 single impact crashes, four involved vehicles with bull bars and 28 involved vehicles with no evidence of bull bars. In only one of the four bull bar cases, the impact was with the bull bar. The percentage of frontal impacts was higher among the 28 vehicles without bull bars (24 out of 28).

These figures indicate that in some crashes with animals, bull bars play no protective role, either because the impact is not at the front of the vehicle, or the crash conditions are so severe that the fatality will occur regardless of the presence of a bull bar. However, these figures do give some indication of a possible protective role. Restricting attention to the fatal crashes occurring in rural regions, the fitment rate is 23% for the animal strike crashes and 18% for the avoidance manoeuvre crashes (Table 11). Assuming that other factors are equal, the magnitude of the protective effect is equivalent to the extent of the difference between the observed fitment rate and the underlying fitment rate in rural regions where animal strikes occur. For example, if the underlying fitment rate was 50%, and there was no protective effect, one would expect equal number of animal strike crashes for vehicles with and without bull bars. The figures in Table 11 indicate 34 expected, but only 10 observed, a saving of 24 (or approximately 5 fatal crashes per year). Since the fitment rate in urban regions is low (certainly under 5%), the lack of animal strike crashes with bull bar equipped vehicles is consistent with expectation, so there are no estimated savings in urban regions. Applying the same calculation to the fatal avoidance crashes results in 23 expected versus 5 observed; a saving of 18 (or approximately 4 fatal crashes per year).

The same calculation can be attempted on the hospitalisation crashes, but it is even more speculative. Not only do we need to assume an underlying rural fitment rate (50% as above), but we also have no data on the fitment rate for vehicles involved in hospitalisation crashes with animals in rural regions. If we assume a figure of 20% (averaging that observed for vehicles involved in rural fatal animal strike crashes and avoidance manoeuvre crashes), the estimate of hospitalisation crashes prevented is 78 per year (based on a total of 130 hospitalisation crashes with animals in rural regions per year, 26 postulated with bull bars and 104 without).

In summary, these calculations suggest that up to nine fatal crashes, but considerably more serious injury crashes, are forestalled by bull bars each year. These calculations are only intended to provide a guide to the possible order of magnitude of a protective effect. They are based on a small numbers of crashes, with incomplete data on bull bar status. Furthermore, they require assumptions of underlying fitment rates and do not take into account variation in fitment rate or crash involvement by vehicle type. Finally, the estimate does not include lives that may be saved by preventing stranding of vehicle occupants in remote areas.

Summary and discussion

This report attempts to quantify the contribution of bull bars to road trauma in Australia based on a literature review and an analysis of ATSB's national Road Fatality Crash Database, which contains detailed information on fatal road crashes occurring in 1990, 1992, 1994, 1996 and 1997.

There has been wide debate on the pros and cons of bull bars and they remain popular for both city and country drivers, but there has been little scientific quantification of the various effects on road safety. To date there does not appear to have been an estimation of the contribution of bull bars to the total road toll. This is not surprising since, to do this formally, one needs valid estimates of increased risks for relevant crash scenarios, as well as the relative likelihood of bull bar impacts (based on the underlying prevalence of bull bar equipped vehicles and the crash involvement rates for bull bar eligible vehicles). Experimental studies have concentrated on injury ratings for pedestrians, but largely ignored other scenarios, such as side impact crashes. Definitive bull bar fitment rates could not be located in the published literature. Moreover, no results were found on the safety benefits to occupants in animal collisions.

Our results help elucidate the scope and magnitude of the problem by taking advantage of the detailed information on all types of fatal crashes captured in the ATSB Road Fatality Crash Database. However, for the reasons outlined below, it was not possible to provide accurate risk estimates for any of the groups of road users who are potentially at risk in road crashes involving vehicles with bull bars. Nor was it possible to accurately estimate fitment rates.

Estimation using the information in the Fatality Crash Database is limited by the fact that this is a biased selection of vehicles and by incompleteness of information on bull bar status. Even though the incidence of missing data has been decreasing in recent years, bull bar status was not recorded for 40% of vehicles involved in fatal crashes. In addition to the magnitude of missing data, it also appears that the information is not missing at random and is related to factors, such as vehicle type and location, both of which are related to the likelihood of bull bar fitment (eg bull bar status is more commonly reported for cars and for vehicles in capital city crashes, both of which have relatively low likelihood of bull bar fitment).

A further limitation in risk estimation comes from the association between the presence of a bull bar on a vehicle and other risk related factors such as vehicle size and speed. Bull bars are, for example, more likely to be fitted to larger vehicles and more likely to be fitted in rural regions where roads generally have higher speed limits. This means that it is difficult to isolate any detrimental effect of a bull bar from the increased risk posed by extra weight, height and speed of the vehicle itself.

In regard to pedestrian collisions, experimental studies conducted in Australia and Germany showed that there is a likelihood of more severe injury to pedestrians who are hit by bull bars. The effect was quantified as being roughly equivalent to a doubling of the impact speed without a bull bar. This was confirmed by Bowd (1995) using Australian data from a small number of fatal pedestrian crashes in urban Adelaide. However, this result could not be replicated here using more recent national data on similar crashes. An interesting new finding was the different injury profile of pedestrians killed in bull bar impacts. Although they had the same high level of head injury as pedestrians killed in non-bull bar impacts, they were more likely to sustain severe abdominal and chest injury as well.

The experimental results for pedestrians have been extrapolated to other vulnerable road users (such as bicyclists, and to a lesser extent motor cyclists). The relative contribution of bull bars in crashes with these vehicles is probably smaller, however, due to their own speed prior to impact.

