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# UPDATED CORRELATION OF RESULTS FROM THE AUSTRALIAN NEW CAR ASSESSMENT PROGRAM WITH REAL CRASH DATA FROM 1987 TO 1996

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## Abstract:

A number of ongoing major initiatives have been established to assess relative vehicle occupant protection performance for consumer information. Two of these initiatives are the Australian New Car Assessment Program (ANCAP) and the Used Car Safety Ratings (also known as Vehicle Crashworthiness Ratings and Driver Protection Ratings). The first of these estimates the relative occupant safety of current model vehicles by measuring dummy responses in controlled crash testing. The second initiative estimates the relative risk of severe driver injury for individual models of vehicles involved in real crashes by examining mass crash data. A study by Newstead and Cameron (1997) has examined the relationship between the results from these two programs. The broad aim of this project was to further assess the relationships between the results of these two programs using more current data and covering a wider range of vehicle models.

The results of correlation of ANCAP test results with real crash outcomes as measured by crashworthiness ratings suggest a number of relationships. Firstly, whilst the results from full frontal ANCAP testing have some association with real crash outcomes, the associations between offset ANCAP testing and real crashes are much stronger. The ANCAP test results and their associated measures have strong association with both the injury risk and injury severity components of the crashworthiness rating when considering all crash types, and with the injury severity component of crashworthiness rating when considering two-car head-on crashes. Correlations were generally stronger between ANCAP results and two-car head-on crashes than with all crash types but this difference was not large. Mass adjustment of the ANCAP probability measures also improved their relationship with real crash outcomes. Detailed analysis of injury data by body region generally confirmed the results of the correlation analysis using a more detailed and specific method of analysis.

Logistic regression models of crashworthiness ratings and its components as a function of ANCAP measures were built, providing a direct functional relationship between the two programs as compatible and consistent measures of relative vehicle occupant protection.



**Key Words: (IRRD except where marked*)**
vehicle safety, crashworthiness, crash test, injury, vehicle occupant, collision, passenger car unit, data analysis, statistical analysis.





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# EXECUTIVE SUMMARY

Motor vehicle occupant protection continues to be a growing issue not only for Government authorities concerned with road safety, but also for motor vehicle consumers and manufacturers. A number of ongoing major initiatives have been established to assess relative vehicle occupant protection performance for consumer information. Two of these initiatives are the Australian New Car Assessment Program (ANCAP) and the Used Car Safety Ratings (also known as Vehicle Crashworthiness Ratings and Driver Protection Ratings). The first of these estimates the relative occupant safety of current model vehicles by measuring dummy responses in controlled crash testing. The second initiative estimates the relative risk of severe driver injury for individual models of vehicles involved in real crashes by examining mass crash data.

A study by Newstead and Cameron (1997) has examined the relationship between the results from these two programs. The broad aim of this project was to further assess the relationships between the results of these two programs using more current data covering a wider range of vehicle models whose relative occupant protection has been assessed in both programs. Comparison has been made using the most currently available crashworthiness ratings based on all crash types, limited crashworthiness ratings derived from crashes of specific types, and modelling of crash outcomes as a function of ANCAP test results. A second stage of the project examined the relationship between injuries recorded in Transport Accident Commission claim data and the corresponding measurements taken from the crash test dummies in the ANCAP test procedures.

The results of correlation of ANCAP test results with real crash outcomes as measured by crashworthiness ratings suggest a number of relationships. Firstly, whilst the results from full frontal ANCAP testing have some association with real crash outcomes, the associations between offset ANCAP testing and real crashes are much stronger. The ANCAP test results and their associated measures have strong association with both the injury risk and injury severity components of the crashworthiness rating when considering all crash types, and with the injury severity component of crashworthiness rating when considering two-car head-on crashes. Correlations were generally stronger between ANCAP results and two-car head-on crashes than with all crash types but this difference was not large. Mass adjustment of the ANCAP probability measures also improved their relationship with real crash outcomes.

Capitalising on these relationships, logistic regression techniques were able to successfully build accurate models of crashworthiness ratings and its components as a function of ANCAP measures, providing a direct functional relationship between the two programs as compatible and consistent measures of relative vehicle occupant protection.

Detailed analysis of injury data by body region broadly confirmed the results of the correlation analysis and was consistent with results of logistic regression modelling estimated using a more detailed and specific method of analysis. The relationships found, however, were not as strong as in the original study of Newstead and Cameron (1997). A strong statistically significant association was found between full frontal ANCAP femur loading readings and average maximum AIS to the leg region in real crashes along with a strong statistically significant association between the offset ANCAP chest loading and average maximum AIS to the chest in real crashes.

# 1. INTRODUCTION

Motor vehicle occupant protection continues to be a growing issue not only for Government authorities concerned with road safety, but also for motor vehicle consumers and manufacturers. Increasingly, manufacturers are using safety features as major marketing focus for their new vehicles and many consumers give safety high priority in the process of selecting a vehicle for purchase (VicRoads 1994). In response to these needs and decisions by Government agencies and automobile clubs, a number of ongoing major initiatives have been established to assess relative vehicle occupant protection performance for consumer information.

Two of these initiatives are the New Car Assessment Program (ANCAP) and the Used Car Safety Ratings (also known as Vehicle Crashworthiness Ratings and Driver Protection Ratings). The first of these estimates the relative occupant safety of current model vehicles by measuring dummy responses in controlled crash testing. The second initiative estimates the relative risk of severe driver injury for individual models of vehicles involved in real crashes by examining mass crash data. A study by Newstead and Cameron (1997) has examined the relationship between the results from these two programs. The broad aim of this project was to further assess the relationships between the results of these two programs using more current data covering a wider range of vehicle models assessed under both programs.

## 1.1 THE ANCAP PROGRAM

Australia's New Car Assessment Program (ANCAP) was announced in December 1989 with testing commencing in 1992 and built upon the procedures established by the US NCAP program run by the US Department of Transportation's National Highway Traffic Safety Administration, commencing in 1978. The goals of the Australian program are the same as those of the US program, namely to provide consumers with a measure of the relative safety potential of automobiles and to establish market forces which encourage vehicle manufacturers to design higher levels of safety into their vehicles. In addition, Griffiths et al. (1994) state the Australian program aims to compare the relative safety of the Australian vehicle fleet to other fleets, in particularly the US fleet. Griffiths et al (1994) gives a detailed description of the ANCAP program.

The ANCAP program involves laboratory crashes of current model cars into a concrete barrier. Instrumented "Hybrid III" dummies placed in the driver and front left passenger seating positions, restrained by the vehicle's seat belts, measure the severity of impacts to the head, chest and legs. From more than 60 channels of data collected, they publish Head Injury Criterion (HIC), Chest Deformation (CD), chest loading (measured as chest acceleration in Gs) and right and left femur and lower leg loadings (femur loadings measured in kN and lower leg loadings quoted as an index). The first tests published from the program were of ten large and medium sized cars. They were subjected only to full frontal impacts with a solid concrete barrier at a speed of 56.3 km/h (35 mph) (New Car Assessment Program, 1993). All subsequent vehicle assessments have included not only the results of full frontal impact testing, but also from an off-set frontal impact test (New Car Assessment Program, 1994a). The offset test, developed by the European Experimental Vehicles Committee (EEVC), involves only 40% of the driver's side front of the car overlapping the barrier at impact. Initial offset tests were conducted at a speed of 60 km/h. Crash speed was increased to 64 km/h for offset tests with results published from November 1995 to align with United Sates and European offset test procedure. Unlike the rigid concrete barrier used for full frontal crash testing, the barrier used for offset testing has a crushable pad on the front made from aluminium. Use of a deformable barrier for the offset tests is designed to simulate the effect of crashing into another vehicle whilst the higher impact speed is used to make the impact severity directly comparable to a rigid barrier impact at 56.3 km/h. The first set of ANCAP tests conducted in 1993 did not include the offset configuration as Australian NCAP was still awaiting the outcome of decisions on the test by the EEVC. Regular updates of results from the on-going program of ANCAP testing are released as they become available, with published results at the end of 1997 covering some 68 different vehicle models or model variants.

Comparative performance of each car tested in the ANCAP program is based on the measurements taken from the instrumented driver and front passenger dummies used in the test and structural deformation of the vehicle. As described above, ANCAP publishes HIC, CD, chest loading and femur loading, with separate femur loadings being taken on the left and right legs of each dummy. Published offset test results also include lower left and right leg loading index for the driver side dummy. HIC is a measure of the risk of head injury and is a function of the maximum deceleration experienced by the dummy's head during impact. Similarly, CD is a measure of the risk of chest injury and is given as the maximum depth of compression of the dummy's chest in millimetres. The chest loading measurement is the force required to produce the observed chest compression. Upper leg injury risk is reflected in the femur loading, measured in kiloNewtons. The lower leg index is a function of the maximum bending moment measured on the dummy's lower leg during the barrier test.

Results of ANCAP testing are presented to consumers in detailed and summary forms The detailed published ANCAP results give the numerical values of the measurements on each of the two dummies for each vehicle tested. Each numerical result is also classified into one of three broad categories of injury likelihood, the three categories being "injury likely", "injury possible" and "injury unlikely". These three levels are represented by color coding of the numerical results in the brochure to facilitate easy visual comparison. Later ANCAP results (for example, NCAP 1994b) further add a summary measure of overall injury risk in the presentation of the results. This measure will be discussed further below. In the latest publications of results, the overall injury risk has been classified into one of four categories for presentation (labelled Good/Acceptable/Marginal/Poor) following the presentation style used by the US Insurance Institute for Highway Safety in presenting their offset crash barrier test results.

By inclusion of results from both full frontal and offset impact testing, the ANCAP program claims to represent 60 percent of real world crashes. The ANCAP program however, does not claim to represent the full range of crash circumstances and the ability of the particular car to protect its occupants. To quote:

*"In a frontal collision with a fixed object, NCAP measures the performance afforded to restrained occupants, regardless of vehicle weight. In such circumstances it is acceptable to compare NCAP scores of small and large vehicles. However, in full frontal collisions between vehicles of different weights, the occupant of the lighter vehicle is exposed to a higher injury risk. Therefore, the NCAP data is most meaningful when assessing relative injury risk in multi-vehicle crashes when vehicles compared are within a weight range of 230 kg." (NCAP, 1994b).*

This qualifier has important implications in interpretation of the results of the ANCAP program, especially in the context of real crashes. Firstly it highlights the potential importance of relative vehicle mass in determining injury likelihood in crashes between two vehicles. Secondly, it highlights that the current Australian NCAP program seeks to be representative of collisions involving frontal impacts to the vehicle (a side impact test is in use in the European NCAP program and will be included in the Australian NCAP program from mid 1999). These two points have been closely considered in the design of this study to be discussed below.

## 1.2 CRASHWORTHINESS RATINGS AND REAL CRASHES

Crashworthiness ratings rate the relative safety of vehicles by examining injury outcomes in real crashes, in contrast to ANCAP that uses laboratory crash tests. The crashworthiness rating of a vehicle is a measure of the risk of serious injury to a driver of that vehicle when it is involved in a crash. This risk is estimated from large numbers of records of injury severity to drivers of that vehicle type involved in real crashes on the road.

In 1998, the Monash University Accident Research Centre (MUARC) produced vehicle crashworthiness ratings based on crash data from Victoria and New South Wales during 1987-96 (Newstead et al., 1998). These ratings updated earlier MUARC sets produced by Newstead et al (1996) and Cameron et al. (1994a,b). Crashworthiness was measured in two components:

1. Rate of injury for drivers involved in tow-away crashes (injury risk)
2. Rate of serious injury (death or hospital admission) for injured drivers (injury severity).

The crashworthiness rating was formed by multiplying these two rates together; it then measured the risk of serious injury for drivers involved in tow-away crashes. Measuring crashworthiness in this way was first developed by Folksam Insurance who publishes the well-known Swedish ratings (Gustafsson et al 1989).

The results of these ratings are summarised in Newstead et al 1998 including a full technical description of the analysis methods. These ratings use an analysis method that was developed to maximise the reliability and sensitivity of the results from the available data. In addition to the speed zone and driver sex, the method of analysis adjusts for the effects of driver age and the number of vehicles involved, producing results with all those factors taken into account.

The results of the 1998 MUARC crashworthiness ratings cover 130 individual vehicle models and are given as estimates of risk of severe injury given crash involvement for each model along with 95% confidence limits on each estimate.

## 1.3 PROJECT AIMS

The aim of this project was to update the study of Newstead and Cameron (1997) investigating the relationship between ANCAP test results and data from real crashes in assessing relative occupant protection. This study has followed the methodology of Newstead and Cameron (1997) in comparing the results of crashworthiness ratings to the outcomes of ANCAP testing for those vehicle models rated under both programs.

**TABLE 1:** Models covered in ANCAP program and Crashworthiness Ratings to date.

| Make/model tested in ANCAP program | Make/model with Crashworthiness Rating based on 1987-96 crashes |
|---|---|
| Daihatsu Charade 1993-96 | Daihatsu Charade 1994-96 |
| Ford Falcon 1994-98 | Ford Falcon EF 1994-96 |
| Ford Falcon EB Series 2 1992-94 | Ford Falcon EB Series 2 & ED 1992-94 |
| Ford Festiva 1994-97 | Ford Festiva WB 1994-96 |
| Ford Laser 1990-94 | Ford Laser KF/KH 1991-94 |
| Holden Barina 1991-94 | Holden Barina 1989-94 |
| Holden Commodore VR 1993-95 | Holden Commodore VR/VS 1993-96 |
| Holden Commodore VP 1991-93 | Holden Commodore VN/VP 1988-93 |
| Honda Civic (no airbag) 1993-95 | Honda Civic 1992-95 |
| Hyundai Excel 1990-94 | Hyundai Excel 1990-94 |
| Hyundai Excel (no airbag) 1994-98 | Hyundai Excel 1995-96 |
| Hyundai Lantra 1992-95 | Hyundai Lantra 1991-95 |
| Mazda 121 1990-97 | Mazda 121 1991-96 |
| Mazda 626 1992 | Mazda 626 1992-96 |
| Mitsubishi Lancer 1992-96 | Mitsubishi Lancer CC 1995-96 |
| Mitsubishi Magna TR 1991-94 | Mitsubishi Magna TR/TS 1991-94 |
| Nissan Patrol 1992-97 | Nissan Patrol / Ford Maverick 1988-96 |
| Nissan Pintara PR 1992 | Nissan Pintara 1989-92 |
| Nissan Pulsar 1991-95 | Nissan Pulsar 1992-95 |
| Subaru Liberty 1989-94 | Subaru Liberty 1989-94 |
| Suzuki Vitara 1991-95 | Suzuki Vitara 1988-96 |
| Toyota Camry 1992-93 | Toyota Camry 1987-92 |
| Toyota Camry 1993-95 | Toyota Camry 1993-96 |
| Toyota Corolla 1991-94 | Toyota Corolla 1988-94 |
| Toyota Corolla 1994-95 | Toyota Corolla 1995-96 |
| Toyota Landcruiser 1992-98 | Toyota Landcruiser 1990-96 |
| Toyota Spacia 1993-96 | Toyota Tarago 1983-90 |
| Toyota Tarago 1990-95 | Toyota Tarago 1991-96 |

Crashworthiness ratings cover both earlier and later vehicle models (1982-96 years of manufacture) whilst the ANCAP program covers more recent or current models (1992 onwards). There were a number of ANCAP tested models whose design had not changed for a number of years and sufficient real crash experience had accumulated for a reliable crashworthiness rating to be calculated. Table 1 lists 28 ANCAP tested models and the comparable models for which a crashworthiness rating has been calculated (in some cases the rating is based on crashes involving "rebadged" models of the same design/manufacturer as well) that have been analysed in this study.

## 2. STUDY DESIGN

The study design and methods used in this study follow those used in the original study by Newstead and Cameron (1997). A brief summary of the considerations made in designing the study is given here. Newstead and Cameron (1997) give a detailed review of the papers from which the study design and methods used in their work and here are derived.

### *Crash Type*

From the description of the Australian NCAP program given in the published brochures (NCAP 1993,1994a,b) and by Griffiths et al (1994), it is evident that ANCAP is concerned with assessing relative occupant protection performance in frontal impacts. This is recognised in many of the studies of the relationship between NCAP programs and real crashes carried out to date. Most of these studies focus specifically on certain crash types, such as two-vehicle head-on crashes and frontal crashes of single vehicles into fixed objects (see for example Zador et al. (1984), Kahane et al (1993) and Langweider (1994)). Campbell (1982) has examined the relationship between NCAP measures and all crash types.

This study followed the methods of the previous study. Where possible, crashworthiness ratings for front to front two car collisions were compared with ANCAP test results. The crashworthiness ratings of Newstead et al (1998), based on all crash types, were also compared with ANCAP results in this study. Crashworthiness ratings for single vehicle crashes with fixed objects were not estimated, as it was impossible to reliably identify crashes of this type in the data. Comparisons with crashworthiness ratings have been made against full frontal and offset ANCAP results separately, as well as both impact types combined in a single index.

### *The Effect of Vehicle Mass*

Studies by Zador et al (1984), Evans (1994), Langweider et al (1994) and Viano (1994) have all highlighted the important influence of vehicle mass on relative occupant protection performance in car to car collisions. This point is also emphasised in the ANCAP brochure (NCAP (1993)) in describing how to interpret the test results (see section 1.1). For the purpose of this study, as in the original one, these results highlight the need to consider vehicle mass, either absolute or relative, when examining crashworthiness ratings for vehicle to vehicle crashes. The effect of mass on vehicle crashworthiness has been re-examined in this study with vehicle mass being taken into account in analysis concerning vehicle to vehicle impacts. The study also limits analysis, where possible, to crashes between two light vehicles (light vehicle being designated as passenger vehicles or commercial vehicle weighing less than 4500kg). This precludes crashes between vehicles of highly disparate masses, such as cars and trucks, where the outcome for occupants of the lighter vehicle is typically severe, regardless of vehicle design.

***Analysis Methods***

Multivariate logistic modelling has been the main statistical technique used in the literature to assess the relationship between real crashes and NCAP test results (see Kahane et al (1994) and Jones et al (1988)). Two methods of analysis have been explored in this study. Firstly, crashworthiness ratings have been calculated for various crash types using the methods of Newstead et al (1998). These were then correlated with the measurements produced from the ANCAP test procedure to assess association. A more complex modelling procedure similar to that used by Jones et al (1988) has been explored. This involved modifying the methods of Newstead et al (1998) to include functions of ANCAP scores as potential predictors of crashworthiness, and then testing the statistical significance of each predictor. These methods are described in Section 4.1.3 below.

***Single Index Rating From NCAP Scores***

Combining the results of NCAP testing into a single rating has been used by a number of authors as a means of summarising the results of a number of separate readings on a single dummy obtained from a crash test (see Zador et al (1984) and Kahane et al (1994)). One particular single index of NCAP results stems from Viano & Arepally (1994) who derived injury risk functions from relating crash test dummy responses to biomechanical data for assessing safety performance of vehicles in crash tests.

The equations they derived relating the probability of an AIS 4 or greater injury (serious, life threatening injury or worse, see AAAM (1985) for a description of AIS) to HIC (Head Injury Criterion) and chest loading (Chest Gs) respectively are;

$$P_{head} = [1 + \exp(5.02 - 0.00351 \times HIC)]^{-1} \ \ and$$
$$P_{chest} = [1 + \exp(5.55 - 0.0693 \times ChestG)]^{-1}$$

Similarly, the equation relating the probability of an AIS 3 or greater injury (severe, but not life threatening, injury or worse) to femur loading is

$$P_{femur} = [1 + \exp(7.59 - 0.00294 \times Femur\ Loading)]^{-1}$$

where Femur Loading is the greater of the measurements from both legs and is expressed in pounds.

The probabilities $P_{head}$ and $P_{chest}$ are used together to calculate a combined probability of AIS 4 or greater injury from head or chest injuries, $P_{comb2}$, for ANCAP results published in NCAP (1994b) and onwards, by applying the law of additive probability for independent but non-mutually exclusive events (Mendenhall et al 1986). This gives

$$P_{comb2} = P_{head} + P_{chest} - P_{head} \times P_{chest}$$

Combining the probabilities of severe head and chest injuries in this way reflects the fact that an individual suffering multiple injuries has a higher risk of death or disability than if injury to only one body region was sustained. It should be noted, however, that this combination method assumes the probabilities of injury to the head and chest are independent which is most likely not the case perhaps questioning its validity.

Extending this logic, and again assuming independence of the probability measures for each body region, the combined probability of sustaining one or more of an AIS 4 or greater head or chest injury and an AIS 3 or greater leg injury, $P_{comb3}$, would be

$$\begin{aligned} P_{comb3} = & P_{head} + P_{chest} + P_{femur} \\ & - P_{head} \times P_{chest} - P_{head} \times P_{femur} - P_{chest} \times P_{femur} \\ & + P_{head} \times P_{chest} \times P_{femur} \end{aligned}$$

The results of full frontal and offset testing for driver and front passenger separately are also combined in the latest ANCAP results. This is achieved by weighting the combined probabilities of injury for full frontal and right offset crashes by the ratio for which these crash types occur on the road resulting in injury to driver or front passenger. Combined probabilities for each full frontal and offset test case are then

$$\begin{aligned} P_{FF+O}(driver) &= 0.59 \times P_{comb}(full) + 0.41 \times P_{comb}(offset) \\ P_{FF+O}(F\ Pass) &= 0.71 \times P_{comb}(full) + 0.29 \times P_{comb}(offset) \end{aligned}$$

Being based on the relative exposure to real crash types, it is expected that these combined probabilities, $P_{FF+O}$, will be representative of the actual risk of injury to drivers in real crashes of NCAP severity. If this is so, this measure for the vehicle driver, $P_{FF+O}(driver)$, may have a stronger relationship with the crashworthiness ratings, which measure risk of serious injury to drivers in all types of crashes of tow-away severity or above, than its separate components. This relationship has been examined in this study along with the relationship between the crashworthiness ratings and the individual full and offset probabilities, $P_{comb}(full)$, $P_{comb}(offset)$, for combinations of both two and three injury probabilities.

Also studied here was the relationship between crashworthiness ratings and the basic ANCAP readings HIC, CD and femur loading, along with their estimated individual probabilities of injury, $P_{head}$, $P_{chest}$ (based on chest loading) and $P_{femur}$. Such a comprehensive approach was useful in assessing the relevance of the injury probability estimates and combinations in reflecting real crash outcomes. It also had the potential to point to a particular subset of ANCAP readings which best reflects injury outcome in real crashes.

## 3. DATA SOURCES

For comparison of current crashworthiness ratings and NCAP test results, data were taken from the relevant reports and brochures detailing the results of each program.

The analysis methods detailed in Section 4 below required calculation of crashworthiness ratings for specific crash types and further regression analysis of the crash data. Hence the data used in calculating the crashworthiness ratings of Newstead et al (1998) have also been used here. This data includes crashes from two States, NSW and Victoria, covering the common period 1987-96.

## 3.1 VICTORIAN CRASHES

The Transport Accident Commission (TAC) as part of its responsibilities to provide road transport injury compensation has collected detailed injury data. For each claimant, a description of the injuries was recorded, as well as whether the person was admitted to hospital. TAC obtained some details of the vehicle occupied (but not its model) from the VicRoads registration system. VicRoads supplied Vehicle Identification Numbers for later model vehicles.

TAC injury claims from drivers of cars and station wagons manufactured since 1982, who were involved in crashes in the period 1987 to 1996, had been merged with Police crash reports in producing the crashworthiness ratings (Newstead et al 1998). This resulted in a merged file covering 29,019 injured drivers of 1982-96 model cars. Police reports were on all drivers involved in crashes, no matter whether the Police officer recorded the person as injured or uninjured (this procedure was followed because it was possible for an injury claim to be made in circumstances where injury was not apparent at the time of the crash). Crashes are reported to the Police in Victoria if a person is killed or injured, if property is damaged but names and addresses are not exchanged, or if a possible breach of the Road Traffic Regulations has occurred (Green 1990).

## 3.2 NEW SOUTH WALES CRASHES

For calculation of the existing crashworthiness ratings, the NSW RTA supplied files covering 431,690 light passenger vehicles involved in Police reported crashes during 1987-96 which resulted in death or injury or a vehicle being towed away. The NRMA had added the model and year of manufacture to these vehicles after matching with the NSW vehicle register via registration number and vehicle make. The files supplied covered only vehicles manufactured during 1982-96, but covered four-wheel drive vehicles, passenger vans, and light commercial vehicles as well as cars and station wagons.

The vehicle files (which also contained driver age and sex) were merged with files supplied by NSW RTA covering details of the person casualties (killed and injured persons) and the reported crashes for the same years. Each vehicle/driver matched uniquely with the corresponding crash information, but only injured drivers could match with persons in the casualty files. A driver who did not match was considered to be uninjured. Out of the 431,690 drivers involved in tow-away crashes during 1987-96, 66,582 were injured.

The presence of uninjured drivers in the merged data file meant that it was suitable for measuring the risk of driver injury (in cars sufficiently damaged to require towing). This contrasted with the Victorian data file, which could not be used to measure injury risk directly because not all uninjured drivers were included.

## 3.3 COMBINED DATA FROM THE TWO STATES

When the data on the injured drivers was combined for analysis, it covered 84,035 drivers of 1982-96 model vehicles who were injured in crashes in Victoria or NSW during 1987-96 This information was used to assess the injury severity of the injured drivers of the different makes and models.

The information on the 431,690 drivers involved in tow-away crashes in NSW was used to assess the injury rate of drivers of the different makes and models.

## 3.4 MODELS OF VEHICLES

Vehicle model information for vehicle manufactured over the period 1982 to 1996 was decoded from the Victorian and NSW crash data using the methods described in Newstead et al (1998). The primary method used was a system of Vehicle Identification Number decoding for NSW vehicles and Victorian vehicles for which a VIN was available (further details are given by Pappas (1993)). In combination with this, a logic system for vehicle model decoding developed jointly by the RACV and Monash University Accident Research Centre based on the make, year and power-mass units of the vehicle was used for Victorian vehicles for which no VIN was available.

## 3.5 ANCAP DATA

Data from ANCAP for use in this study was supplied by the ANCAP program Technical Committee and covers all data in the published ANCAP brochures. This data included the measurements of HIC, CD and femur loading from both the driver and passenger side dummies in full frontal impacts for all 28 ANCAP tested cars listed in Table 1. In addition, the results from offset impacts for the 21 car models for which these results are available were given including the lower leg index, measured only in this crash configuration.

# 4. METHODS

## 4.1 CRASHWORTHINESS RATINGS

The crashworthiness rating (C) is a measure of the risk of serious injury to a driver of a car when it is involved in a crash. It is defined to be the product of two probabilities (Cameron et al, 1992a):

i) the probability that a driver involved in a crash is injured (injury risk), denoted by R;

and

ii) the probability that an injured driver is hospitalised or killed (injury severity), denoted by S.

That is

$$C = R \times S.$$

Measuring crashworthiness in this way was first developed by Folksam Insurance who publishes the well-known Swedish ratings (Gustafsson et al, 1989).

For the estimation of crashworthiness ratings in Newstead et al (1998), each of the two components of the crashworthiness rating were obtained by logistic regression modelling techniques. Such techniques are able to simultaneously adjust for the effect of a number of factors (such as driver age and sex, number of vehicles involved, etc.) on probabilities such as the injury risk and injury severity. Full details of this technique are given in Newstead et al (1998) including methods for calculating confidence limits on both the individual injury risk and severity component estimates as well as the crashworthiness ratings. Technical details of the logistic regression procedure can be found in, amongst others, Hosmer & Lemeshow (1989).

***Crashworthiness Ratings for Specific Crash Type***

The logistic regression methods described by Newstead et al (1998) were used in producing estimates of vehicle crashworthiness based on all crash types. One aim of this project was to compare the results of the ANCAP program with crashworthiness ratings derived from specific crash types. Producing crashworthiness ratings based on specific crash type was carried out using exactly the same methods as for all crashes, but restricting the analysis to crashes meeting the defined criteria. The criteria for crash inclusion also affected the choice of other covariates to be adjusted for in the analysis.

The specific crash type similar to the ANCAP crash configuration and examined here is head on crashes between two light vehicles. Crashes in this category are defined to be those occurring between two passenger cars where the primary source of impact for both vehicles was the front of the car. In this type of crash, relative vehicle mass is thought to be an important factor in determining occupant injury severity outcome. It should also be recalled that the ANCAP scores purport to measure the relative crashworthiness of vehicles crashing with other vehicles of approximately equal mass (see section 1.1). As proposed, two measures have been taken before examining the correlation between ANCAP and real world crashes. Firstly crashes between the ANCAP tested car models and other vehicles of highly disparate weight have been excluded from the mass data analysis. This included crashes with such vehicles as light, rigid and articulated trucks as well as buses and emergency vehicles. Exclusion of crashes involving these vehicle types was possible in both the Victorian and NSW data sets.

The second measure was a correction for the mass difference between the two vehicles. Having excluded crashes with heavy vehicles, the analysis then centred on crashes between two passenger cars. Whilst these crashes typically involve vehicles of much closer mass, there is still potential for a mass effect in these crashes. To provide this correction, ideally the actual mass of each vehicle in a crash relative to its contacting vehicle (mass ratio) should be included in the analysis. Examination of the data however revealed that considering only crashes where the mass of both vehicles was known reduced the amount of data which could be included in the analysis by 34% which was considered unacceptable given the small amounts of total data available.

A best compromise to meet the proposed requirement for mass adjustment would be to adjust for the absolute mass of each vehicle model in the analysis, rather than relative mass, to account for the possibly worse performance of lighter cars, on average, in terms of crashworthiness. Experience with the data available for analysis here showed that including vehicle mass as a covariate in the logistic regression analysis proved difficult, creating convergence problems in the model fitting process. As an alternative, a method of considering the effects of mass in the estimated crashworthiness ratings has been developed and is described in section 4.3.

The remaining factors that were appropriate to adjust for in the analysis of two car head-on crashes were:

- **sex:** driver sex (male, female)
- **age:** driver age (≤25 years; 26-59 years; ≥60 years)
- **speedzone:** speed limit at the crash location (≤75 km/h; ≥80 km/h)

## 4.2 CORRELATION OF CRASHWORTHINESS RATINGS WITH ANCAP SCORES

Simple correlation analysis, estimating Pearson’s correlation co-efficient, was one of the primary analyses used in assessing the relationship between ANCAP and real crashes outcomes. Correlations against not only the final crashworthiness measure (*injury risk* x *injury severity*) have been made, but also against the injury risk and injury severity components separately. This has been carried out for crashworthiness ratings based on all crash types as well as for crashworthiness ratings for two-vehicle head-on crashes.

Correlations of crashworthiness with the following ANCAP measures have been calculated:

- Head Injury Criterion: HIC
- Chest compression/deflection: CD
- femur loading
- Probability of AIS 4 or greater head injury: $P_{head}$
- Probability of AIS 4 or greater chest injury: $P_{chest}$
- Probability of AIS 3 or greater leg injury: $P_{femur}$
- Probability of head and/or chest injury: $P_{comb2}$
- Probability of head and/or chest and/or leg injury: $P_{comb3}$

These correlations have been calculated for both full and offset ANCAP results separately as well as combined using the methods of NCAP (1994b).

### 4.3 MASS EFFECTS AND CRASHWORTHINESS RATINGS

It has been found that the crashworthiness ratings are, at least in part, a function of vehicle mass with heavier vehicles tending to exhibit superior crashworthiness ratings when considering all crash types (Cameron et al (1994a,b)). It is important to establish quantitatively the role that vehicle mass plays in determining crashworthiness for use in comparison with ANCAP scores. As stated in the guidelines for interpreting ANCAP scores, the results of testing are considered to be independent of vehicle mass. To enable valid comparison of ANCAP with crashworthiness ratings test results, the effect of vehicle mass, if any, should be taken into account. The philosophies and techniques for achieving this are explored here.

**Figure 1** : Crashworthiness vs. Mass (tare mass)

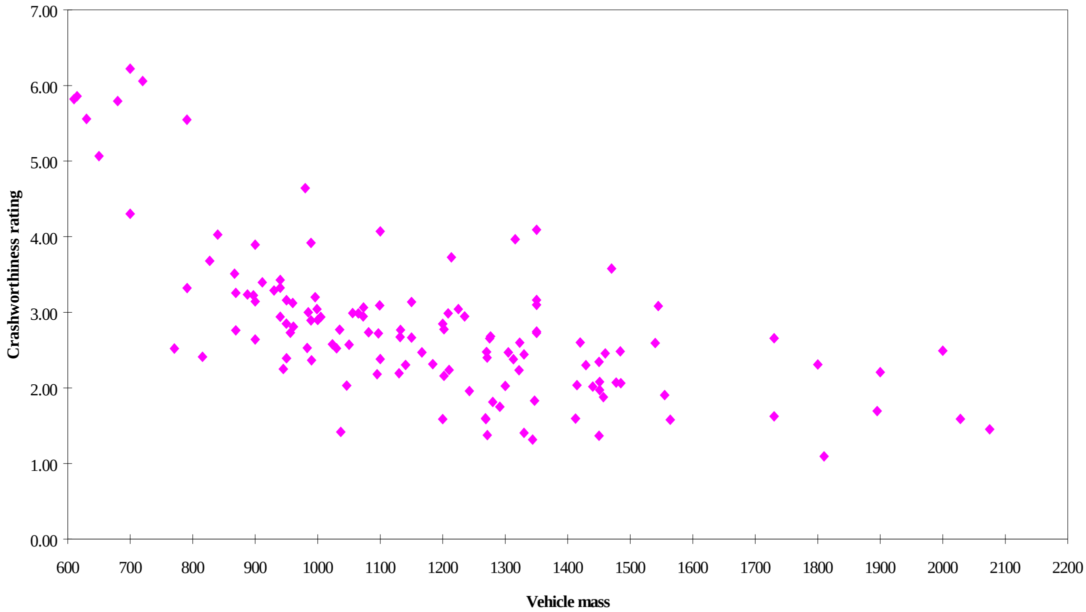



Figure 1 shows the relationship between vehicle crashworthiness ratings and vehicle mass for the crashworthiness ratings of Newstead et al (1998). There is a clear trend to decreasing (better) crashworthiness rating with increasing mass shown by the decreasing trend in the plotted points in Figure 1. This analysis demonstrates the need to consider vehicle mass when comparing crashworthiness ratings with the mass independent ANCAP test scores. Two options for accounting for the effects of mass are considered here.