Another major category of road users potentially at risk in bull bar impacts is occupants of side impacted vehicles. This does not appear to have been investigated or verified in experimental studies. An attempt was made to estimate the relative risk of death in side impact collisions with and without bull bars. No statistically significant association was found between bull bar presence and higher likelihood of fatality in the side impacted vehicle, although the direction of the estimate is suggestive of increased risk (OR 1.9, 95% confidence interval 0.4, 8.6). This analysis had several limitations, however. Firstly, it was based only on a subset of serious crashes in which at least one person died. Ideally, it would have included less serious crashes. Secondly, there was incomplete information on bull bar status. It was not recorded in one third of cases. Thirdly, there was strong confounding by vehicle size, since both risk and bull bar fitment are both related to the size of the striking vehicle. A partial adjustment, only, was achieved for this using broad vehicle classes. Fourthly, there was also possible confounding by other factors such as age and seat belt use, which was not taken into account. Additional adjustment for vehicle size and these other factors could have the effect of further reducing the estimate of bull bar attributable risk. Finally, even though the analysis was conducted on data aggregated from five years, there were still insufficient data to provide precise estimates, partly due to the low fitment rate of bull bars to passenger vehicles.

A fourth group of road users potentially at risk comprises occupants of bull bar equipped vehicles involved in frontal impacts with fixed objects. Experimental studies have shown that bull bars change the crash pulse of fatal impacts and can negate some occupant protection systems such as crumple dynamics and air bag triggering. It was not possible to estimate increased risk to these vehicle occupants from the Fatality Crash Database since the number of cases was relatively small.

An added complication is the growing diversity in bull bar style and in the material used. The experimental data indicate that risk varies by style and composition. Any attributable risk assessment should thus ideally take into account these variables. Finally, even if risks associated with bull bars in particular crash situations could be estimated accurately and without bias, no comprehensive data on fitment rates of bull bars in the vehicle fleet at large could be found. Thus, no detailed estimation of the number of bull bar attributable injuries or fatalities could be made.

As previously stated, data limitations prevented a formal estimation of bull bar attributable road trauma. However, the descriptive analysis confirms that pedestrians and the occupants of side impacted vehicles are the groups most at risk. There were approximately 30 pedestrians, 10 bicyclists and motor cyclists and 50 occupants of side impacted vehicles that were fatally injured in impacts with bull bars in 1997.

These counts are potentially underestimated through incomplete bull bar identification in the database and potentially overestimated due to the severity of the impacts regardless of bull bar status. Unfortunately, based on the data available, we were unable to quantify the extent to which these biases cancel each other.

Finally, an attempt was made to quantify the protective effects of bull bars in impacts with animals. Analysis from first principles suggests that bull bars would not offer significant protection in most instances, though there may be some advantage to front seat occupants of forward control vehicles, by reducing the likelihood of intrusion into the cabin space. Animal strikes make up only 1% of crashes that result in serious injury or death. It is suggested that the number of lives saved is not a particularly large number in relation to the total road toll.

It is clear that further research is needed to more fully assess the impact of bull bars on road trauma. Additional data need to be collected beyond that available from the national Fatality Crash Database. In particular, it is necessary to obtain estimates of:

- fitment rates by vehicle type and vehicle location (city/country)
- fitment rates by bull bar design (both shape and material)
- fitment rates for vehicles involved in casualty crashes as well as fatal crashes.

Conclusion

In summary, the lack of comprehensive data on bull bars in the vehicle fleet at large and for vehicles involved in crashes precludes drawing detailed conclusions with regard to bull bar attributable road trauma. With respect to the negative impact of bull bars, it would appear, on balance, that bull bars present an additional risk to pedestrians and other vulnerable road users, and also possibly to occupants of side impacted vehicles. It is postulated that the extent of this risk is not likely to be great because it is difficult to isolate the influence of the bull bar from other factors known to be strongly associated with injury outcomes, such as vehicle size and speed.

Recent improvements in the design and fitting of bull bars may have reduced the risk below that imposed by the older style bull bars used in the experimental studies and present in many of the crash records analysed here. Issues concerned with air bag deployment and the proper operation of crumple zones appear to have been addressed by recent improvements in bull bar design.

This report provides no conclusive basis for opposing the use of newer-style bull bars. There does, however, appear to be some case for considering measures to phase out the use of older style, protruding, rigid bull bars, especially in urban areas. This would not be a panacea for road safety. It would have a minor effect on the road toll as a whole. Nevertheless, there is the potential to save pedestrian lives and those of other relatively unprotected road users, such as bicyclists, as well as to reduce the risk to both the occupants of other vehicles and to the occupants of bull bar-fitted vehicles themselves.

Tables and figures

Figure 1. Vehicles involved in fatal crashes by bull bar status, impact location, collision type and crash year

Bull bar

Year	Vehicles	% of yr
1990	261	9%
1992	227	9%
1994	290	12%
1996	290	12%
1997	242	11%
Total	1310	10%

Not recorded

Year	Vehicles	% of yr
1990	1209	42%
1992	1240	51%
1994	839	34%
1996	685	28%
1997	481	22%
Total	4454	36%

No bull bar

Year	Vehicles	% of yr
1990	1049	36%
1992	715	29%
1994	1078	44%
1996	1230	50%
1997	1269	57%
Total	5341	43%

Not eligible*

Year	Vehicles	% of yr
1990	368	13%
1992	262	11%
1994	269	11%
1996	279	11%
1997	241	11%
Total	1419	11%

Frontal impact

Year	Vehicles	% of yr
1990	149	57%
1992	135	59%
1994	174	60%
1996	169	58%
1997	128	53%
Total	755	58%

Other impacts

Year	Vehicles	% of yr
1990	112	43%
1992	92	41%
1994	116	40%
1996	121	42%
1997	114	47%
Total	555	42%

Hit pedestrian

Year	Vehicles	% of yr
1990	24	16%
1992	24	18%
1994	41	24%
1996	24	14%
1997	27	21%
Total	140	19%

Hit motorcyclist/cyclist

Year	Vehicles	% of yr
1990	18	12%
1992	13	10%
1994	15	9%
1996	17	10%
1997	11	9%
Total	74	10%

Hit vehicle

Year	Vehicles	% of yr
1990	98	66%
1992	92	68%
1994	101	58%
1996	116	69%
1997	78	61%
Total	485	64%

Hit object

Year	Vehicles	% of yr
1990	9	6%
1992	6	4%
1994	17	10%
1996	12	7%
1997	12	9%
Total	56	7%