### 4.3.1 Adjusting For Mass Effects in Crashworthiness Ratings

The risk of driver injury for crashes in Great Britain by car make and model have been calculated from real crash data, using philosophies similar to that of Cameron et al (1994a,b), with the results and methods detailed in Craggs and Wilding (1995). As part of that study, a method of mass adjusting the car safety ratings produced is described and applied to produce relative driver injury risk ratings by car model which have the effects of the mass of the vehicle model removed. In short, this method involves fitting a linear regression model of vehicle mass against driver injury rating, with the estimated regression line at a given mass representing the average driver risk for all vehicles of that mass. Mass adjusted driver injury ratings are calculated by subtracting the average driver injury risk for a given vehicle mass, estimated from the regression equation, from the original estimate of driver injury risk. In this way, vehicle models with estimated driver injury risks which lie below the mass regression line represent those which exhibit greater driver protection than average for their given mass whilst those which lie above are vehicles which offer worse than average driver protection for their mass.

A paper by Broughton (1994) discusses the theoretical merits of the methods used to produce the British driver injury ratings, and their mass adjusted counterparts, of Craggs and Wilding (1995). In this paper, Broughton (1994) discusses the roles of both the mass adjusted and unadjusted driver injury ratings. To quote :

I. "the unadjusted index is relevant to the car buyer who wishes to compare the safety of models he is considering, since his personal safety will be of concern to him"
II. "the mass-adjusted index is of interest to regulators and the motor industry, as it shows whether particular models achieve good safety records by added mass rather than good design"

In a similar way to which Craggs and Wilding (1995) produced mass adjusted driver injury ratings for their British study, a method which could, in principle, be used to adjust the Australian crashworthiness ratings of Newstead et al (1998) is described here. Unlike Craggs and Wilding (1995), who used linear regression for their mass adjustment curve, here use of a logistic regression curve is proposed instead. Use of logistic regression for adjustment ensures the resulting mass adjusted crashworthiness ratings lie between 0 and 1, a requirement not met by linear regression. The proposed method for adjusting crashworthiness ratings is described here.

For car model j, with mass $W_j$, the quantities $C_j$, $R_j$, $S_j$, $n_j$ and $m_j$ are defined as the crashworthiness rating, injury risk, injury severity, number of crash involved and number of injured drivers in vehicle model j respectively. To adjust the crashworthiness ratings for the effect of mass, firstly a logistic regression of crashworthiness ratings against vehicle mass was fitted, resulting in a relationship of the form

$$\log\left(\frac{C_j^m}{1 - C_j^m}\right) = \alpha + \beta W_j$$

where $\alpha$ and $\beta$ are the estimated parameters of the logistic regression. $C_j^m$ then represents the average crashworthiness for vehicles of mass $W_j$. For a given mass $W_j$, a vehicle with actual crashworthiness rating, $C_j$, which is less than $C_j^m$ can be said to have a better than average crashworthiness for vehicles of that mass. The quantity

$$C_j - C_j^m$$

gives a measure of the relative crashworthiness of vehicle j amongst all vehicles of mass $W_j$. Scaling this quantity to the average crashworthiness for vehicles of overall average mass, $C_{\overline{W}}^m$, gives the mass adjusted crashworthiness for vehicle j, $C_j^{MA}$. That is

$$C_j^{MA} = C_j - C_j^m + C_{\overline{W}}^m$$

The logistic regression of crashworthiness ratings against vehicle mass could be again carried out using the LR module of the BMDP statistical analysis package. The logistic regression is weighted by the number of cases used in calculating each crashworthiness rating $C_j$, which is $n_j + m_j$. This gives greater weight in the regression to crashworthiness ratings that have been calculated from larger quantities of data and are hence more accurate. Testing of the statistical significance of parameter β in the fitted logistic regression equation indicates whether vehicle mass has a significant influence on crashworthiness rating. Where the parameter β is not statistically significantly different from zero, indicating no relationship between vehicle mass and crashworthiness, no mass adjustment should be made to the crashworthiness rating.

Whilst this procedure has been illustrated for mass adjustment of crashworthiness ratings, it is equally applicable to mass adjustment of the injury risk component, $R_j$, or injury severity component, $S_j$, of the crashworthiness rating.

### 4.3.2 Inclusion of a Mass Correction in ANCAP Measures

The discussion above considers a method of compensating for the effects of vehicle mass in the crashworthiness ratings. Here an alternative method of accounting for the effect of vehicle mass on crashworthiness is proposed where by the results from ANCAP, which are described as being independent of vehicle mass, are adjusted to reflect the role mass plays in influencing injury outcome in real crashes. The method proposed uses the established relationship between crashworthiness and vehicle tare mass to calculate an adjustment factor to the ANCAP test results which reflects the difference in the ANCAP vehicle's test mass from the average tare mass of the vehicle fleet from which the crashworthiness ratings are derived.

As the adjustment factor proposed is derived from the crashworthiness ratings, which are a measure of driver injury risk across all body regions, it is considered to only be appropriate to apply this adjustment to NCAP measures which also represent a measure of injury risk to multiple body regions. Hence the adjustment procedure is only valid for the ANCAP measures $P_{comb}$ and $P_{real}$, as defined in Section 2.2.

The method for correcting the ANCAP injury probability measures for the effects of vehicle mass are as follows. Again the notation of Section 4.1 for car model j is used, with the quantities $W_j$, $C_j$, $R_j$, $S_j$, $n_j$ and $m_j$ as defined above. The same logistic regression of crashworthiness ratings against vehicle mass, as described in section 4.3.1 above, of the form

$$\log\left(\frac{C_j^m}{1-C_j^m}\right)=\alpha+\beta W_j$$

is used, where $\alpha$ and $\beta$ are the estimated parameters of the logistic regression. $C_j^m$ again represents the average crashworthiness for vehicles of tare mass $W_j$. Let $W_{AV}$ be the average tare mass of the vehicle fleet whose crashworthiness ratings were used in calculating the logistic regression curve above and let $P_{NCAP}$ be the ANCAP injury probability to be mass adjusted.

Firstly a calibration factor, $\alpha_c$ , is calculated for the estimated crashworthiness-mass logistic regression curve so that the expected value of the logistic curve is equal to $P_{NCAP}$ at the vehicle fleet average mass, $W_{AV}$. That is $\alpha_c$ is calculated such that;

$$\ln\left(\frac{P_{NCAP}}{1-P_{NCAP}}\right)=\alpha_c+\alpha+\beta\times W_{AV}$$

Calibrating the logistic regression in this way assumes the mass independent ANCAP measure to apply to a vehicle of average mass for the fleet. The mass adjusted ANCAP measure, denoted $P_{NCAP(ADJ)}$ , is calculated, once $\alpha_c$ has been calculated, by substituting the mass of the ANCAP tested vehicle to which $P_{NCAP}$ relates, denoted $W_{NCAP}$, into the equation above and solving for $P_{NCAP(ADJ)}$ . This gives

$$P_{NCAP(ADJ)}=\frac{\exp(\alpha+\alpha_c+\beta\times W_{NCAP})}{1+\exp(\alpha+\alpha_c+\beta\times W_{NCAP})}$$

This mass adjustment process is repeated for each ANCAP probability measure.

Whilst the method of mass adjustment of crashworthiness ratings, as well as its components, has been explored in Section 4.3.1 above, the method of mass adjusting ANCAP probability measures described here will be used for the analysis presented in this report. Both the raw ANCAP measures, as well as the mass adjusted ANCAP injury probability measures, have been compared with the crashworthiness ratings and their injury risk and severity components using the methods described.

## 4.4 LOGISTIC MODELLING OF CRASHWORTHINESS AS A FUNCTION OF ANCAP SCORES

It has proven the case in Newstead and Cameron (1997) that the relatively small amount of real crash data typically available for ANCAP tested vehicle models means that case-based logistic regression of ANCAP scores proved unsuccessful. An alternative method for regression of the ANCAP scores against real crash outcomes which uses the estimated crashworthiness ratings and their constituent components is described here.

Section 4.3 above described a method for mass adjustment of crashworthiness ratings. As part of this process, the crashworthiness ratings, or their injury risk or severity components, were modelled as a function of vehicle mass via logistic regression analysis. In the same way, crashworthiness ratings, or their components, can be modelled as a function of ANCAP scores via logistic regression. The form of the relationship in this case would be

$$\log\left(\frac{C_i}{1-C_i}\right) = \beta_0 + \beta_1 (HIC_i) + \beta_2 (CD_i) + \beta_3 (Femur\ Loading_i)$$

where the suffix, *i*, refers to the crashworthiness rating and ANCAP scores of vehicle *i*, and the β's are the regression parameters. Vehicle mass as well as lower leg index scores for offset ANCAP tests have also been included as a predictor in the logistic regression as could linear interaction terms between ANCAP measures. Associations between crashworthiness and a particular ANCAP measure can be assessed by testing its associated regression parameter estimate for a statistically significant difference from zero.

This method of associating ANCAP scores and crashworthiness ratings using logistic regression techniques has also served to provide the basis for an alternative validation for the correlation analyses described in Section 4.2.

## 4.5 COMPARISON OF INJURY PATTERNS WITH ANCAP SCORES

There is detailed information on the particular injuries of those drivers involved in crashes recorded in the Transport Accident Commission (TAC) claims records. By extracting the TAC claims by drivers of the ANCAP models involved in relevant crash types, as described in section 1, it was possible to make a comparison between real-life crash injuries and ANCAP scores by the injury levels of each body region. This analysis required two steps;

(i) The TAC records the injuries of drivers in the form of a code designed for the classification of morbidity and mortality information for the indexing of hospital records by disease and operations, namely the *9th Revision of the International Classification of Disease* (ICD-9). This injury data from TAC must be converted into a form that measures the level of injury incurred from each accident. A dBase III Plus program, called ICDMAP, was run to obtain these injury levels.

(ii) A specific comparison between the injury levels of real crashes and the individual ANCAP measurements by body region was made.

### 4.5.1 ICD MAP Program

ICDMAP (MacKenzie et al 1989, ICDMAP 1988) is a computerised conversion table that maps injury diagnoses that are coded using the Clinical Modification of the *9th Revision of the International Classification of Disease* (ICD-9-CM) into 1985 Abbreviated Injury Scale (AIS) severity scores and body regions. ICD-9-CM is a more detailed and precise code than ICD-9, the coding applied by TAC, hence in most cases the conversion process will not be as accurate and severity may be underestimated.

AIS is a numerical scale ranging from 1 (minor injury) to 6 (maximum injury-virtually unsurvivable). AIS scores are assigned to valid trauma related diagnoses (ICD 800-959, excluding 905-909; 930-939; 958) and there is an option of assigning a low or high AIS score for those diagnoses that are associated with a range of AIS values. The high option was used here.

After obtaining a file of relevant driver claims, each record containing up to 5 ICD-9 codes, the ICDMAP program is run. The following information can then be obtained:

- AIS scores assigned to all valid diagnoses, scores ranges from 1 to 6 or the value 9 (which indicates it was not possible to determine if an injury occurred).

- Body region codes assigned to ICD coded diagnostics using two alternative classifications. The first defines body regions in only 6 areas whilst the second uses a more detailed classification. The second option is preferred so that 'Lower Extremities' and 'Head only' injuries, as opposed to 'Extremities' and 'Head/Neck', can be examined.

- Maximum AIS scores per body region, again using the second option of a more detailed classification of body regions. These scores are often used to summarise the type and extent of injury.

- The Injury Severity Score (ISS), a widely used AIS-based measure for rating overall case severity that takes into account the combined effect of injuries to multiple body systems.

From this output, results of the maximum AIS scores per body region are of importance because it allows a comparison between the ANCAP scores for Head, Chest, and Femurs and the Maximum AIS scores for 'Head only', 'Chest' and 'Lower Extremities' of drivers injured in real crashes.

### 4.5.2 Use of Maximum AIS Scores by Body Region

Having obtained maximum AIS scores by body region using the ICDMAP program on the TAC claims data, comparison of these scores with the corresponding ANCAP score for each body region was made. Analysis involved comparison of the average maximum AIS score by body region for each of the ANCAP tested vehicle models with the relevant ANCAP score. For example, average AIS score for the head region was compared with the ANCAP HIC reading and its associated transformations. Correlation analysis was used to assess the relationship between the average AIS scores and ANCAP test results. Graphical comparison was also made to confirm the results of the correlation analyses.

## 5. RESULTS

The results of the analysis undertaken are presented in a number of stages. Each stage investigates a different or graduated aspect of the relationship between ANCAP test results and real crash outcomes. The results stages are as follows:

1. *Estimation of two car head-on crashworthiness ratings and investigation of mass effects*. These are preliminary analyses providing results for use in subsequent main analyses. Crashworthiness ratings have been estimated for two light vehicle head-on crashes whilst the relationship between vehicle mass and crashworthiness has been examined leading to the estimation of mass adjusted ANCAP scores.
2. *Correlation analyses of crashworthiness ratings and its components against ANCAP measures*. This first stage of the main analyses examines for general associations between crashworthiness and ANCAP measures using bivariate correlation analyses. These results provide a general measure of the association between each ANCAP measure individually and real crash outcomes as measured by crashworthiness ratings and their components.
3. *Logistic regression analyses*: Two approaches to logistic regression analyses of ANCAP scores against real crash outcomes have been undertaken.
    a) *Univariate logistic regression analyses*: Here each ANCAP measure is regressed individually against real crash outcomes in a series of univariate regression analyses. The results of these analyses serve to validate the results of the correlation analyses performed above under a different hypothesis-testing framework. Concordance between the results of the two analysis techniques indicates robust relationships.
    b) *Multivariate logistic regression analyses*: Whilst the correlation and univariate logistic regression analyses described above assess the relationship between ANCAP measures and real crash outcomes on an individual basis, they take no account of potential relationships between the ANCAP measures themselves. They also make no real assessment of the predictive power of ANCAP measures in describing real crash outcomes beyond general association. Multivariate logistic regression analyses chooses the best subsets of available ANCAP measures, including interactions between these measures, and builds functional relationships which best describe real crash outcomes as measured by crashworthiness ratings and their components. The potential predictive power of ANCAP scores in describing real crash outcomes is measured by these results. These results also potentially provide the closest links between ANCAP and real crash measures.

4. *Correlation of real crash injury outcome by body region with ANCAP scores by body region:* The results of these analyses performed by specific body region further validate the analyses results described above. Investigating relationships by specific body region provides more closely linked cause-and-effect type understanding of any relationships found in the general analyses described above (eg: a strong association between HIC and real crash severity stems from a strong association between HIC and real crash head injury level).

## 5.1 CRASHWORTHINESS RATINGS FOR TWO CAR HEAD-ON CRASHES

This section details the results of estimation of crashworthiness ratings for head-on crashes between two light vehicles. Table 4, given in section 5.4 below in this report, gives an indication of the relative number of crashes identified in the data for this crash type.

It should be noted that the number of two light vehicle head-on crashes identified in the data for the ANCAP tested vehicles represented only around 4% of all crashes. This, however, is not indicative of the real proportion of frontal impact type crashes occurring in the data as selection from the crash data is limited by the coding conventions adopted in the data. In the NSW crash data, no direction of impact on the vehicle is coded but rather broad crash type descriptions are used. Two-car, head on-crashes were the only crash type that could be selected which reliably identified frontal impacts. This represented the majority of the data available from the two states combined. In Victoria, frontal impacts were identified from a code specifying direction of impact on the vehicle. Hence, from the Victorian data, other frontal impacts besides two-car head on crashes have been included in the analysis.

To ensure convergence of the logistic models used in estimating crashworthiness ratings for all crash type, Newstead et al (1998) restricted analysis to those vehicles which had at least 100 cases of driver involvement and at least 30 cases of driver injury appearing in the data. Because of the smaller amount of data available for analysis of two light vehicle head-on crashes, these model inclusion criteria have been relaxed. Vehicle models were included in this analysis if there were at least 80 involved drivers and at least 20 injured drivers of those vehicles appearing in the data. Being the focus of the analysis, as many as possible of the ANCAP tested models listed in Table 1 were included in the logistic regressions regardless of the number of cases of involvement or injury in the data. Of the 28 ANCAP tested models in Table 1, 22 were able to be included in the analysis without adversely effecting convergence of the logistic model. Vehicle models that were not included in the analysis due to insufficient cases numbers were: Daihatsu Charade (1993-96), Hyundai Excel (1994-98), Hyundai Lantra (1992-95), Mitsubishi Lancer (1992-96), Toyota Corolla (1994-95) and Toyota Tarago (1991-96). Crashworthiness ratings for two-car head-on crashes were obtained for 60 vehicle models, including the 22 ANCAP tested models.

### *Injury Risk*

A total of 16,239 drivers of vehicles in tow away crashes satisfying the crash type and model inclusion criteria for this analysis were identified in the NSW data. A logistic regression model incorporating all the factors listed in Section 4.1.1 was estimated.

Both driver age and sex as well as speedzone were significantly associated with injury risk, as were the first order interaction effects of driver sex with age and driver age with speedzone.

***Injury Severity***

There were 11,540 drivers of vehicle models satisfying the entry criteria and injured in two light vehicle head-on crashes identified in the Victorian and NSW data. Logistic regression analysis found injury severity to be significantly influenced by speedzone and driver sex and age, as well as all first order interactions between speedzone and driver sex, driver sex and age, speedzone and number of vehicles and driver sex and number of vehicles.

***Crashworthiness Ratings***

Appendix A shows the estimated injury risk and severity, as well as the resulting crashworthiness rating, for head on crashes between two light vehicles. Upper and lower confidence limits and confidence limit width for each estimated crashworthiness rating are also given in Appendix A, along with the all model average injury risk, severity and crashworthiness rating. It is interesting to note that the average head-on crashworthiness rating shown in Appendix A is substantially higher than that for all crashes estimated by Newstead et al (1998). This reflects the relatively high risk of serious injury in crashes of this type.