Hit side of vehicle

Year	Vehicles	% of yr
1990	26	27%
1992	40	43%
1994	39	39%
1996	45	39%
1997	44	56%
Total	194	40%

Hit other part of vehicle

Year	Vehicles	% of yr
1990	72	73%
1992	52	57%
1994	62	61%
1996	71	61%
1997	34	44%
Total	291	60%

Hit animal

Year	Vehicles	% of yr
1990	0	0%
1992	0	0%
1994	1	6%
1996	0	0%
1997	1	8%
Total	2	4%

Hit other object

Year	Vehicle	% of yr
1990	9	100%
1992	6	100%
1994	16	94%
1996	12	100%
1997	11	92%
Total	54	96%

Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997

*Not eligible includes bicycles, motor cycles

Table 1. Number of external and internal fatalities resulting from frontal impacts with vehicles with bull bars by crash year

	Crash year					
Fatalities	1990	1992	1994	1996	1997	Total
External to bull bar vehicle						
Pedestrians	25	25	42	24	29	145
Motor cyclists, bicyclists, animal riders	20	13	17	18	11	79
Occupant of side impacted vehicle	31	48	41	56	49	225
Occupant of non-side impacted vehicle	77	60	57	70	37	301
Total external fatalities	153	146	157	168	126	750
Internal (occupant of vehicle with bull bar)						
Hit side of other vehicle	2	3	3	1	3	12
Hit other part of other vehicle	11	14	13	17	4	59
Hit animal	0	0	1	0	1	2
Hit other object (pole, tree, embankment)	10	6	16	12	11	55
Total internal fatalities	23	23	33	30	19	128

Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997

Table 2. Bull bar status by crash year, vehicle type, vehicle test and crash location for bull bar eligible vehicles involved in fatal crashes

Crash and vehicle characteristics	Bull bar status				Total bull bar eligible veh	
	Not recorded		Recorded			
Crash year						
1990	1209	48%	1310	52%	2519	100%
1992	1240	57%	942	43%	2182	100%
1994	839	38%	1368	62%	2207	100%
1996	685	31%	1520	69%	2205	100%
1997	481	24%	1511	76%	1992	100%
Vehicle type						
Car	2682	36%	4789	64%	7471	100%
Passenger van	117	47%	130	53%	247	100%
4WD	299	39%	472	61%	771	100%
Light truck	358	49%	371	51%	729	100%
Heavy rigid truck	261	44%	327	56%	588	100%
Articulated truck	388	45%	474	55%	862	100%
Bus	51	38%	82	62%	133	100%
Other/unknown	298	98%	6	2%	304	100%
Vehicle test						
Yes	990	21%	3700	79%	4690	100%
No	3178	52%	2911	48%	6089	100%
Unknown	286	88%	40	12%	326	100%
State/Territory						
NSW	1605	43%	2116	57%	3721	100%
Vic	872	35%	1624	65%	2496	100%
Qld	1153	53%	1023	47%	2176	100%
SA	213	24%	687	76%	900	100%
WA	386	36%	701	64%	1087	100%
Tas	47	14%	299	86%	346	100%
NT	128	48%	136	52%	264	100%
ACT	50	43%	65	57%	115	100%
Urban/rural crash location						
Capital city	1289	35%	2359	65%	3648	100%
Other urban	1143	47%	1284	53%	2427	100%
Rural	1878	40%	2818	60%	4696	100%
Unknown	144	43%	190	57%	334	100%
Crash type						
Single vehicle	1283	40%	1929	60%	3212	100%
Multiple vehicle	2506	41%	3639	59%	6145	100%
Pedestrian crash	665	38%	1083	62%	1748	100%
Total vehicles	4454	40%	6651	60%	11105	100%

Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997

Table 3. Bull bar status by crash year, vehicle type, vehicle test and crash location for bull bar eligible vehicles involved in fatal crashes

Crash and vehicle characteristics	Bull bar status						Total bull bar eligible veh.	
	Yes		No		Not recorded			
Crash year								
1990	261	10%	1049	42%	1209	48%	2519	100%
1992	227	10%	715	33%	1240	57%	2182	100%
1994	290	13%	1078	49%	839	38%	2207	100%
1996	290	13%	1230	56%	685	31%	2205	100%
1997	242	12%	1269	64%	481	24%	1992	100%
Vehicle type								
Car	132	2%	4657	62%	2682	36%	7471	100%
Passenger van	59	24%	71	29%	117	47%	247	100%
4WD	371	48%	101	13%	299	39%	771	100%
Light truck	163	22%	208	29%	358	49%	729	100%
Heavy rigid truck	168	29%	159	27%	261	44%	588	100%
Articulated truck	394	46%	80	9%	388	45%	862	100%
Bus	20	15%	62	47%	51	38%	133	100%
Other/unknown	3	1%	3	1%	298	98%	304	100%
Vehicle test								
Yes	746	16%	2954	63%	990	21%	4690	100%
No	557	9%	2354	39%	3178	52%	6089	100%
Unknown	7	2%	33	10%	286	88%	326	100%
State/Territory								
NSW	358	10%	1758	47%	1605	43%	3721	100%
Vic	278	11%	1346	54%	872	35%	2496	100%
Qld	230	11%	793	36%	1153	53%	2176	100%
SA	113	13%	574	64%	213	24%	900	100%
WA	216	20%	485	45%	386	36%	1087	100%
Tas	49	14%	250	72%	47	14%	346	100%
NT	59	22%	77	29%	128	48%	264	100%
ACT	7	6%	58	50%	50	43%	115	100%
Urban/rural crash location								
Capital city	317	9%	2042	56%	1289	35%	3648	100%
Other urban	243	10%	1041	43%	1143	47%	2427	100%
Rural	710	15%	2108	45%	1878	40%	4696	100%
Unknown	40	12%	150	45%	144	43%	334	100%
Crash type								
Single vehicle	338	11%	1591	50%	1283	40%	3212	100%
Multiple vehicle	787	13%	2852	46%	2506	41%	6145	100%
Pedestrian crash	185	11%	898	51%	665	38%	1748	100%
Total vehicles	1310	12%	5341	48%	4454	40%	11105	100%