From Appendix A, the effects of the smaller quantities of data compared with all crash types on estimate accuracy can be seen in the confidence interval width. This is particularly evident for some of the 22 ANCAP tested models. Of the 60 models for which a crashworthiness rating was obtained, the following models had a rating significantly worse than the overall average:

- Daihatsu Charade 1988-92
- Ford Laser 1991-94
- Mitsubishi Passenger Vans
- Holden Astra / Nissan Pulsar 1984-86
- Holden Camira
- Ford Laser / Meteor 1982-89

whilst the following models have a rating significantly better than average:

- Toyota Landcruiser 1990-96
- Nissan Patrol / Ford Maverick 1988-96
- Toyota Landcruiser 1982-89
- Holden Commodore / Toyota Lexcen VR/VS 1993-96
- Ford Falcon EB Series II / ED
- Nissan 720 Utility
- Toyota 4Runner / Hilux
- Subaru 1800 / Leone
- Ford Falcon Ute / Nissan XFN Ute
- Ford Falcon EA / EB Series I

Whilst the ratings produced for this crash type are still useful for comparison with ANCAP test results, the wide confidence limits on the ratings for the ANCAP tested vehicle models should serve as a cautionary note in interpretation of these results. Addition of further years' crash data would improve the accuracy of the ratings obtained here.

## 5.2 MASS EFFECTS AND CRASHWORTHINESS RATINGS

The methods described in Section 4.3.2 were used to adjust for mass effects, if present, in the measures of injury risk derived from ANCAP results. This was carried out for each of the crash types considered, being all crashes and two light vehicle head-on crashes.

Table 2 summarises the coefficients of vehicle tare mass in the logistic regressions used to quantify the relationship between vehicle mass and crashworthiness ratings. For interest, logistic regressions were also estimated to quantify the relationship between vehicle tare mass and the injury risk and injury severity components of crashworthiness for the two crash types considered. A cell with *NS* signifies that mass was not a statistically significant predictor of crashworthiness, injury risk or severity in the fitted logistic regression.

**Table 2 :** Coefficients of vehicle mass in the mass effect logistic regressions.

| Crash Type | Injury Risk | Injury Severity | Crashworthiness Rating |
|---|---|---|---|
| **All Crashes** | $-6.257 \times 10^{-4}$ ($p$ *<0.001 ) | *NS* | $-5.317 \times 10^{-4}$ ($p$ *<0.001 ) |
| **Two Light Vehicle Head On Crashes** | $-8.525 \times 10^{-4}$ ($p$ *< 0.001) | $-3.227 \times 10^{-4}$ ($p$ *< 0.001) | $-8.636 \times 10^{-4}$ ($p$ *< 0.001) |

NS = No statistically significant effect

Table 2 shows that, for all crashes and two light vehicle head on crashes, both the crashworthiness rating and injury risk component are dependent on vehicle mass. The negative sign on the logistic regression coefficient indicates that vehicles of higher mass have on average better crashworthiness or smaller injury risk. An association between vehicle mass and injury severity was found for two light vehicle head-on crashes with the negative sign on the regression coefficient again indicating decreasing injury severity with increasing vehicle mass. The relationship between vehicle mass and head on crash injury severity was not found by Newstead and Cameron (1997) but may have emerged here as a result of increased statistical power from greater quantities of data. Indeed, the plot of head on crash injury severity given in Newstead and Cameron (1997) showed evidence of a decreasing trend in injury severity with increasing vehicle mass. No association between injury severity and mass was found for all crash types.

Appendix B shows the mass adjusted ANCAP measures, calculated from the logistic regression functions of mass estimated above, along with plots of crashworthiness rating, injury risk and injury severity against vehicle mass. The fitted logistic regression curve, where significant, is also given on each graph.

## 5.3 CORRELATION OF ANCAP SCORES WITH CRASHWORTHINESS RATINGS

This section details the results of correlation analyses of the ANCAP test results with various measures of real crash outcomes. The raw ANCAP test scores have been used as well as their associated individual and combined measures of injury risk described in Section 2.2, along with the mass adjusted ANCAP measures estimated in Section 5.2. Full frontal and offset ANCAP test scores have been considered separately. Measures of real crash outcomes used are the crashworthiness ratings of Newstead et al (1998) and the two light vehicle head on crashworthiness ratings estimated in Section 5.1 above. The injury risk and injury severity components of the crashworthiness ratings, along with the crashworthiness ratings themselves, have been considered.

Table 3, parts (A) - (C), summarise the main results of the correlation analyses. Each of the correlations presented in Table 3 has been tested for statistically significant difference from 0 (ie. the null hypothesis of no association). Correlations statistically significantly different from zero are indicated by shading, with darker shading for greater significance according to the key shown on the table. PheadD, PchestD and Pfemload are the injury risk probabilities derived from the ANCAP readings of HIC, Chest Loading and Femur Loading respectively. Pc1 and Pc2 refer to the combined probability of injury to head and/or chest and head and/or chest and/or femur respectively. Preal1 and Preal2 are the associated combined probability of injury derived from both full frontal and offset ANCAP test scores not including and including femur loading measurements respectively. Appendix C gives a full set of all the results of correlation analyses performed as well as some plots of the key significant relationships between ANCAP and real crash outcome measures.

Part (A) of Table 3 shows the correlations of each of the full frontal ANCAP test measures with the crashworthiness ratings and its components for each of the two crash types considered. Analysis presented covers the 28 ANCAP tested models that also appear in the crashworthiness ratings of Newstead et al (1998) based on all crashes, and the 22 ANCAP tested models for which two car head-on crashworthiness ratings were estimated. Part (B) of Table 3 gives analogous information for offset ANCAP test results. This analysis covers the 21 models for which offset ANCAP results crash crashworthiness ratings based on all crash types were available, and the 15 models for which offset ANCAP results and crashworthiness ratings based on two-car head-on crashes were available.

**Table 3 :** Correlation of ANCAP test results with real crash outcomes. Summary of Correlation Analyses.

**(A) FULL FRONTAL ANCAP TEST RESULTS**

| | All Crashes (28 Models) | | | 2 Car Head-on Crashes (22 Models) | | |
|---|---|---|---|---|---|---|
| | *Crash-worthiness Rating* | *Injury Severity* | *Injury Risk* | *Crash-worthiness Rating* | *Injury Severity* | *Injury Risk* |
| HIC | 0.049 | 0.140 | -0.064 | 0.140 | **0.309** | -0.126 |
| Chest G | 0.105 | -0.100 | **0.274** | **0.335** | 0.223 | **0.361** |
| Femload | -0.009 | -0.117 | 0.098 | 0.136 | -0.144 | **0.315** |
| PheadD | 0.050 | 0.133 | -0.056 | 0.126 | **0.306** | -0.140 |
| PchestD | 0.070 | -0.154 | **0.273** | **0.297** | 0.164 | **0.337** |
| Pfemload | 0.073 | 0.032 | 0.083 | 0.167 | -0.007 | 0.257 |
| Pc1(full) | 0.098 | 0.054 | 0.102 | 0.240 | **0.345** | 0.023 |
| Pc2(full) | 0.093 | 0.050 | 0.099 | 0.230 | **0.322** | 0.026 |
| Mass Adj. Pc1 | **0.255** | 0.172 | 0.233 | **0.440** | **0.557** | 0.184 |
| Mass Adj. Pc2 | **0.255** | 0.172 | 0.233 | **0.435** | **0.544** | 0.190 |

**(B) OFFSET ANCAP TEST RESULTS**
**(including combined offset and full frontal measures - Preal)**

| | All Crashes (21 Models) | | | 2 Car Head-on Crashes (15 Models) | | |
|---|---|---|---|---|---|---|
| | *Crash-worthiness Rating* | *Injury Severity* | *Injury Risk* | *Crash-worthiness Rating* | *Injury Severity* | *Injury Risk* |
| HIC | **0.312** | 0.233 | 0.225 | 0.292 | 0.225 | 0.274 |
| Chest G | **0.477** | 0.197 | **0.513** | **0.391** | 0.196 | **0.476** |
| Femload | **0.398** | **0.359** | 0.285 | 0.160 | 0.120 | 0.157 |
| Lower Leg Index | **0.435** | 0.088 | **0.577** | 0.300 | 0.189 | 0.330 |
| PheadD | **0.364** | 0.240 | 0.288 | 0.238 | 0.243 | 0.194 |
| PChestD | **0.408** | 0.160 | **0.432** | 0.323 | 0.147 | **0.391** |
| PFemload | 0.156 | **0.307** | -0.017 | -0.027 | -0.017 | -0.033 |
| Pc1(offset) | **0.467** | 0.252 | **0.430** | 0.284 | 0.258 | 0.257 |
| Pc2(offset) | **0.516** | **0.409** | **0.383** | 0.291 | 0.265 | 0.262 |
| Preal1 | **0.321** | 0.151 | **0.317** | 0.348 | **0.372** | 0.229 |
| Preal2 | **0.376** | 0.271 | **0.304** | **0.355** | **0.378** | 0.235 |
| Mass Adj. Pc1(offset) | **0.559** | **0.332** | **0.499** | **0.394** | **0.395** | 0.338 |
| Mass Adj. Pc2(offset) | **0.596** | **0.471** | **0.449** | **0.400** | **0.402** | 0.344 |
| Mass Adj. Preal1 | **0.505** | **0.297** | **0.465** | **0.554** | **0.612** | **0.404** |
| Mass Adj. Preal2 | **0.550** | **0.404** | **0.447** | **0.557** | **0.615** | **0.408** |

**(C) FULL FRONTAL ANCAP TEST RESULTS**
**FOR THE SAME VEHICLE MODELS AS ANALYSED IN TABLE 3 (B)**

| | All Crashes (21 Models) | | | 2 Car Head-on Crashes (15 Models) | | |
|---|---|---|---|---|---|---|
| | *Crash-worthiness Rating* | *Injury Severity* | *Injury Risk* | *Crash-worthiness Rating* | *Injury Severity* | *Injury Risk* |
| HIC | -0.013 | 0.097 | -0.131 | 0.142 | 0.272 | -0.072 |
| Chest G | 0.133 | -0.158 | **0.374** | **0.477** | 0.351 | **0.479** |
| Femload | -0.050 | -0.079 | 0.021 | 0.192 | -0.034 | 0.339 |
| PheadD | -0.022 | 0.085 | -0.134 | 0.124 | 0.265 | -0.089 |
| PchestD | 0.086 | -0.229 | **0.373** | **0.447** | 0.289 | **0.466** |
| Pfemload | 0.010 | 0.047 | -0.018 | 0.172 | 0.038 | 0.266 |
| Pc1(full) | 0.034 | -0.019 | 0.067 | 0.300 | **0.373** | 0.116 |
| Pc2(full) | 0.018 | -0.022 | 0.048 | 0.286 | 0.347 | 0.118 |
| Mass Adj. Pc1 | 0.222 | 0.126 | 0.219 | **0.522** | **0.622** | 0.305 |
| Mass Adj. Pc2 | 0.212 | 0.127 | 0.205 | **0.516** | **0.610** | 0.311 |

**NNN** = Statistically significant at the 1% level
**NNN** = Statistically significant at the 5% level
**NNN** = Statistically significant at the 10% level

Examination of Table 3 parts (A) and (B) reveals some indication of the relationships between ANCAP scores and real crash outcomes. Firstly, Table 3 shows a stronger association between real crash outcome measures and offset ANCAP results than between real crash outcome measures and full frontal ANCAP results. This is particularly the case when considering all crash types but is also generally true for two car head-on crashes. There is a somewhat stronger correlation between the full frontal ANCAP test results and two-car head on crashes than between the full frontal ANCAP test results and all crash types. The differential between the relationship with each crash type is not so marked when considering the correlation with offset ANCAP test results. For the full frontal ANCAP test results and the offset ANCAP test results in relation to all crashes, the ANCAP scores show little difference in strength of relationship between the injury risk or injury severity component of the crashworthiness rating, particularly when considering the offset ANCAP configuration. When considering two-car head-on crashes, the injury severity component of the crashworthiness rating shows the stronger association with both full frontal and offset ANCAP results.

When considering individual ANCAP measures, both the full frontal and offset ANCAP test chest loading measure shows consistently the strongest association with real crash measures. In each instance in Table 3 parts (A) and (B), the combined measures of injury risk across all body regions (Pc1, Pc2 and Preal), derived from the ANCAP scores, show the strongest association with crashworthiness and its components. The strength of these associations demonstrates the worth of these measures as summaries of ANCAP test results. Mass adjustment of these combined ANCAP measures of injury risk consistently increases their correlation with real crash measures. This demonstrates the role that vehicle mass plays in real crashes and reinforces the need to consider this when relating ANCAP results to real crash outcomes.

Results of correlation of the offset ANCAP scores with real crashes relate to only 21 of the 28 models analysed in all crashes and 15 of the 22 models analysed in head on crashes. Because of this, Table 3 part (C) gives the results of correlation of the full frontal ANCAP scores for the same subset of cars analysed in Table 3, part (B). The correlations in Table 3 part (C) are then directly comparable with those in part (B). Generally, the patterns of relationships observed in part (C) of Table 3 are consistent with those observed in Part (A), validating the comparisons of parts (A) and (B) made above.

In summary, the results of correlation of ANCAP test results with real crash outcomes as measured by crashworthiness ratings suggest a number of relationships. Firstly, whilst the results from full frontal ANCAP testing have some association with real crash outcomes, the associations between offset ANCAP testing and real crashes are much stronger. The ANCAP test results and their associated measures have equally strong association with both the injury risk and injury severity components of the crashworthiness rating when considering all crash types, and the injury severity component of crashworthiness when considering two-car head-on crashes. Correlations were generally stronger between ANCAP results and two-car head-on crashes than with all crash types but this difference was not large. Mass adjustment of the ANCAP probability measures also improved their relationship with real crash outcomes.

## 5.4 LOGISTIC MODELLING OF ANCAP SCORES

Whilst the results of the correlation analyses, described in section 5.3 above, give a good indication of the strength or weakness of relationship between ANCAP measures and real crash outcomes, the logistic regression methods described in Section 4.4 provide a potentially powerful method of validating and exploring these relationships.

Table 4 gives the number of cases identified in the Victorian and NSW data for use in the logistic regressions of ANCAP scores against crashworthiness, injury risk and injury severity, described in Section 4.4.1 for the two crash types considered in this study. Table 4 shows that, whilst there were sufficient quantities of data on each of the 28 ANCAP tested models under consideration for all crashes, the data for two car, head on crashes was relatively sparse.

**Table 4 :** Number of injured or involved drivers of cars available for logistic regression analysis of ANCAP scores against real crash outcomes in 1987-96 Victorian and NSW data.

| **Crash Type** | **All** | | **2 Car Head On** | |
|---|---|---|---|---|
| **Make/model with Crashworthiness Rating based on 1987-96 crashes and tested in the ANCAP program** | **Involved Drivers** | **Injured Drivers** | **Involved Drivers** | **Injured Drivers** |
| Daihatsu Charade 1994-96 | 359 | 81 | 22 | 17 |
| Ford Falcon EF 1994-96 | 1584 | 279 | 73 | 59 |
| Ford Falcon EB Series 2 & ED 1992-94 | 2814 | 438 | 113 | 104 |
| Ford Festiva WB 1994-96 | 657 | 161 | 22 | 32 |
| Ford Laser KF/KH 1991-94 | 2239 | 470 | 81 | 97 |
| Holden Barina 1989-94 | 2708 | 630 | 109 | 104 |
| Holden Commodore VR/VS 1993-96 | 3444 | 590 | 165 | 118 |
| Holden Commodore VN/VP 1988-93 | 13976 | 2442 | 799 | 506 |
| Honda Civic 1992-95 | 595 | 101 | 22 | 21 |
| Hyundai Excel 1990-94 | 1356 | 387 | 45 | 73 |
| Hyundai Excel 1995-96 | 419 | 95 | 16 | 14 |
| Hyundai Lantra 1991-95 | 323 | 82 | 9 | 14 |
| Mazda 121 1991-96 | 806 | 215 | 39 | 46 |
| Mazda 626 1992-96 | 892 | 148 | 47 | 42 |
| Mitsubishi Lancer CC 1995-96 | 450 | 104 | 15 | 22 |
| Mitsubishi Magna TR/TS 1991-94 | 2613 | 405 | 104 | 116 |
| Nissan Patrol / Ford Maverick 1988-96 | 1167 | 148 | 114 | 28 |
| Nissan Pintara 1989-92 | 2565 | 441 | 135 | 82 |
| Nissan Pulsar 1992-95 | 862 | 181 | 39 | 31 |
| Subaru Liberty 1989-94 | 966 | 153 | 51 | 28 |
| Suzuki Vitara 1988-96 | 677 | 136 | 33 | 16 |
| Toyota Camry 1987-92 | 7835 | 1413 | 383 | 285 |
| Toyota Camry 1993-96 | 2068 | 335 | 110 | 81 |
| Toyota Corolla 1988-94 | 5020 | 1045 | 202 | 207 |
| Toyota Corolla 1995-96 | 350 | 70 | 21 | 17 |
| Toyota Landcruiser 1990-96 | 702 | 99 | 75 | 24 |
| Toyota Tarago 1983-90 | 2366 | 425 | 159 | 46 |
| Toyota Tarago 1991-96 | 349 | 48 | 16 | 8 |
| *Totals* | *60162* | *11122* | *3019* | *2238* |

Logistic regression modelling was used to model the estimated crashworthiness ratings or injury risk or severity components as a function of ANCAP scores using a method similar to that used to mass adjust the crashworthiness ratings. The crashworthiness, injury risk and injury severity are already adjusted for the effects of driver age and sex, speedzone and number of vehicles in the crash. Case aggregated logistic regressions have been carried out in two ways here;

1. *Univariate case aggregated logistic regression*: Here, the ANCAP test scores HIC, Chest Loading and Femur Loading were individually modelled against the crashworthiness ratings or injury risk or injury severity. Such models give a measure of association between the crashworthiness measures and each ANCAP measure in isolation. The measures of association obtained from the univariate logistic regressions are directly comparable with the results of the correlation analyses presented above and serve as a means of verification of these results.

2. *Multivariate case aggregated logistic regression*: In this approach, the ANCAP measures HIC, Chest Loading and Femur Loading, along with first and higher order linear interactions between these measures were modelled against crashworthiness or its components simultaneously. A stepwise approach has been employed in order to build a model which best describes the crashworthiness ratings or components as a function of ANCAP measures, with only significant factors being included in the final model. This approach yields potentially different results to the univariate models described above as it takes into account possible association between the ANCAP measures and their interactions in describing real crash outcomes. A well fitting multivariate logistic model of this type provides a fully specified functional link between ANCAP measures and real crash outcomes as measured by crashworthiness ratings.

On application, these methods proved successful in providing a comprehensive set of results for comparison with the correlation analyses results as well as enabling models of the crashworthiness ratings and associated components to be built as functions of ANCAP test measures. The results of the two modelling approaches are detailed below.

### 5.4.1 Univariate Logistic Regression Models

Table 5 parts (A) to (C) detail the results of the univariate logistic regression analyses of crashworthiness and its components against the raw ANCAP scores HIC, Chest Loading and Femur Loading for both all crashes and two car head-on crashes. Parts (A) to (C) of Table 5 are directly comparable to the top three lines of the correlation analyses in table 3, parts (A) to (C). Only the raw ANCAP measures have been considered as the corresponding injury risk probability transformations are already calculated from a logistic relationship and hence would be inappropriate to further test after a double logistic transform. Each entry in Table 5 is the probability that the ANCAP measure has <u>no</u> association with real crash outcomes under the null hypothesis of no association between the two measures with low probabilities indicating significant relationships.

The results of the logistic regression analyses, detailed in Table 5, are broadly consistent with the results of the correlation analyses in measuring the relative strength of association of each ANCAP measure with the real crash outcomes considered. The relative ordering of significance probabilities in Tables 5 and 3 demonstrates this. Hence the results and conclusions drawn from the correlation analyses above have been broadly validated by this analysis. As before, the results from offset ANCAP testing have a much stronger association with real crash outcomes than do the results of full frontal ANCAP testing. For all crash types, the ANCAP test results have the strongest association with the injury risk component of the crashworthiness rating. Associations were generally slightly stronger between ANCAP results and two-car head-on crashes than with all crash types.

**Table 5:** Univariate logistic regression analysis of case aggregated crashworthiness ratings and their components against ANCAP measures.

**(A) P-VALUE FOR REGRESSION AGAINST FULL FRONTAL ANCAP TEST RESULTS**

| | All Crashes (28 Models) | | | 2 Car Head-on Crashes (22 Models) | | |
|---|---|---|---|---|---|---|
| | *Crash-worthiness Rating* | *Injury Severity* | *Injury Risk* | *Crash-worthiness Rating* | *Injury Severity* | *Injury Risk* |
| HIC | 0.3056 | **0.0929** | 0.7772 | 0.3043 | **0.0141** | 0.2156 |
| Chest G | 0.8832 | 0.4694 | 0.5625 | 0.2489 | 0.4417 | 0.3087 |
| Femload | **0.0871** | 0.8064 | **0.0011** | 0.3514 | 0.5706 | **0.0952** |

**(B) P-VALUE FOR REGRESSION AGAINST OFFSET ANCAP TEST RESULTS**

| | All Crashes (21 Models) | | | 2 Car Head-on Crashes (15 Models) | | |
|---|---|---|---|---|---|---|
| | *Crash-worthiness Rating* | *Injury Severity* | *Injury Risk* | *Crash-worthiness Rating* | *Injury Severity* | *Injury Risk* |
| HIC | **0.0034** | 0.1151 | **0.0004** | **0.0001** | **0.0287** | **0.0020** |
| Chest G | **0.0001** | **0.0658** | **0.0001** | **0.0001** | **0.0289** | **0.0001** |
| Femload | **0.0004** | **0.0680** | **0.0001** | **0.0016** | **0.0931** | **0.0088** |
| Lower Leg I | **0.0027** | 0.9561 | **0.0001** | **0.0586** | 0.4100 | **0.0851** |

**(C) P-VALUE FOR REGRESSION AGAINST FULL FRONTAL ANCAP TEST RESULTS FOR THE SAME VEHICLE MODELS ANALYSED IN TABLE 5 (B)**

| | All Crashes (21 Models) | | | 2 Car Head-on Crashes (15 Models) | | |
|---|---|---|---|---|---|---|
| | *Crash-worthiness Rating* | *Injury Severity* | *Injury Risk* | *Crash-worthiness Rating* | *Injury Severity* | *Injury Risk* |
| HIC | 0.3060 | 0.1616 | 0.8460 | 0.1162 | **0.0573** | 0.7140 |
| Chest G | 0.1281 | 0.5964 | **0.0104** | **0.0030** | 0.2501 | **0.0112** |
| Femload | 0.1013 | 0.2974 | **0.0620** | **0.0409** | 0.3488 | **0.0145** |

**NNN** = Statistically significant at the 1% level
**NNN** = Statistically significant at the 5% level
**NNN** = Statistically significant at the 10% level

### 5.4.2 Multivariate Logistic Regression Models

A forward inclusion, likelihood ratio based stepwise regression approach was used to fit the multivariate regression models of crashworthiness against ANCAP scores using the logistic regression procedure of the statistical package SAS. Using this approach it was hoped to build the best possible models describing crashworthiness and its components as a function of ANCAP scores including only terms in the final models which were significant predictors of real crash outcomes. Main effect terms included in the stepwise procedure, along with vehicle mass (in kg), were; full frontal ANCAP HIC, chest loading (in Gs) and femur loading (in kN) and offset ANCAP HIC, chest loading, femur loading and lower leg index. Linear first and higher order interactions between these main effect terms were also included. Linear interaction terms are obtained by simply multiplying the terms of the interaction being considered (eg: the first order linear interaction between HIC and chest loading = HIC *x* Chest Loading). As noted above, the crashworthiness ratings and components being modelled were already adjusted for the effects of driver age and sex, speed zone and number of vehicles involved meaning further consideration of these factors was not required.

Two sets of best fit models for crashworthiness, injury risk and injury severity were obtained; one for crashworthiness based on all crash types and one for crashworthiness based on two car head-on crashes. The resulting best fitting models are given here.

***All crash Types***

Execution of the forwards inclusion stepwise logistic regression routine in SAS produced the following best fitting model of all crash type crashworthiness ratings as a function of the variables selected from the full frontal and offset ANCAP measures and their interactions;

$$
\begin{aligned}
logit(CWR) = -3.0983 - 0.00058 \times (Vehicle\ Mass) \\
+ 0.00012 \times (Offset\, HIC \times OffsetLowerLeg\, Index)
\end{aligned}
$$

The stepwise regression routine estimated all crash type crashworthiness ratings to be best described by vehicle mass along with a first order interaction between offset ANCAP HIC and offset ANCAP lower leg index. Coefficients of each factor estimated for the best fitting model by the regression procedure are given in the equation above. The likelihood ratio test of goodness of fit of the final model showed it to be a satisfactory fit to the data (Chi-Squared = 12.4779, D.F. = 18, p-value = 0.8216: the higher the p-value, the better the fit). Notably, the next best fitting logistic model of all crash crashworthiness was a function of vehicle mass and full frontal ANCAP chest loading only (with positive correlation between full frontal chest loading and crashworthiness). This model was also a good fit to the data.

Predicted crashworthiness for a particular vehicle model from the logistic model obtained is calculated by substituting the ANCAP measures into the above formula and applying the reverse logistic transform which is defined as:

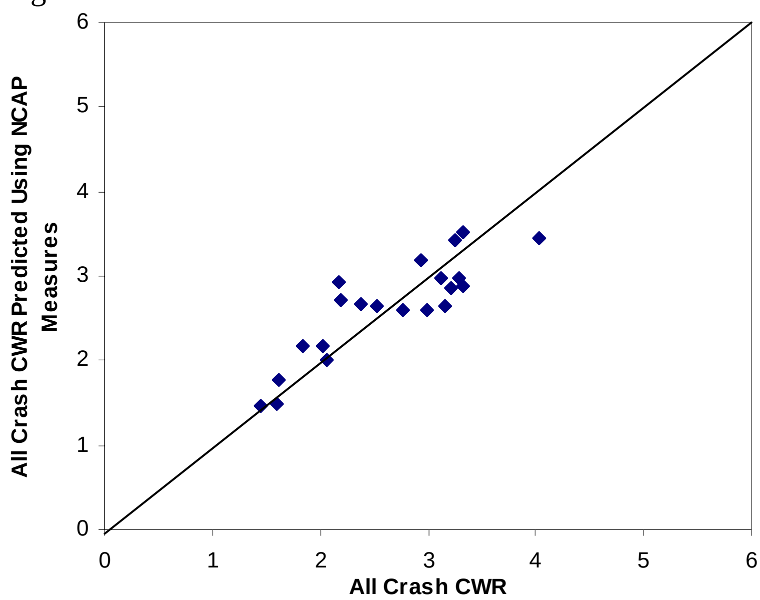
$$
CWR = \frac{\exp(\alpha)}{1 + \exp(\alpha)}
$$

$$
where \quad \alpha = \log it(CWR)
$$

Visual verification of the level of fit of the final model to the all-crash type crashworthiness ratings is displayed in Figure 2. Figure 2 plots the actual all crash crashworthiness ratings against the fitted values from the logistic model estimate shown above. Also shown on Figure 2 is the line of perfect fit along which all the points would be expected to lie if the logistic model was a perfect fit to the crashworthiness ratings. Appendix D shows figure 2 with the addition of 95% error bars for both the logistic model estimates and the actual crashworthiness ratings being modelled. Confidence limits for the crashworthiness ratings are taken from Newstead et al (1998).

Examination of Figure 2 shows the fitted values from the logistic model are quite close to the actual crashworthiness ratings, with most points lying quite close to the line of perfect fit. Appendix D shows that for all of the 21 models included in the analysis, the line of perfect fit lies within the 95% confidence limit of either the actual crashworthiness rating or the logistic model estimate. This means the logistic model estimate and the original crashworthiness ratings are consistent within the bounds of their respective estimation errors.

**Figure 2** : All crash crashworthiness ratings vs. predicted values from logistic model using ANCAP scores




Whilst the above analysis has produced a model of crashworthiness ratings for all crash types as a function of ANCAP scores, it is also of interest to build separate models of the two components of the crashworthiness ratings as a function of ANCAP scores. Given the results of the correlation analysis above it might be expected that the best fitting models for each of the crashworthiness rating components would be quite different in terms of the ANCAP measures included to that describing the crashworthiness ratings themselves.

The best fitting model of injury risk for all crash types arrived at by the forward stepwise regression procedure is given by;

$$
\begin{aligned}
logit(Injury\,Risk) = &-1.7704 - 0.00038 \times (Vehicle\,Mass) \\
&+ 0.000000000704 \times (FFHIC \times FFChest\ Loading \times FFFemur\ Loading) \\
&+ 0.000202 \times (OSHIC \times OSLower\ Leg\ \ Index) \\
&+ 0.000000000057 \times (OSHIC \times OSChest\,Loading \times OS\,Femur\,Loading)
\end{aligned}
$$

Injury risk was best described as a function of the interaction between full frontal ANCAP HIC, chest loading and femur loading, the interaction between offset ANCAP HIC and lower leg index, as well as the interaction between offset HIC, chest loading and femur loading. Vehicle mass was also a significant predictor of injury risk in the final model. Although the likelihood ratio test of goodness of fit of the final model showed it to be a satisfactory fit to the data (Chi-Squared = 22.4609, D.F. = 16, p-value = 0.1305) the fit was not quite as good as the model for crashworthiness ratings above or injury severity below.

The best fitting model of injury severity for all crash types arrived at by the forward stepwise regression procedure is given by;

$$logit(Injury\,Severity) = -\,0.9434 - 0.00032 \times (Vehicle Mass)$$

As evident, none of the ANCAP measures proved to be a significant predictor of real crash injury severity after inclusion of the vehicle mass effect which was the dominant predictor. The likelihood ratio test of goodness of fit of the final model, however, showed it to be a satisfactory fit to the data (Chi-Squared = 13.8910, D.F. = 19, p-value = 0.7900).

***Two Car Head on Crashes***

A forward stepwise logistic regression routine was again executed in SAS to produce the following best fitting model of two car head-on crashworthiness ratings as a function of the variables selected from the full frontal and offset ANCAP measures and their interactions;

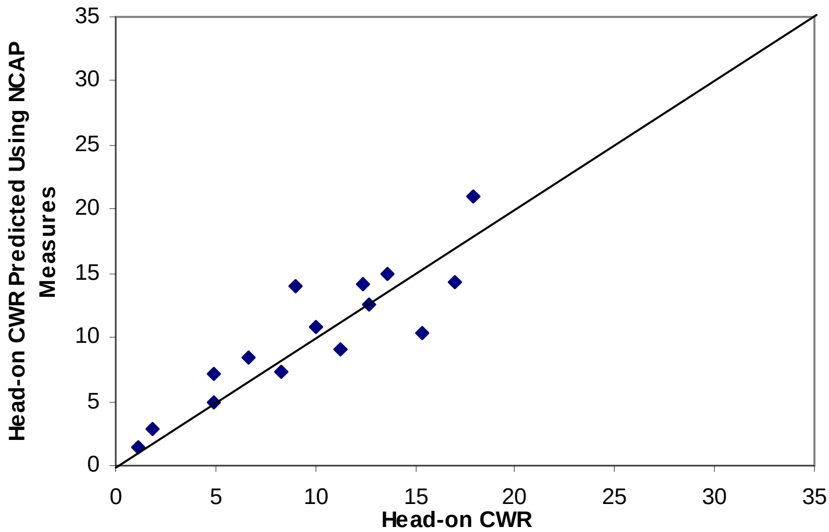
$$
\begin{aligned}
logit\ (CWR\ ) = &-2.4397\ - 0.00169\ \times (Vehicle\ \ Mass\ ) \\
&+ 0.0345\ \times (Full\ Frontal\ \ Chest\ \ Loading\ \ )
\end{aligned}
$$

The stepwise logistic regression routine estimated two car head-on crashworthiness ratings to be best described by vehicle mass and full frontal ANCAP chest loading. Coefficients of each factor estimated for the best fitting model by the regression procedure are given in the equation above. The likelihood ratio test of goodness of fit of the final model suggested it to be a satisfactory fit to the data (Chi-Squared = 8.9501, D.F. = 12, p-value = 0.7072).

Visual verification of the level of fit of the final model to the two car head-on crashworthiness ratings is displayed in Figure 3 which again shows the actual head-on crash crashworthiness ratings against the fitted values from the logistic model estimate shown above. Figure 3 also shows the line of perfect fit along which all the points would be expected to lie if the logistic model was a perfect fit to the crashworthiness ratings. Appendix D shows figure 3 with the addition of 95% error bars for both the logistic model estimates and the actual crashworthiness ratings being modelled. Confidence limits for the crashworthiness ratings are taken from Appendix A.

Examination of Figure 3 shows similar concordance between the fitted values from the logistic model and the actual two car head-on crashworthiness ratings to that observed for all crash types. Again, as shown in Appendix D, the line of perfect fit passes within the 95% confidence band of either the logistic model estimates or the actual crashworthiness ratings for all points, showing the logistic model as a function of ANCAP scores is a consistent predictor of the crashworthiness ratings.

**Figure 3** : Two car head-on crashworthiness ratings vs. predicted values from logistic model using ANCAP scores




Separate models were again estimated for two-car head-on crash injury risk and injury severity. The best fitting model of injury risk for two car head on crashes arrived at by the forward stepwise regression procedure is given by;

$$\begin{aligned} logit(Injury Risk) = & -2.2557 - 0.00074 \times (Vehicle\ Mass) + 0.0153 \times (FF\ Chest Loading) \\ & + 0.0291 \times (OSChest\ Loading) \\ & - 0.00000412 \times (OSChest\ Loading \times OSFemur\ Loading) \end{aligned}$$

Two car head-on crash injury risk was best described as a function of both full frontal and offset ANCAP chest loading along with the interaction between offset ANCAP chest and femur loading. Vehicle mass was again a significant predictor of injury risk in the final model. The likelihood ratio test of goodness of fit of the final model showed it to be a satisfactory fit to the data (Chi-Squared = 7.5104, D.F. = 11, p-value = 0.7564).

The best fitting model of injury severity for two car head-on crashes arrived at by the forward stepwise regression procedure is given by;

$$logit(Injury Severity) = 0.7112 - 0.00121 \times (Vehicle\ Mass)$$

As for all crash types, the regression procedure showed no ANCAP measures to be significant predictors of real crash injury severity. Vehicle mass was the only predictor to enter the model. The likelihood ratio test of goodness of fit of the final model, however, showed it to be a reasonable fit to the data (Chi-Squared = 8.8364, D.F. = 13, p-value = 0.7852).