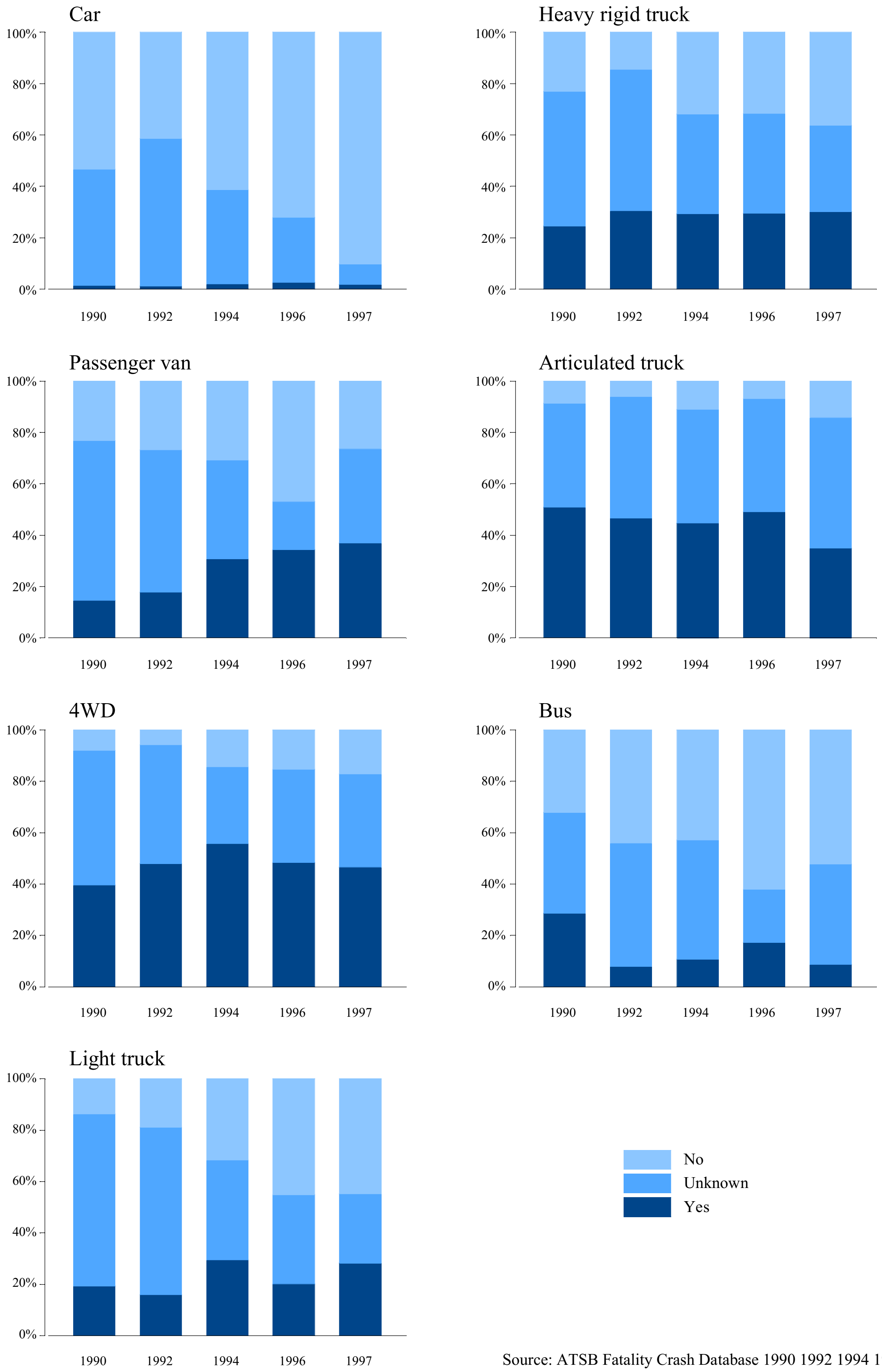
Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997

Table 4. Bull bar status by crash year and vehicle type for bull bar eligible vehicles involved in fatal crashes (also illustrated in Figure 2)

Vehicle type	Bull bar status						Total bull bar eligible veh.	
Crash year	Yes		No		Not recorded			
Car								
1990	23	1%	937	53%	798	45%	1758	100%
1992	17	1%	623	41%	867	58%	1507	100%
1994	30	2%	918	61%	548	37%	1496	100%
1996	39	3%	1066	72%	373	25%	1478	100%
1997	23	2%	1113	90%	96	8%	1232	100%
Passenger van								
1990	12	15%	19	23%	51	62%	82	100%
1992	10	18%	15	27%	31	55%	56	100%
1994	12	31%	12	31%	15	38%	39	100%
1996	11	34%	15	47%	6	19%	32	100%
1997	14	37%	10	26%	14	37%	38	100%
4WD								
1990	40	40%	8	8%	53	52%	101	100%
1992	58	48%	7	6%	56	46%	121	100%
1994	82	56%	21	14%	44	30%	147	100%
1996	101	48%	32	15%	76	36%	209	100%
1997	90	47%	33	17%	70	36%	193	100%
Light truck								
1990	31	19%	22	14%	108	67%	161	100%
1992	27	16%	32	19%	110	65%	169	100%
1994	56	29%	60	32%	74	39%	190	100%
1996	25	20%	56	45%	43	35%	124	100%
1997	24	28%	38	45%	23	27%	85	100%
Heavy rigid truck								
1990	35	24%	33	23%	75	52%	143	100%
1992	36	31%	17	14%	65	55%	118	100%
1994	34	29%	37	32%	45	39%	116	100%
1996	29	30%	31	32%	38	39%	98	100%
1997	34	30%	41	36%	38	34%	113	100%
Articulated truck								
1990	111	51%	19	9%	88	40%	218	100%
1992	77	47%	10	6%	78	47%	165	100%
1994	73	45%	18	11%	72	44%	163	100%
1996	79	49%	11	7%	71	44%	161	100%
1997	54	35%	22	14%	79	51%	155	100%
Bus								
1990	8	29%	9	32%	11	39%	28	100%
1992	2	8%	11	44%	12	48%	25	100%
1994	3	11%	12	43%	13	46%	28	100%
1996	5	17%	18	62%	6	21%	29	100%
1997	2	9%	12	52%	9	39%	23	100%
Other/unknown								
1990	1	4%	2	7%	25	89%	28	100%
1992	0	0%	0	0%	21	100%	21	100%
1994	0	0%	0	0%	28	100%	28	100%
1996	1	1%	1	1%	72	97%	74	100%
1997	1	1%	0	0%	152	99%	153	100%
Total vehicles	1310	12%	5341	48%	4454	40%	11105	100%

Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997

Figure 2. Bull bar presence for vehicles involved in fatal crashes by vehicle type and crash year (based on numbers in Table 4)



Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997

Table 5. Bull bar status by crash year, vehicle type and crash location for bull bar eligible vehicles involved in fatal frontal impacts with pedestrians

Crash and vehicle characteristics	Bull bar status						Total bull bar eligible veh.	
	Yes		No		Not recorded			
Crash year								
1990	24	7%	145	45%	152	47%	321	100%
1992	24	10%	88	36%	134	54%	246	100%
1994	41	16%	147	56%	76	29%	264	100%
1996	24	11%	157	71%	40	18%	221	100%
1997	27	12%	170	78%	21	10%	218	100%
Vehicle type								
Car	22	2%	634	66%	311	32%	967	100%
Passenger van	8	22%	10	27%	19	51%	37	100%
4WD	45	68%	5	8%	16	24%	66	100%
Light truck	22	30%	25	34%	27	36%	74	100%
Heavy truck/bus	43	38%	33	29%	37	33%	113	100%
Other/unknown	0	0%	0	0%	13	100%	13	100%
Urban/rural								
Capital city	66	8%	464	59%	254	32%	784	100%
Other urban	34	10%	168	50%	133	40%	335	100%
Rural	37	26%	70	50%	34	24%	141	100%
Unknown	3	30%	5	50%	2	20%	10	100%
Speed limit								
≤ 60 km/h	75	9%	491	57%	293	34%	859	100%
70-80 km/h	23	13%	100	55%	60	33%	183	100%
90+ km/h	38	19%	99	51%	59	30%	196	100%
Unknown	4	13%	17	53%	11	34%	32	100%
Time								
Day	60	10%	338	56%	210	35%	608	100%
Night (6pm-6am)	80	12%	369	56%	213	32%	662	100%
Total vehicles	140	11%	707	56%	423	33%	1270	100%

Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997

Table 6. Estimated vehicle speed (km/h) in fatal frontal impacts between bull bar eligible vehicles and pedestrians by bull bar status. (Number of vehicles in brackets.)

	Bull bar status			
	Yes	No	Not recorded	Total
Total vehicles	(42)	(317)	(128)	(487)
Mean	53	54	47	52
Median	58	55	50	55
Standard deviation	15	17	16	17
Vans/4WD vehicles	(17)	(7)	(11)	(35)
Mean	56	43	50	51
Median	60	51	55	57
Standard deviation	11	20	16	15

Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997

Table 7. Characteristics of pedestrians fatally injured in frontal impacts with bull bar eligible vehicles

Pedestrian characteristics	Bull bar status of vehicle					
	Yes		No		Not recorded	
Total pedestrians killed	145	100%	716	100%	426	100%
Age group						
<16	27	19%	105	15%	51	12%
16-59	79	54%	323	45%	210	49%
60+	39	27%	286	40%	164	39%
Sex						
Male	100	69%	487	68%	306	72%
Female	45	31%	229	32%	120	28%
BAC						
Not tested	21	14%	106	15%	66	15%
≤ 0.05	54	37%	309	43%	166	39%
>0.05	54	37%	193	27%	111	26%
Unknown	16	11%	108	15%	83	19%
Number of severe injuries*						
Head						
None	41	29%	202	30%	105	28%
1	47	34%	185	27%	88	24%
2	24	17%	115	17%	71	19%
3+	28	20%	181	27%	107	29%
Neck						
None	137	98%	681	100%	369	99%
1	2	1%	2	0%	2	1%
2	1	1%	0	0%	0	0%
Chest						
None	42	30%	319	47%	204	55%
1	55	39%	216	32%	103	28%
2	26	19%	95	14%	42	11%
3+	17	12%	53	8%	22	6%
Abdomen/pelvic contents						
None	93	66%	580	85%	326	88%
1	35	25%	83	12%	37	10%
2	7	5%	13	2%	4	1%
3+	5	4%	7	1%	4	1%
Spine						
None	122	87%	594	87%	330	89%
1	13	9%	76	11%	34	9%
2	5	4%	11	2%	5	1%
3+	0	0%	2	0%	2	1%
Lower extremity						
None	131	94%	664	97%	360	97%
1	9	6%	19	3%	11	3%
Upper extremity						
None	140	100%	683	100%	371	100%
Combination of severe injuries to the head, chest, abdomen/pelvic contents						
Head Chest Abdomen	30	21%	43	6%	24	6%
Head Chest	42	30%	198	29%	85	23%
Head Abdomen	4	3%	19	3%	7	2%
Head	23	16%	221	32%	150	40%
Chest Abdomen	12	9%	30	4%	10	3%
Chest	14	10%	93	14%	48	13%
Abdomen	1	1%	11	2%	4	1%
Other	14	10%	68	10%	43	12%

Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997

*Severe refers to AIS severity in the range 4-6 (ie severe, critical or maximum)
AIS coding was available for a subset of fatalities (93%).