### 5.5 INJURY PATTERNS IN TAC CLAIMS

Interrogation of the Victorian crash data revealed 2982 observations of driver injury in the 28 ANCAP tested vehicles. The number of cases by model is given in Table 6.

**Table 6 :** Number of drivers injured in the 28 ANCAP tested cars by model identified in the Victorian crash data file.

| Make/model with Crashworthiness Rating based on 1987-96 crashes and tested in the ANCAP program | Number of identifiable observations in Victorian crash data file 1987-96 |
|---|---|
| Daihatsu Charade 1994-96 | 14 |
| Ford Falcon EF 1994-96 | 104 |
| Ford Falcon EB Series 2 & ED 1992-94 | 156 |
| Ford Festiva WB 1994-96 | 25 |
| Ford Laser KF/KH 1991-94 | 129 |
| Holden Barina 1989-94 | 146 |
| Holden Commodore VR/VS 1993-96 | 194 |
| Holden Commodore VN/VP 1988-93 | 640 |
| Honda Civic 1992-95 | 30 |
| Hyundai Excel 1990-94 | 139 |
| Hyundai Excel 1995-96 | 36 |
| Hyundai Lantra 1991-95 | 26 |
| Mazda 121 1991-96 | 72 |
| Mazda 626 1992-96 | 57 |
| Mitsubishi Lancer CC 1995-96 | 28 |
| Mitsubishi Magna TR/TS 1991-94 | 163 |
| Nissan Patrol / Ford Maverick 1988-96 | 32 |
| Nissan Pintara 1989-92 | 107 |
| Nissan Pulsar 1992-95 | 66 |
| Subaru Liberty 1989-94 | 43 |
| Suzuki Vitara 1988-96 | 13 |
| Toyota Camry 1987-92 | 353 |
| Toyota Camry 1993-96 | 65 |
| Toyota Corolla 1988-94 | 294 |
| Toyota Corolla 1995-96 | 25 |
| Toyota Landcruiser 1990-96 | 20 |
| Toyota Tarago 1983-90 | 1 |
| Toyota Tarago 1991-96 | 4 |

Because the number of cases for a few of the models listed in Table 6 was limited, it was decided to exclude those with 30 or less cases of driver injury before proceeding with the analysis using the methods described in section 4.5. This left 19 vehicle models with full frontal ANCAP scores and 12 vehicle models with both full frontal and offset ANCAP scores for analysis. The ICDMAP program was used to produce maximum AIS scores by body region from the coded driver injury data for each of the 2826 remaining cases available for analysis. For each vehicle model, the average maximum AIS score for each of the head, chest and leg regions was calculated using a simple arithmetic average over the drivers injured in each model.

Tables 7 and 8 summarise the maximum AIS scores against the corresponding ANCAP readings (HIC, Chest Loading and Femur Loading) for each of the three body regions for each vehicle model for full frontal and offset ANCAP results respectively. Also included at the bottom of these tables is the correlation between each ANCAP measure and the corresponding average maximum AIS score as a measure of the association between the two variables.

**Table 7:** Full Frontal ANCAP Test Results and Average Maximum AIS Scores By Body Region For 19 ANCAP Tested Models.

| BODY REGION | | HEAD | | CHEST | | FEMUR | |
|---|---|---|---|---|---|---|---|
| **MODEL** | **No. Cases** | **ANCAP HIC** | **Av. Max. AIS** | **ANCAP Chest G** | **Av. Max. AIS** | **ANCAP Femur L** | **Av. Max. AIS** |
| CIVIC (92-95) | 30 | 1456 | 0.00 | 63 | 0.13 | 3.20 | 0.23 |
| NISSAN PATROL (88-90) | 32 | 1750 | 0.19 | 67 | 0.13 | 2.80 | 0.06 |
| HYUNDAI EXCEL (95-96) | 36 | 1411 | 0.22 | 60 | 0.11 | 2.60 | 0.08 |
| SUBARU LIBERTY (89-94) | 43 | 1360 | 0.09 | 58 | 0.16 | 3.90 | 0.21 |
| MAZDA 626/MX6 (92-94) | 57 | 1160 | 0.14 | 60 | 0.35 | 2.60 | 0.26 |
| TOYOTA CAMRY (93-96) | 65 | 1040 | 0.09 | 61 | 0.20 | 1.90 | 0.08 |
| NISSAN PULSAR (92-95) | 66 | 1464 | 0.15 | 50 | 0.29 | 4.80 | 0.11 |
| MAZDA 121 (91-96) | 72 | 1525 | 0.11 | 61 | 0.21 | 4.70 | 0.22 |
| FORD FALCON EF (94-96) | 104 | 910 | 0.27 | 74 | 0.18 | 7.40 | 0.23 |
| NISSAN PINTARA (89-92) | 107 | 1750 | 0.11 | 64 | 0.26 | 2.40 | 0.20 |
| FORD LASER (91-94) | 129 | 1903 | 0.20 | 68 | 0.25 | 8.60 | 0.26 |
| HYDAI EXCEL (90-94) | 139 | 1318 | 0.20 | 54 | 0.14 | 3.60 | 0.19 |
| BARINA (89-93) | 146 | 1005 | 0.14 | 59 | 0.25 | 3.90 | 0.16 |
| FORD FALCON EB SERIES II (92-94) | 156 | 1340 | 0.11 | 74 | 0.16 | 6.00 | 0.15 |
| MITSUBITSHI MAGNA TR/TS (91-95) | 163 | 1140 | 0.08 | 60 | 0.15 | 3.80 | 0.15 |
| HOLDEN COMMODORE VR/VS (93-96) | 194 | 1170 | 0.08 | 51 | 0.15 | 3.20 | 0.15 |
| TOYOTA COROLLA (90-94) | 294 | 1499 | 0.13 | 60 | 0.21 | 9.40 | 0.19 |
| TOYOTA CAMRY (88-92) | 353 | 1090 | 0.08 | 63 | 0.28 | 3.90 | 0.15 |
| HOLDEN COMMODORE VN/VP (87-93) | 640 | 1690 | 0.19 | 82 | 0.21 | 1.20 | 0.16 |
| **CORRELATION ANALYSES** | | **HIC with Av. Max. AIS to HEAD** | | **CG with Av. Max. AIS to CHEST** | | **FL with Av. Max. AIS to LEGS** | |
| **All Models** | | 0.12 (p=0.3148) | | -0.06 (p=0.5949) | | 0.40 (p=0.0451) | |

Examination of Table 7 shows strong statistically significant association between full frontal ANCAP femur loading readings and average maximum AIS to the leg region in real crashes for the 19 models included in the analysis. Appendix E shows a plot of maximum AIS to the leg region in real crashes against full frontal ANCAP femur loading. Whilst table 7 also shows indication of a weak association between HIC and real crash head injury severity for this ANCAP test configuration, the result is not statistically significant. No association between full frontal ANCAP chest loading and maximum AIS to the chest region in real crashes was observed. These results are not entirely consistent with those of the correlation analysis above that show full frontal ANCAP chest loading to have the strongest association with real crash outcomes. These results are, however, consistent with both the univariate and multivariate logistic regression analyses that found femur loading and HIC, or their interaction, to be significant predictors of real crash outcomes.

Table 8 shows a strong statistically significant association between the offset ANCAP chest loading and average maximum AIS to the chest in real crashes for the 12 car models for which offset scores are available. No association was found between ANCAP and real crash measures for the head or leg regions. These results are generally consistent with the results of the correlation analyses presented where offset ANCAP chest loading was the raw measure with the strongest association with real crash outcomes, confirming those results with a more detailed and specific method of analysis. A plot of offset ANCAP scores versus average maximum AIS score to the chest appears in Appendix E.

**Table 8:** Offset ANCAP Test Results and Average Maximum AIS Scores By Body Region For 12 ANCAP Tested Models.

| BODY REGION | | HEAD | | CHEST | | FEMUR | |
|---|---|---|---|---|---|---|---|
| **MODEL** | **No. Cases** | **ANCAP HIC** | **Av. Max. AIS** | **ANCAP Chest G** | **Av. Max. AIS** | **ANCAP Femur L** | **Av. Max. AIS** |
| CIVIC (92-95) | 30 | 623 | .03 | 40 | .13 | 1.30 | .23 |
| NISSAN PATROL (88-90) | 32 | 897 | .00 | 37 | .13 | 4.60 | .06 |
| HYUNDAI EXCEL (95-96) | 36 | 1270 | .06 | 49 | .11 | 4.70 | .08 |
| TOYOTA CAMRY (93-96) | 65 | 640 | .03 | 42 | .20 | 3.50 | .08 |
| NISSAN PULSAR (92-95) | 66 | 2161 | .03 | 78 | .29 | 18.00 | .11 |
| MAZDA 121 (91-96) | 72 | 1566 | .01 | 69 | .21 | 7.40 | .22 |
| FORD FALCON EF (94-96) | 104 | 596 | .11 | 53 | .18 | 3.70 | .23 |
| FORD LASER (91-94) | 129 | 3234 | .07 | 84 | .25 | 11.20 | .26 |
| HYDAI EXCEL (90-94) | 139 | 1195 | .06 | 58 | .14 | 4.90 | .19 |
| BARINA (89-93) | 146 | 1213 | .03 | 56 | .25 | 8.30 | .16 |
| HOLDEN COMMODORE VR/VS (93-96) | 194 | 730 | .09 | 37 | .15 | 2.60 | .15 |
| TOYOTA COROLLA (90-94) | 294 | 1024 | .06 | 52 | .21 | 6.20 | .19 |
| **CORRELATION ANALYSES** | | **HIC with Av. Max. AIS to HEAD** | | **CG with Av. Max. AIS to CHEST** | | **FL with Av. Max. AIS to LEGS** | |
| **Models with offset ANCAP scores** | | -0.04 (p=0.5478) | | 0.74 (p=0.0022) | | -0.01 (p=0.5120) | |

# 6. DISCUSSION

Analysis completed under this project further investigates the relationship between ANCAP test results and the outcomes of real crashes, adding to the work of Newstead and Cameron (1997) by including two additional years of real crash data. This has also allowed eight extra vehicle models to be included in the analysis. Again, the analysis is staged to give a graduated understanding of the relationship between ANCAP barrier test results and real crash outcomes.

The basic correlation analysis is the first stage of the investigation that establishes the presence and relative level of association between ANCAP measures and real crash outcomes. A number of results from the correlation analysis are noteworthy. As found by Newstead and Cameron (1997), a consistently stronger association was observed here between offset ANCAP test results and real crash outcomes, than between full frontal ANCAP scores and real crash outcomes. One possible reason for this may be that the offset ANCAP test configuration is more demanding of vehicle structural integrity, which may be the factor that affects injury protection performance in the full range of real life crashes.

Stronger association was also found between real crash injury severity and ANCAP test results when considering head on crashes whilst strong association between injury severity and offset ANCAP measures was also found for all crash types. This relationship possibly arises because of the relative severity of the ANCAP test configuration impact. For real crashes of the severity of the ANCAP configuration, the likelihood of injury is quite high (ie: injury risk, see Fildes et al 1991, Chapter 5), and hence the differentiating factor of interest is the relative injury severity between vehicle models. This result is also consistent with the hypotheses presented by Cameron et al (1992b) who suggested that injury severity is largely a function of vehicle design whilst injury risk is strongly affected by vehicle mass, a relationship also confirmed by the analyses presented here. There is however association between real crash injury risk and ANCAP test results, particularly for offset ANCAP and all crash types, suggesting the relationships and mechanisms are somewhat more complex than those suggested above.

The slightly stronger association found between two-car head on crashes and ANCAP measures is as expected given the similarity in crash configuration and again follows the findings of Newstead and Cameron (1997). The ANCAP program itself claims to only represent injury risk in fontal crash configurations (NCAP 1994a,b) whilst similar studies to this conducted in the United States also found stronger relationships with real-world frontal crashes. However, it is the correlation of ANCAP measures with the outcomes of crashes of all types that is likely to be of primary interest to the consumer. Hence the good correlation between the offset ANCAP measures and the crashworthiness ratings based on all crash types is important.

General confirmation of the results of the correlation analyses was made by the results of univariate logistic regression analyses. The univariate logistic regression results validate the results of correlation analyses for basic ANCAP measures but under an alternative and more rigorous framework of statistical testing indicating the robustness of the findings.

Results achieved from multivariate logistic regression modelling provide perhaps the strongest and most useful link between real crash outcomes and ANCAP measures. With these results, it has been possible to express reasonably accurately real crash outcomes, as measured by crashworthiness ratings, as a function of ANCAP measures whilst adjusting for the co-dependency between ANCAP measures themselves. Importantly, the results obtained were particularly good for all crash types even though ANCAP supposedly represents injury likelihood for frontal impacts only.

It should be noted in examining the best fitting models of crashworthiness or its components as a function of ANCAP measures, that typically not all ANCAP measures that showed strong correlation with real crash outcomes appear in the best fitting model. Some ANCAP measures do not appear in these models even though they have a strong correlation with the real crash measure in a univariate analysis because of high colinearity between the ANCAP measures. For example, say both HIC and chest loading have a strong association with a real crash measure but only one of these is required in a multivariate regression model because high HIC values were for, the example purposes, associated with high chest loadings for all cases included in the model. It would be possible to build models including all ANCAP measures as predictors. In these models, however, the estimated coefficients of many of the terms would probably not be statistically significantly different from zero (implying no predictive power of the factor) and the level of fit of the model may be compromised by the loss of extra degrees of freedom.

Ideally, the logistic regression models of crashworthiness and its components as a function of ANCAP measures arrived at in the original study by Newstead and Cameron (1997) would be the same as those estimated here. There are, however, a number of differences between the multivariate logistic regression models estimated here and in the original work. In the case of all six logistic models of crashworthiness and its components estimated, the combination of factors included in the best fitting model has changed since the original study. Despite this, there is a general consistency in the combination of ANCAP measures that have been included in each model. For example, crashworthiness based on all crash types is still best described by a combination of offset ANCAP measures whilst crashworthiness for head on crashes is best described as a function of full frontal ANCAP chest loading. Corresponding similarities exist between the other models.

Vehicle mass did not appear as a predictor in the multivariate logistic models of crashworthiness based on all crash types as a function of ANCAP measures estimated by Newstead and Cameron (1997). This was noted as being unusual given the relationships found between crashworthiness and vehicle mass when considering all models for which a crashworthiness rating had been estimated. Vehicle mass appears as a significant predictor in all the multivariate logistic models estimated here. This is as expected given the relationships between crashworthiness and its components established in section 5.2 except for the model of injury severity based on all crash types. Mass was not found to be a significant predictor of injury severity in section 5.2 when considering all vehicles with a crashworthiness rating, although mass was the sole predictor in the estimated multivariate logistic model fitted to only ANCAP tested vehicles. This suggests that the analysed sample of vehicle models with

ANCAP test results is perhaps not representative of all cars when considering injury severity based on all crash types. The multivariate logistic models of injury severity were also unusual in that they only included vehicle mass as a predictor in the best fitting model even though some of the strongest associations in the correlation analysis were observed between offset ANCAP measures and injury severity. The reasons for this are unclear and would require more investigation to establish.

The fact that the multivariate logistic regression models have changed from one study to the next, along with the noted possible inconsistencies in the model estimated here, highlights the importance of ongoing investigation of this relationship. This will allow more vehicle models to be continually included until the factors included in the best fitting logistic regression models converge to a consistent state.

Results of the multivariate logistic regression analysis provide a functional link to directly convert the results of ANCAP testing into an estimate of crashworthiness rating consistent with that obtained from real crash data. The explicit functional relationship obtained could be used as an alternative ANCAP single index rating to the one currently being published by ANCAP. It should be noted however, that the old and proposed alternative single index represent two different estimates of risk and are hence not directly comparable. The old single index rating represents the risk of AIS 4 or greater injury in a crash of ANCAP configuration and severity. The new single index provides an estimate of crashworthiness and is hence a measure of the risk of driver death or serious injury given involvement in a crash of at least tow-away severity. Use of the new single index developed from the results offers the potential to unify both ANCAP and crashworthiness vehicle safety rating systems under a common measure to provide consistent consumer information on relative vehicle safety.

Whilst the relationships between ANCAP measures and real crash outcomes developed using multivariate logistic regression techniques appear promising, it should be remembered that the current results are based on data from only 21 vehicle models. Further validation and calibration of these relationships should be carried out as more real crash data becomes available for vehicle models with ANCAP test results.

Results of the detailed injury analysis of the TAC insurance claims were less conclusive than that described in Newstead and Cameron (1997), with the measured correlations being weaker and relatively few of them statistically significant. As in the earlier work, the detailed body region analysis for full frontal ANCAP scores found strongest relationship between the leg region measures. The relationship between the head measures previously found when considering full frontal ANCAP scores was not found here. Newstead and Cameron (1997) found significant association between offset ANCAP test results and real crash injury levels for all body regions. The work here however found only significant and strong association for the chest region. This is, however, consistent with the results of the multivariate logistic modelling of crashworthiness based on all crashes against ANCAP scores obtained here.