Table 8. Fatal outcomes in front into side crashes by bull bar status of striking vehicle and type of struck vehicle

Bull bar status of striking veh.	Struck vehicle (struck on the side) Car	Van	4WD	Light truck	Truck/ bus	Other/ Unknown	Total
Number of crashes							
No bull bar	383	9	6	10	30	0	438
Bull bar	175	2	4	2	11	0	194
Not recorded	289	1	3	12	21	2	328
Total	847	12	13	24	62	2	960
Percentage of crashes with occupant fatalities in striking vehicle (with frontal impact)							
No bull bar	9%	0%	50%	50%	100%	.	16%
Bull bar	2%	0%	25%	0%	64%	.	6%
Not recorded	6%	0%	67%	17%	90%	50%	13%
Total	6%	0%	46%	29%	90%	50%	13%
Percentage of crashes with occupant fatalities in struck vehicle (with side impact)							
No bull bar	94%	100%	67%	50%	0%	.	86%
Bull bar	99%	100%	75%	100%	36%	.	95%
Not recorded	97%	100%	67%	83%	10%	50%	90%
Total	96%	100%	69%	71%	10%	50%	89%

Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997

Table 9. Single vehicle fatal frontal impact crashes by vehicle type, crash characteristics and bull bar status (pedestrian crashes excluded)

Vehicle and crash characteristics	Bull bar status						Total bull bar eligible veh.	
	Yes		No		Not recorded			
Vehicle type								
Car	18	3%	366	64%	184	32%	568	100%
Passenger van	7	44%	3	19%	6	38%	16	100%
4WD	11	48%	2	9%	10	43%	23	100%
Light truck	5	11%	16	36%	24	53%	45	100%
Heavy truck/bus	15	28%	9	17%	29	55%	53	100%
Other/unknown	0	0%	1	33%	2	67%	3	100%
Speed limit								
≤ 60 km/h	9	5%	124	63%	64	32%	197	100%
70-80 km/h	3	4%	52	64%	26	32%	81	100%
90+ km/h	40	10%	204	51%	155	39%	399	100%
Unknown	4	13%	17	55%	10	32%	31	100%
Urban/rural								
Capital city	11	7%	112	66%	46	27%	169	100%
Other urban	7	5%	67	49%	62	46%	136	100%
Rural	38	10%	210	54%	140	36%	388	100%
Unknown	0	0%	8	53%	7	47%	15	100%
Object hit								
Tree	31	8%	210	56%	134	36%	375	100%
Pole/post	7	5%	85	59%	52	36%	144	100%
Culvert, embankment	6	11%	26	49%	21	40%	53	100%
Other	12	9%	76	56%	48	35%	136	100%
Total single vehicle crashes	56	8%	397	56%	255	36%	708	100%

Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997

Table 10. Number of fatal and hospitalisation crashes by crash type and year

Crash severity	Crash year	Crash type						Total	
		Struck animal		Other crash		Not recorded			
Fatal	1990	7	0.3%	2044	99.4%	5	0.2%	2056	100%
	1991	12	0.6%	1864	99.1%	4	0.2%	1880	100%
	1992	7	0.4%	1728	99.2%	7	0.4%	1742	100%
	1993	17	1.0%	1717	98.8%	3	0.2%	1737	100%
	1994	13	0.8%	1690	98.8%	7	0.4%	1710	100%
	1995	16	0.9%	1796	98.7%	7	0.4%	1819	100%
	1996	11	0.6%	1753	99.2%	4	0.2%	1768	100%
	1997	11	0.7%	1584	98.9%	7	0.4%	1602	100%
	1990-97	94	0.7%	14176	99.0%	44	0.3%	14314	100%
Hospitalisation	1990	208	1.0%	19722	98.5%	84	0.4%	20014	100%
	1991	197	1.1%	17586	98.6%	61	0.3%	17844	100%
	1992	176	1.0%	16853	98.5%	79	0.5%	17108	100%
	1993	161	0.9%	16913	98.5%	90	0.5%	17164	100%
	1994	175	1.0%	17276	98.4%	109	0.6%	17560	100%
	1995	169	0.9%	17591	98.8%	43	0.2%	17803	100%
	1996	149	0.9%	17326	99.0%	30	0.2%	17505	100%
	1997	157	0.9%	16960	98.9%	33	0.2%	17150	100%
	1990-97	1392	1.0%	140227	98.6%	529	0.4%	142148	100%
Total	1990-97	1486	0.9%	154403	98.7%	573	0.4%	156462	100%

Source: ATSB Casualty Crash Database 1990 - 1997

Table 11. Total fatal crashes involving animals by crash type, location and bull bar status

Fatal crash type	Bull bar status of vehicle impacting or avoiding an animal					
Location	Yes		No or not recorded		Total	
Animal struck						
Urban	0	0%	8	100%	8	100%
Rural	10	23%	34	77%	44	100%
Total	10	19%	42	81%	52	100%
Avoided animal						
Urban	0	0%	10	100%	10	100%
Rural	5	18%	23	82%	28	100%
Total	5	13%	33	87%	38	100%

Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997

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Appendix. Regression model results

Table A1. Adjusted odds ratios (OR) and 95% confidence intervals (95% CI) for bull bar status known by crash and vehicle factors for 11,105 bull bar eligible vehicles involved in fatal crashes

Crash & vehicle characteristics	OR	95% CI	df	p
Crash year			4	0.000
1990	1.00	- -		
1992	0.69	0.61 0.78	1	0.000
1994	1.52	1.34 1.74	1	0.000
1996	2.48	2.17 2.84	1	0.000
1997	4.74	4.04 5.56	1	0.000
Vehicle type			7	0.000
Car	1.00	- -		
Passenger van	0.59	0.45 0.79	1	0.000
4WD	0.79	0.67 0.94	1	0.008
Light truck	0.62	0.52 0.74	1	0.000
Heavy rigid truck	0.70	0.57 0.84	1	0.000
Articulated truck	0.75	0.64 0.88	1	0.000
Bus	0.92	0.62 1.36	1	0.7
Other/unknown	0.01	0.01 0.03	1	0.000
Vehicle test			2	0.000
Yes	1.00	- -		
No	0.23	0.20 0.25	1	0.000
Unknown	0.14	0.09 0.22	1	0.000
State/Territory			7	0.000
NSW	1.00	- -		
Vic	0.95	0.85 1.07	1	0.4
Qld	0.42	0.37 0.48	1	0.000
SA	1.20	1.00 1.44	1	0.05
WA	0.54	0.46 0.64	1	0.000
Tas	2.05	1.46 2.88	1	0.000
NT	0.44	0.33 0.59	1	0.000
ACT	0.31	0.21 0.47	1	0.000
Urban/rural			3	0.000
Capital city	1.00	- -		
Other urban	0.78	0.69 0.88	1	0.000
Rural	0.78	0.70 0.87	1	0.000
Unknown	0.49	0.37 0.66	1	0.000
Crash type			2	0.003
Single	1.00	- -		
Multiple	1.11	1.00 1.23	1	0.06
Pedestrian	1.29	1.11 1.49	1	0.001

Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997
df = degrees of freedom
p = p value

Note: The Hosmer & Lemeshow goodness of fit test indicates a large amount of variation is left unexplained by the model above (including only main effect terms) (test statistic 69.8 on 8 df, $p<0.001$). Thus the significance levels are probably overstated. This is not surprising given the large number of observations. Further models including interaction terms were fitted. The following interactions were statistically significant (crash year by vehicle type, State/Territory by vehicle testing by year (and associated 2-way interactions), State/Territory by urban/rural) and goodness of fit testing indicates a substantially better fit (test statistic 7.5 on 8 df, $p=0.5$).

Table A2. Adjusted odds ratios (OR) and 95% confidence intervals (95% CI) for bull bar presence vs absence or no information by crash and vehicle factors for 11,105 bull bar eligible vehicles involved in fatal crashes

Crash & vehicle characteristics	OR	95% CI		df	p
Crash year				4	0.05
1990	1.00	-	-		
1992	1.00	0.80	1.25	1	1.0
1994	1.26	1.01	1.57	1	0.04
1996	1.21	0.97	1.51	1	0.09
1997	0.97	0.77	1.22	1	0.8
Vehicle type				7	0.000
Car	1.0	-	-		
Passenger van	19.5	13.7	27.6	1	0.000
4WD	56.7	44.9	71.7	1	0.000
Light truck	17.3	13.4	22.2	1	0.000
Heavy rigid truck	25.9	20.0	33.6	1	0.000
Articulated truck	59.8	47.4	75.5	1	0.000
Bus	10.7	6.4	18.0	1	0.000
Other/unknown	1.8	0.5	6.0	1	0.4
Vehicle test				2	0.000
Yes	1.00	-	-		
No	0.40	0.34	0.47	1	0.000
Unknown	0.14	0.06	0.33	1	0.000
State/Territory				7	0.000
NSW	1.00	-	-		
Vic	1.33	1.09	1.63	1	0.005
Qld	0.80	0.65	0.99	1	0.04
SA	1.37	1.04	1.82	1	0.03
WA	1.66	1.31	2.10	1	0.000
Tas	1.07	0.72	1.60	1	0.7
NT	2.30	1.55	3.43	1	0.000
ACT	0.47	0.19	1.12	1	0.09
Urban/rural				3	0.05
Capital city	1.00	-	-		
Other urban	0.96	0.77	1.19	1	0.7
Rural	1.21	1.01	1.46	1	0.04
Unknown	1.02	0.65	1.59	1	0.9
Crash type				2	0.000
Single	1.00	-	-		
Multiple	1.31	1.10	1.55	1	0.002
Pedestrian	1.64	1.28	2.10	1	0.000

Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997
df = degrees of freedom
p = p value

Note: The Hosmer & Lemeshow goodness of fit test indicates this model is a good fit to the data (test statistic 4.7 on 8 df, p=0.8).

Table A3. Regression coefficients (B), standard errors (SE) and p values (p) estimated from a multiple linear regression of estimated vehicle speed (km/h) of 452 bull bar eligible vehicles before a fatal frontal impact with a pedestrian (R-square 0.14)

Variable	B	SE	p
Bull bar presence (vs no)			
Yes	3.29	3.41	0.3
Unknown	-5.55	1.80	0.002
Age of pedestrian (vs 16-59 y)			
<16 y	-1.35	2.30	0.6
60+ y	-5.45	1.66	0.001
Gender (vs male)			
Female	0.25	1.57	0.9
Vehicle type (vs car)			
Van	-2.95	4.40	0.5
4WD	-3.36	4.29	0.4
Light truck	-9.88	3.45	0.004
Heavy truck/bus	-11.35	3.73	0.003
Time of day (vs day)			
Night	5.68	1.59	0.0004
Braked (vs no)			
Yes	2.37	1.48	0.1
Year	0.1268	0.3213	0.7
(Constant)	-198.69	640.42	0.8

Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997

Note: Standard regression diagnostics indicated no major deviations from normality.

Table A4. Adjusted odds ratios (OR) and 95% confidence intervals (95% CI) for 3 separate logistic regressions for severe* head, chest and abdominal/pelvic contents injury by bull bar status, vehicle type, age of pedestrian and speed zone based on 1165 fatal pedestrian frontal impact crashes