It should be noted in interpreting the detailed injury analysis that whilst the significant correlation results imply an overall association between the measures compared, it does not mean that high ANCAP measures will always be reflected in poor crashworthiness performance for each vehicle model examined. Examination of the plots of ANCAP measures against average maximum AIS in Appendix E show significant dispersion about the line of perfect correlation with a number of apparent outliers being observed. The tabulated values in Tables 7 and 8 also reflect this. Consequently, care is needed in trying to predict actual injuries from ANCAP results based on data from an individual case.

To a certain degree, the detailed body region analyses have provided a more specific link between ANCAP measures and real crash injury outcomes by relating outcomes by specific body regions, although not to the same degree as was shown in the previous analysis. It should be remembered that these results pertain to all real crash types and it is likely that associations for specific crash type would be stronger if sufficient data were available to allow such analyses. Given this and the reduction in significance between this study and the last, it is considered important to update this analysis in the future with more data in order to continue to investigate these important relationships.

The level of association between ANCAP test results and real crash outcomes found in the original study of Newstead and Cameron (1997) has been further validated in this study. The results here, however, have still been obtained from a relatively small sample of vehicles. The strength and general applicability of these results would be further enhanced by inclusion of more ANCAP tested vehicle models in the analysis. Inclusion of a greater number of vehicle models in the analysis should be possible with continued collection and inclusion of current crash data for use in the analysis methods developed for this study. Future improvement that is promised by the inclusion of more crash data serves as the basis for recommendation of future updates of this project.

# 7. CONCLUSIONS

This project re-investigates the relationship between ANCAP test results and data from real crashes in assessing relative occupant protection originally studied by Newstead and Cameron (1997). The results of correlation of ANCAP test results with real crash outcomes as measured by crashworthiness ratings suggest a number of relationships. Firstly, whilst the results from full frontal ANCAP testing have some association with real crash outcomes, the associations between offset ANCAP testing and real crashes are much stronger. The ANCAP test results and their associated measures have equally strong association with both the injury risk and injury severity components of the crashworthiness rating when considering all crash types, and the injury severity component of crashworthiness when considering two-car head-on crashes. Correlations were generally stronger between ANCAP results and two-car head-on crashes than with all crash types but this difference was not large. Mass adjustment of the ANCAP probability measures also improved their relationship with real crash outcomes.

Capitalising on these relationships, logistic regression techniques were able to successfully build accurate models of crashworthiness ratings and its components as a function of ANCAP measures providing a direct functional relationship between the two programs as compatible and consistent measures of relative vehicle occupant protection.

Detailed analysis of injury data by body region broadly confirmed the results of the correlation analysis and was consistent with results of logistic regression modelling estimated using a more detailed and specific method of analysis. The relationships found, however, were not as strong as in the original study of Newstead and Cameron (1997). A strong statistically significant association was found between full frontal ANCAP femur loading readings and average maximum AIS to the leg region in real crashes along with a strong statistically significant association between the offset ANCAP chest loading and average maximum AIS to the chest in real crashes.

# 8. FURTHER WORK RECOMMENDED

**Re-analysis after inclusion of further years' crash data**

Analysis presented in this report gives strong indication of the existence of relationships between the results of ANCAP testing and the outcomes of real crashes, even more so than the work of Newstead and Cameron (1997). Addition of further years' crash data from both Victoria and NSW, and potentially other states, would continue to enhance the results from the analysis methods used in this report and further hone the understanding of the relationship being investigated. It may also be possible, and highly desirable, to include NCAP tests results and real crash outcome measures from other countries, particularly the USA.

This would allow more vehicle models for comparison than the current 28 with full frontal ANCAP test results (including 21 with offset ANCAP test results) compared in this study. In addition it would allow the comparison measures used in this report to be calculated with still greater precision. This includes more precise calculation of crashworthiness ratings for two car, head on crashes as well as enhancing the accuracy of the detailed analysis of injury patterns in real crashes. It would also serve to strengthen the relationships established in the multivariate logistic regression analyses that are important in defining a consistent and functional link between the two different vehicle safety rating systems.

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# APPENDIX A

# CRASHWORTHINESS RATINGS FOR TWO LIGHT VEHICLE, HEAD ON CRASHES

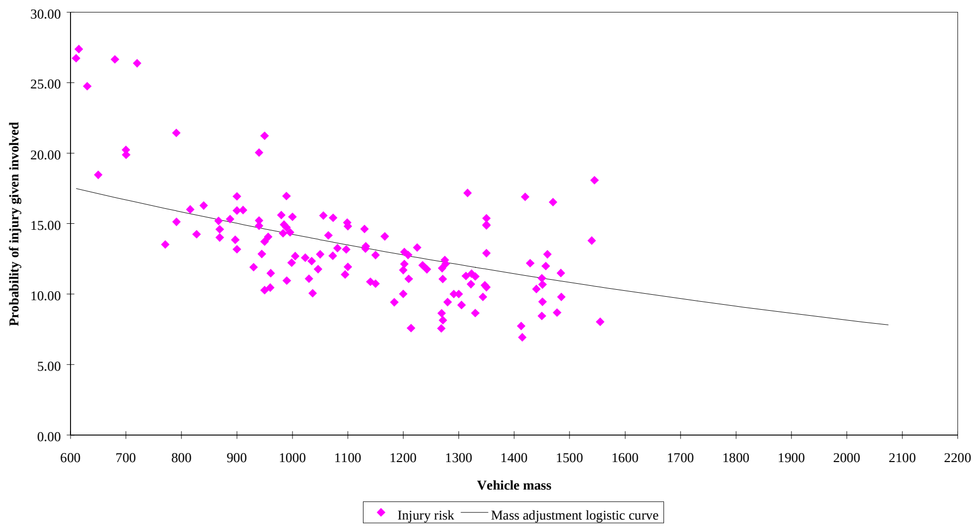
2 CAR HEAD ON CWR
for NSW - VIC (87-96)

| Model of car | Pr(risk) | Pr(severe) | TWO CAR HEAD-ON CRASHWORTHINESS RATINGS | | | |
|---|---|---|---|---|---|---|
| | | | Serious injury rate per 100 drivers involved | Lower 95% CI | Upper 95% CI | Width of CI |
| **ALL MODEL AVERAGE** | **27.81** | **33.37** | **9.28** | **8.95** | **9.61** | **0.66** |
| LANCRUISER >=90 | 18.34 | 6.25 | 1.15 | 0.00 | 3.06 | 3.06 |
| MAVERICK / PATROL 88-96 | 11.75 | 16.01 | 1.88 | 0.00 | 3.78 | 3.78 |
| LANCRUISER <=89 | 12.85 | 32.33 | 4.15 | 1.95 | 6.35 | 4.40 |
| COMMODORE/LEXCEN VR/VS | 17.34 | 28.15 | 4.88 | 2.72 | 7.04 | 4.33 |
| FALCON ED/EB S2 | 24.88 | 19.82 | 4.93 | 2.44 | 7.42 | 4.99 |
| PULSAR 92-95 | 18.38 | 26.85 | 4.94 | 0.48 | 9.39 | 8.90 |
| NISSAN 720 UTE | 26.40 | 18.89 | 4.99 | 0.93 | 9.04 | 8.11 |
| FALCON PANEL VAN | 28.53 | 19.47 | 5.56 | 1.49 | 9.63 | 8.14 |
| 4RUNNER/HILUX | 20.59 | 27.79 | 5.72 | 3.90 | 7.54 | 3.65 |
| SUBARU 1800/LEONE | 21.44 | 27.00 | 5.79 | 3.49 | 8.08 | 4.59 |
| NISSAN XFN UTE/FALCON UTE | 21.37 | 27.19 | 5.81 | 3.10 | 8.52 | 5.42 |
| NAVARA | 25.08 | 24.63 | 6.18 | 2.27 | 10.08 | 7.81 |
| FALCON EF | 28.23 | 23.40 | 6.61 | 2.67 | 10.54 | 7.87 |
| FALCON EA/EB S1 | 26.52 | 26.42 | 7.01 | 5.55 | 8.47 | 2.92 |
| HOLDEN WB SERIES | 22.22 | 35.54 | 7.90 | 2.77 | 13.02 | 10.25 |
| MAGNA TM-TP | 24.22 | 32.99 | 7.99 | 6.47 | 9.51 | 3.04 |
| APPOLO / CAMRY >=93 | 28.97 | 28.56 | 8.27 | 4.51 | 12.04 | 7.53 |
| FALCON XD-XF | 26.59 | 31.56 | 8.39 | 7.49 | 9.29 | 1.80 |
| RODEO | 22.53 | 38.15 | 8.60 | 3.94 | 13.25 | 9.32 |
| TELSTAR/MAZDA 626 >=92 | 23.94 | 36.20 | 8.66 | 2.97 | 14.36 | 11.39 |
| TR/TS MAGNA/ KR\KS VERADA | 32.07 | 27.34 | 8.77 | 5.17 | 12.36 | 7.19 |
| FAIRLANE Z&LTD F 82-87 | 24.80 | 36.07 | 8.95 | 5.59 | 12.30 | 6.72 |
| FESTIVA WB 94-96 | 20.06 | 44.95 | 9.02 | 0.61 | 17.42 | 16.82 |
| TELSTAR/MAZDA 626 88-91 | 30.89 | 29.93 | 9.25 | 5.26 | 13.23 | 7.96 |
| COMMODORE VB-VL | 28.52 | 33.00 | 9.41 | 8.30 | 10.52 | 2.22 |
| PINTARA <=88 | 23.14 | 41.21 | 9.54 | 4.93 | 14.14 | 9.21 |
| LIBERTY <=94 | 25.82 | 37.19 | 9.61 | 3.08 | 16.13 | 13.04 |
| GEMINI 75-84 | 32.38 | 29.67 | 9.61 | 6.56 | 12.66 | 6.10 |
| COMMDORE/LEXCEN VN/VP | 26.56 | 36.43 | 9.68 | 8.10 | 11.25 | 3.16 |
| BLUEBIRD RWD | 27.86 | 35.31 | 9.84 | 7.59 | 12.08 | 4.49 |
| CORONA | 30.95 | 32.11 | 9.94 | 7.90 | 11.98 | 4.08 |
| NOVA/COROLLA 88-93 | 27.54 | 36.37 | 10.01 | 7.13 | 12.90 | 5.77 |
| SKYLINE | 28.58 | 35.16 | 10.05 | 6.06 | 14.04 | 7.98 |
| HIACE/LITEACE | 28.13 | 36.49 | 10.27 | 6.81 | 13.72 | 6.90 |
| CORSAIR / PINTARA FWD | 23.21 | 45.24 | 10.50 | 6.40 | 14.59 | 8.19 |
| BMW 3 82-91 | 31.62 | 33.31 | 10.53 | 4.95 | 16.12 | 11.17 |
| TELSTAR/MAZDA 626 83-87 | 34.38 | 31.34 | 10.77 | 8.81 | 12.73 | 3.92 |
| APPOLO / CAMRY 88-92 | 30.05 | 36.03 | 10.83 | 8.47 | 13.18 | 4.72 |
| COROLLA 81-84 | 35.56 | 30.96 | 11.01 | 8.24 | 13.78 | 5.54 |
| TARAGO 83-89 | 27.62 | 40.76 | 11.26 | 6.39 | 16.12 | 9.73 |
| SIGMA/SCORPION | 30.65 | 36.80 | 11.28 | 9.04 | 13.52 | 4.48 |
| LASER METEOR/MAZDA 323 82-89 | 33.87 | 33.50 | 11.35 | 10.01 | 12.69 | 2.68 |
| CAMIRA | 36.53 | 31.66 | 11.56 | 9.73 | 13.40 | 3.66 |
| ASTRA/PULSAR 88-94 | 29.00 | 40.11 | 11.63 | 8.46 | 14.80 | 6.34 |
| COROLLA 86-88 | 36.56 | 32.57 | 11.91 | 9.11 | 14.70 | 5.59 |
| SUZUKI SIERRA | 32.73 | 36.53 | 11.96 | 5.89 | 18.03 | 12.14 |
| COLT | 36.29 | 33.05 | 11.99 | 9.18 | 14.81 | 5.63 |
| BARINA/SWIFT 85-88 | 26.18 | 46.86 | 12.27 | 7.28 | 17.25 | 9.97 |
| MAZDA 121 >=91 | 33.34 | 37.23 | 12.41 | 5.12 | 19.70 | 14.58 |
| CIVIC 92-95 | 28.20 | 45.01 | 12.69 | 2.12 | 23.27 | 21.15 |
| ASTRA/PULSAR 84-86 | 36.00 | 35.83 | 12.90 | 10.12 | 15.68 | 5.55 |
| MAZDA 929 82-90 | 31.54 | 42.49 | 13.40 | 7.60 | 19.20 | 11.60 |
| BARINA/SWIFT 89-93 | 34.41 | 39.53 | 13.60 | 8.80 | 18.41 | 9.61 |
| EXCEL 90-94 | 35.10 | 43.69 | 15.34 | 8.01 | 22.67 | 14.66 |
| NISSAN COMMERCIAL VANS | 28.26 | 58.46 | 16.52 | 9.22 | 23.83 | 14.61 |
| MITSUBISHI PASS VAN | 38.62 | 43.79 | 16.91 | 12.59 | 21.24 | 8.65 |
| LASER 91-94 | 41.50 | 40.91 | 16.98 | 10.97 | 22.98 | 12.01 |
| VITARA | 40.75 | 43.84 | 17.87 | 5.36 | 30.38 | 25.02 |
| CHARADE 88-92 | 41.09 | 45.54 | 18.71 | 11.75 | 25.67 | 13.92 |

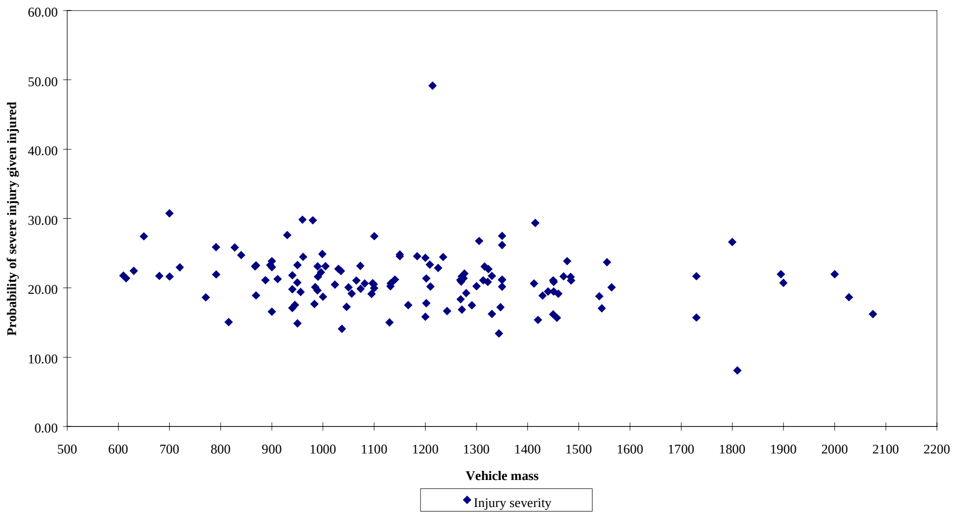
# APPENDIX B

# VEHICLE MASS EFFECTS IN CRASHWORTHINESS RATINGS

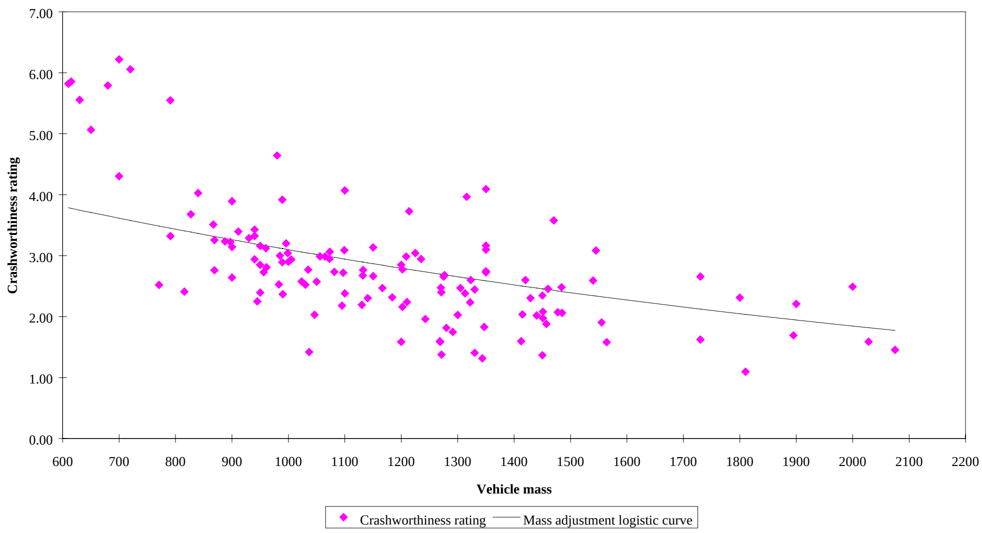
## INJURY RISK vs VEHICLE MASS
FOR ALL TYPES OF CRASHES