Injury location	Vehicle, pedestrian & location factor		OR	95% CI		df	p
Head	Bull bar	No	1.00	-	-	2	0.9
		Yes	0.97	0.58	1.63	1	0.9
		Unknown	1.07	0.80	1.44	1	0.6
		Vehicle type					
	Vehicle type	Car	1.00	-	-	5	0.6
		Passenger van	1.08	0.50	2.32	1	0.9
		4WD	0.83	0.43	1.60	1	0.6
		Light truck	1.15	0.64	2.05	1	0.6
		Heavy truck/bus	1.40	0.83	2.37	1	0.2
		Other/unknown	3.08	0.38	25.07	1	0.3
	Age of pedestrian	<16 y	1.00	-	-	2	0.0001
		16-59 y	0.77	0.50	1.17	1	0.2
		60+ y	0.46	0.30	0.71	1	0.0004
	Speed zone	≤ 60 km/h	1.00	-	-	2	0.2
		70-80 km/h	0.87	0.60	1.25	1	0.4
		90+ km/h	0.72	0.50	1.04	1	0.08
(Hosmer & Lemeshow goodness of fit test 1.5 on 8 df, p=1.0)							
Chest	Bull bar	No	1.00	-	-	2	0.0007
		Yes	1.40	0.86	2.28	1	0.2
		Unknown	0.65	0.50	0.86	1	0.002
	Vehicle type	Car	1.00	-	-	5	0.05
		Passenger van	2.03	0.97	4.23	1	0.06
		4WD	1.77	0.93	3.38	1	0.08
		Light truck	1.07	0.63	1.81	1	0.80
		Heavy truck/bus	1.78	1.10	2.88	1	0.02
		Other/unknown	2.59	0.63	10.71	1	0.2
	Age of pedestrian	<16 y	1.00	-	-	2	0.008
		16-59 y	1.19	0.83	1.71	1	0.4
		60+ y	1.67	1.15	2.42	1	0.007
	Speed zone	≤ 60 km/h	1.00	-	-	2	0.0003
		70-80 km/h	1.50	1.07	2.12	1	0.02
		90+ km/h	1.96	1.38	2.78	1	0.0002
(Hosmer & Lemeshow goodness of fit test 8.7 on 7 df, p=0.3)							
Abdomen	Bull bar	No	1.00	-	-	2	0.004
		Yes	1.79	1.04	3.08	1	0.04
		Unknown	0.69	0.46	1.02	1	0.06
	Vehicle type	Car	1.00	-	-	5	0.3
		Passenger van	1.82	0.77	4.28	1	0.2
		4WD	1.64	0.80	3.35	1	0.2
		Light truck	1.62	0.85	3.06	1	0.1
		Heavy truck/bus	1.60	0.91	2.80	1	0.1
		Other/unknown	2.10	0.41	10.68	1	0.4
	Age of pedestrian	<16 y	1.00	-	-	2	0.4
		16-59 y	0.99	0.61	1.59	1	1.0
		60+ y	0.79	0.48	1.30	1	0.3
	Speed zone	≤ 60 km/h	1.00	-	-	2	0.04
		70-80 km/h	1.11	0.70	1.75	1	0.7
		90+ km/h	1.72	1.13	2.61	1	0.01
(Hosmer & Lemeshow goodness of fit test 11.3 on 8 df, p=0.2)							

Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997

* severe refers to AIS severity in the range 4-6 (ie severe, critical or maximum)

Table A5. Adjusted odds ratios (OR) and 95% confidence intervals (95% CI) for 3 separate logistic regressions for severe* head, chest and abdominal/pelvic contents injury by bull bar status, vehicle type and age of pedestrian based on 802 fatal pedestrian frontal impact crashes in urban speed zones (≤ 60 km/h)

Injury location	Vehicle and pedestrian factors		OR	95% CI		df	p
Head	Bull bar	No	1.00	-	-	2	0.5
		Yes	0.72	0.38	1.40	1	0.3
		Unknown	1.07	0.75	1.52	1	0.7
	Vehicle type	Car	1.00	-	-	5	0.8
		Passenger van	1.32	0.53	3.26	1	0.6
		4WD	1.12	0.48	2.61	1	0.8
		Light truck	1.27	0.62	2.60	1	0.5
		Heavy truck/bus	1.64	0.81	3.32	1	0.2
		Other/unknown	68.60	0.00	∞	1	0.5
	Age of pedestrian	<16 y	1.00	-	-	2	0.0001
		16-59 y	0.58	0.34	0.99	1	0.05
		60+ y	0.36	0.22	0.61	1	0.0001
(Hosmer & Lemeshow goodness of fit test 3.4 on 7 df, p=0.8)							
Chest	Bull bar	No	1.00	-	-	2	0.1
		Yes	1.34	0.73	2.45	1	0.3
		Unknown	0.77	0.56	1.06	1	0.1
	Vehicle type	Car	1.00	-	-	5	0.3
		Passenger van	1.68	0.75	3.76	1	0.2
		4WD	1.74	0.79	3.84	1	0.2
		Light truck	1.36	0.73	2.54	1	0.3
		Heavy truck/bus	1.42	0.78	2.58	1	0.2
		Other/unknown	4.53	0.46	44.43	1	0.2
	Age of pedestrian	<16 y	1.00	-	-	2	0.08
		16-59 y	1.02	0.67	1.56	1	0.9
		60+ y	1.40	0.93	2.11	1	0.1
(Hosmer & Lemeshow goodness of fit test 2.6 on 6 df, p=0.9)							
Abdomen	Bull bar	No	1.00	-	-	2	0.07
		Yes	1.74	0.83	3.65	1	0.1
		Unknown	0.73	0.45	1.20	1	0.2
	Vehicle type	Car	1.00	-	-	5	0.7
		Passenger van	1.51	0.53	4.28	1	0.4
		4WD	1.79	0.70	4.55	1	0.2
		Light truck	1.31	0.58	2.99	1	0.5
		Heavy truck/bus	0.90	0.37	2.18	1	0.8
		Other/unknown	2.71	0.27	27.44	1	0.4
	Age of pedestrian	<16 y	1.00	-	-	2	0.1
		16-59 y	0.97	0.55	1.71	1	0.9
		60+ y	0.63	0.36	1.12	1	0.1
(Hosmer & Lemeshow goodness of fit test 8.7 on 6 df, p=0.2)							

Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997

* severe refers to AIS severity in the range 4-6 (ie severe, critical or maximum)

Table A6. Odds ratios (OR) and 95% confidence intervals (95% CI) for at least one fatality in the side impacted vehicle by bull bar status of the striking vehicle with and without adjustment for vehicle type, number of occupants, speed zone and year of crash based on 960 fatal front-side impact crashes

Bull bar	OR	95% CI		p	Adjustment
Yes vs No	2.97	1.49	5.93	0.002	None
Unknown vs No	1.50	0.95	2.36	0.08	None
Yes vs No	2.19	0.55	8.69	0.3	Vehicle type
Unknown vs No	1.55	0.77	3.09	0.2	Vehicle type
Yes vs No	1.94	0.43	8.79	0.4	Vehicle type, occupants
Unknown vs No	1.49	0.74	2.98	0.3	Vehicle type, occupants
Yes vs No	1.89	0.41	8.64	0.4	Vehicle type, occupants, year, speed zone
Unknown vs No	1.53	0.73	3.18	0.3	Vehicle type, occupants, year, speed zone

Source: ATSB Fatality Crash Database 1990 1992 1994 1996 1997