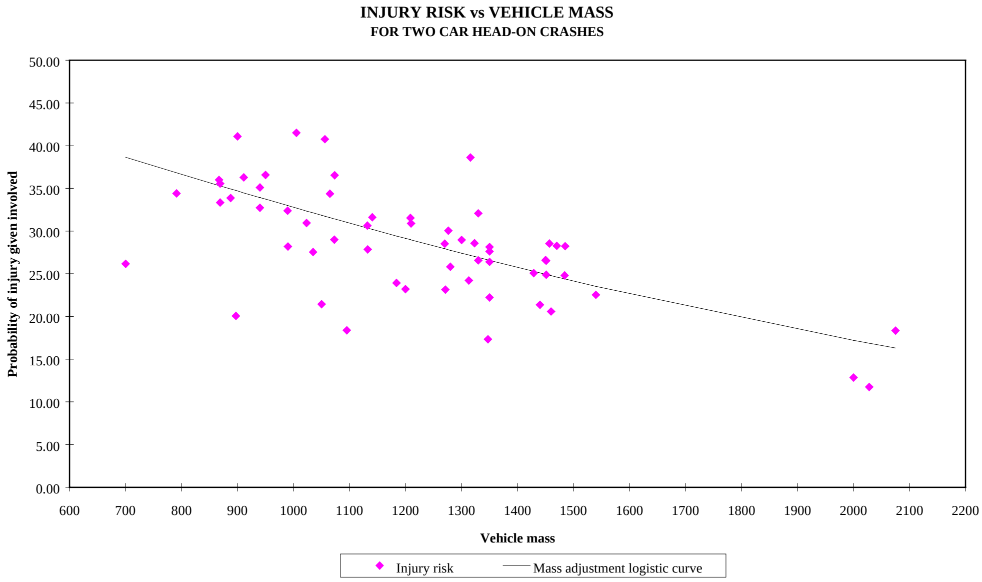


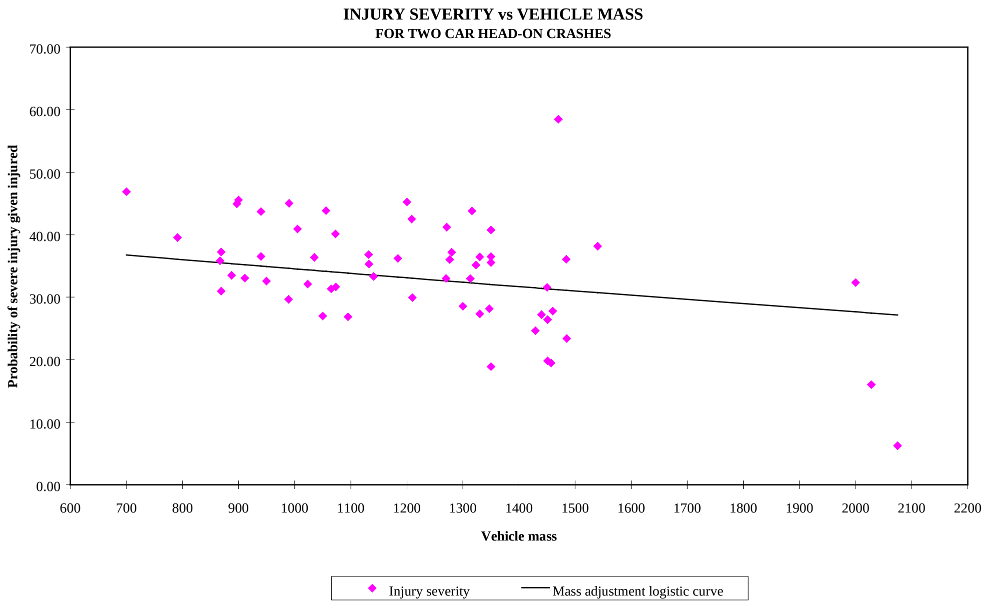

## INJURY SEVERITY vs VEHICLE MASS
FOR ALL TYPES OF CRASHES

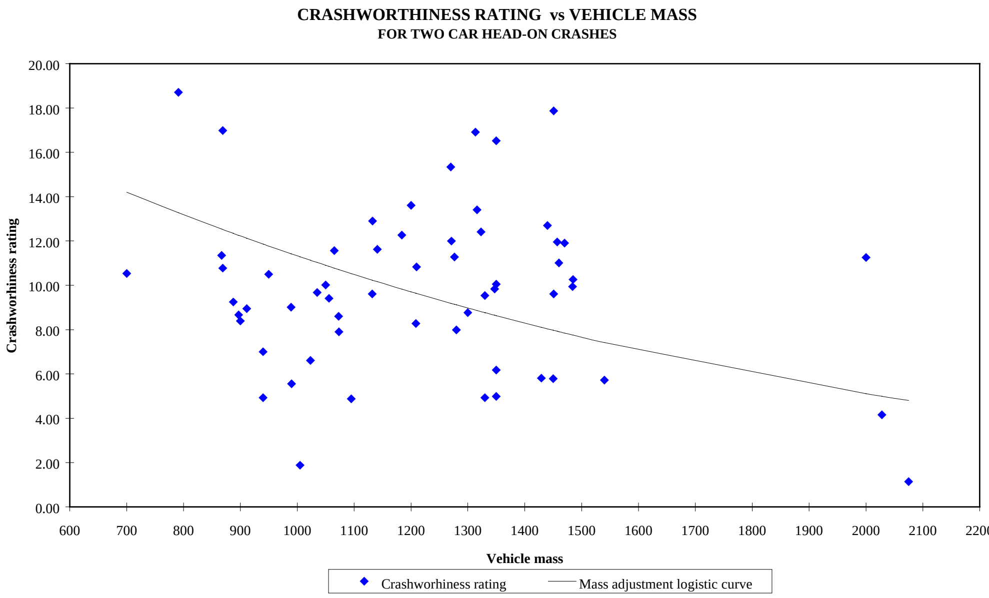



## CRASHWORTHINESS RATING vs VEHICLE MASS
FOR ALL TYPES OF CRASHES




INJURY RISK vs VEHICLE MASS
FOR TWO CAR HEAD-ON CRASHES
Probability of injury given involved
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200
Vehicle mass
Injury risk
Mass adjustment logistic curve


INJURY SEVERITY vs VEHICLE MASS
FOR TWO CAR HEAD-ON CRASHES
Probability of severe injury given injured
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200
Vehicle mass
Injury severity
Mass adjustment logistic curve


CRASHWORTHINESS RATING vs VEHICLE MASS
FOR TWO CAR HEAD-ON CRASHES
Crashworhiness rating
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
Vehicle mass
Crashworhiness rating
Mass adjustment logistic curve

## Mass Adjusted NCAP Measures

**All Crash Types**

| MODEL | Full Frontal NCAP Pcomb1 | Full Frontal NCAP Pcomb2 | Full Frontal NCAP Mass Adjusted Pcomb1 | Full Frontal NCAP Mass Adjusted Pcomb2 | Offset NCAP Pcomb1(offset) | Offset NCAP Pcomb2(offset) | Offset NCAP Preal1 | Offset NCAP Preal2 | Offset NCAP Mass Adjusted Pcomb1 (offset) | Offset NCAP Mass Adjusted Pcomb2 (offset) | Offset NCAP Mass Adjusted Preal1 | Offset NCAP Mass Adjusted Preal2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Holden Commodore VN/VP (87-9 | 0.87 | 0.87 | 0.86 | 0.86 | | | | | | | | |
| Ford Falcon EB Series II (92-94) | 0.65 | 0.66 | 0.62 | 0.63 | | | | | | | | |
| Subaru Liberty (89-94) | 0.54 | 0.54 | 0.53 | 0.53 | | | | | | | | |
| Mitsubishi Magna TR/TS (91-95) | 0.41 | 0.42 | 0.40 | 0.40 | | | | | | | | |
| Mazda 626/MX6 (92-94) | 0.42 | 0.42 | 0.43 | 0.43 | | | | | | | | |
| Nissan Pintara (89-92) | 0.82 | 0.82 | 0.82 | 0.82 | | | | | | | | |
| Toyota Camry (88-92) | 0.41 | 0.42 | 0.40 | 0.41 | | | | | | | | |
| Daihatsu Charade (94-95) | 0.45 | 0.45 | 0.50 | 0.50 | 0.77 | 0.82 | 0.58 | 0.61 | 0.80 | 0.85 | 0.63 | 0.65 |
| Ford Laser (91-94) | 0.89 | 0.90 | 0.90 | 0.91 | 1.00 | 1.00 | 0.93 | 0.94 | 1.00 | 1.00 | 0.94 | 0.95 |
| Holden Barina (89-93) | 0.34 | 0.34 | 0.39 | 0.39 | 0.43 | 0.49 | 0.37 | 0.40 | 0.48 | 0.54 | 0.43 | 0.46 |
| Honda Civic (92-95) | 0.63 | 0.64 | 0.66 | 0.66 | 0.11 | 0.11 | 0.42 | 0.42 | 0.12 | 0.12 | 0.45 | 0.45 |
| Hyundai Excel (90-94) | 0.49 | 0.49 | 0.52 | 0.53 | 0.43 | 0.44 | 0.46 | 0.47 | 0.46 | 0.47 | 0.50 | 0.50 |
| Hyundai Lantra (91-95) | 0.55 | 0.55 | 0.56 | 0.57 | 0.40 | 0.41 | 0.49 | 0.50 | 0.41 | 0.42 | 0.50 | 0.51 |
| Mazda 121 (91-94) | 0.67 | 0.67 | 0.71 | 0.71 | 0.74 | 0.75 | 0.70 | 0.71 | 0.77 | 0.79 | 0.74 | 0.74 |
| Nissan Pulsar (92-95) | 0.58 | 0.59 | 0.60 | 0.60 | 0.96 | 1.00 | 0.74 | 0.76 | 0.96 | 1.00 | 0.75 | 0.77 |
| Toyota Corolla (90-94) | 0.65 | 0.72 | 0.67 | 0.74 | 0.29 | 0.32 | 0.50 | 0.55 | 0.31 | 0.34 | 0.53 | 0.58 |
| Nissan Patrol (88-90) | 0.83 | 0.83 | 0.75 | 0.75 | 0.18 | 0.18 | 0.56 | 0.56 | 0.12 | 0.13 | 0.45 | 0.45 |
| Suzuki Vitara (88-95) | 0.72 | 0.73 | 0.73 | 0.75 | 0.24 | 0.26 | 0.52 | 0.54 | 0.25 | 0.28 | 0.54 | 0.56 |
| Toyota Landcruiser (90-95) | 0.34 | 0.38 | 0.24 | 0.28 | 0.28 | 0.28 | 0.31 | 0.34 | 0.20 | 0.20 | 0.22 | 0.25 |
| Toyota Tarago (83-89) | 0.64 | 0.68 | 0.63 | 0.66 | 0.75 | 0.78 | 0.69 | 0.72 | 0.73 | 0.77 | 0.67 | 0.70 |
| Ford Falcon EF (94-95) | 0.48 | 0.51 | 0.44 | 0.48 | 0.18 | 0.18 | 0.36 | 0.38 | 0.16 | 0.16 | 0.32 | 0.34 |
| Holden Commodore VR/VS (93-9 | 0.37 | 0.37 | 0.35 | 0.36 | 0.12 | 0.13 | 0.27 | 0.27 | 0.12 | 0.12 | 0.26 | 0.26 |
| Toyota Camry (93-95) | 0.37 | 0.37 | 0.36 | 0.36 | 0.12 | 0.13 | 0.27 | 0.27 | 0.12 | 0.12 | 0.26 | 0.26 |
| Ford Festiva (94-95) | 0.82 | 0.82 | 0.84 | 0.84 | 0.47 | 0.47 | 0.68 | 0.68 | 0.51 | 0.52 | 0.71 | 0.71 |
| Mitsubishi Lancer CC (95-96) | 0.46 | 0.47 | 0.50 | 0.50 | 0.43 | 0.85 | 0.45 | 0.62 | 0.46 | 0.86 | 0.48 | 0.65 |
| Hyundai Excel (95-96) | 0.59 | 0.59 | 0.62 | 0.62 | 0.43 | 0.44 | 0.52 | 0.53 | 0.47 | 0.48 | 0.56 | 0.57 |
| Toyota Corolla (95-96) | 0.44 | 0.51 | 0.46 | 0.53 | 0.46 | 0.46 | 0.44 | 0.49 | 0.49 | 0.49 | 0.48 | 0.52 |
| Toyota Tarago (91-96) | 0.81 | 0.81 | 0.77 | 0.77 | 0.47 | 0.47 | 0.67 | 0.67 | 0.40 | 0.40 | 0.61 | 0.61 |

## Mass Adjusted NCAP Measures

### Two Car Head-On Crashes

| | Full Frontal NCAP | | | | Offset NCAP | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MODEL | Pcomb1 | Pcomb2 | Mass Adjusted Pcomb1 | Mass Adjusted Pcomb2 | Pcomb1(offset) | Pcomb2(offset) | Preal1 | Preal2 | Mass Adjusted Pcomb1 (offset) | Mass Adjusted Pcomb2 (offset) | Mass Adjusted Preal1 | Mass Adjusted Preal2 |
| Holden Commodore VN/VP (87-9 | 0.87 | 0.87 | 0.86 | 0.86 | | | | | | | | |
| Ford Falcon EB Series II (92-94) | 0.65 | 0.66 | 0.61 | 0.62 | | | | | | | | |
| Subaru Liberty (89-94) | 0.54 | 0.54 | 0.53 | 0.53 | | | | | | | | |
| Mitsubishi Magna TR/TS (91-95) | 0.41 | 0.42 | 0.39 | 0.40 | | | | | | | | |
| Mazda 626/MX6 (92-94) | 0.42 | 0.42 | 0.43 | 0.44 | | | | | | | | |
| Nissan Pintara (89-92) | 0.82 | 0.82 | 0.82 | 0.82 | | | | | | | | |
| Toyota Camry (88-92) | 0.41 | 0.42 | 0.41 | 0.41 | | | | | | | | |
| Ford Laser (91-94) | 0.89 | 0.90 | 0.91 | 0.92 | 1.00 | 1.00 | 0.93 | 0.94 | 1.00 | 1.00 | 0.95 | 0.95 |
| Holden Barina (89-93) | 0.34 | 0.34 | 0.43 | 0.43 | 0.43 | 0.49 | 0.37 | 0.40 | 0.52 | 0.59 | 0.47 | 0.50 |
| Honda Civic (92-95) | 0.63 | 0.64 | 0.68 | 0.68 | 0.11 | 0.11 | 0.42 | 0.42 | 0.13 | 0.14 | 0.47 | 0.47 |
| Hyundai Excel (90-94) | 0.49 | 0.49 | 0.55 | 0.55 | 0.43 | 0.44 | 0.46 | 0.47 | 0.49 | 0.50 | 0.53 | 0.53 |
| Mazda 121 (91-94) | 0.67 | 0.67 | 0.74 | 0.74 | 0.74 | 0.75 | 0.70 | 0.71 | 0.80 | 0.81 | 0.76 | 0.77 |
| Nissan Pulsar (92-95) | 0.58 | 0.59 | 0.61 | 0.62 | 0.96 | 1.00 | 0.74 | 0.76 | 0.97 | 1.00 | 0.76 | 0.78 |
| Toyota Corolla (90-94) | 0.65 | 0.72 | 0.69 | 0.75 | 0.29 | 0.32 | 0.50 | 0.55 | 0.33 | 0.36 | 0.55 | 0.60 |
| Nissan Patrol (88-90) | 0.83 | 0.83 | 0.71 | 0.71 | 0.18 | 0.18 | 0.56 | 0.56 | 0.10 | 0.10 | 0.39 | 0.39 |
| Suzuki Vitara (88-95) | 0.72 | 0.73 | 0.75 | 0.76 | 0.24 | 0.26 | 0.52 | 0.54 | 0.27 | 0.29 | 0.56 | 0.58 |
| Toyota Landcruiser (90-95) | 0.34 | 0.38 | 0.20 | 0.23 | 0.28 | 0.28 | 0.31 | 0.34 | 0.16 | 0.16 | 0.18 | 0.20 |
| Toyota Tarago (83-89) | 0.64 | 0.68 | 0.62 | 0.65 | 0.75 | 0.78 | 0.69 | 0.72 | 0.73 | 0.77 | 0.67 | 0.70 |
| Ford Falcon EF (94-95) | 0.48 | 0.51 | 0.43 | 0.46 | 0.18 | 0.18 | 0.36 | 0.38 | 0.15 | 0.15 | 0.31 | 0.33 |
| Holden Commodore VR/VS (93-9 | 0.37 | 0.37 | 0.35 | 0.35 | 0.12 | 0.13 | 0.27 | 0.27 | 0.11 | 0.12 | 0.25 | 0.25 |
| Toyota Camry (93-95) | 0.37 | 0.37 | 0.36 | 0.36 | 0.12 | 0.13 | 0.27 | 0.27 | 0.12 | 0.12 | 0.26 | 0.26 |
| Ford Festiva (94-95) | 0.82 | 0.82 | 0.86 | 0.86 | 0.47 | 0.47 | 0.68 | 0.68 | 0.55 | 0.55 | 0.74 | 0.74 |

# APPENDIX C

# DETAILED RESULTS OF CORRELATION ANALYSES AND ASSOCIATED PLOTS

## CORRELATION OF NCAP TEST RESULTS WITH REAL CRASH OUTCOMES
## SUMMARY OF CORRELATION ANALYSES

### (A) FULL FRONTAL NCAP TEST RESULTS

| | All Crashes (28 Models) | | | 2 Car Head-on Crashes (22 Models) | | |
|---|---|---|---|---|---|---|
| | CWR | PR(SEV/INJ) | PR(INJ/INV) | CWR | PR(SEV/INJ) | PR(INJ/INV) |
| HIC | 0.049 | 0.140 | -0.064 | 0.140 | 0.309 | -0.126 |
| CHEST G | 0.105 | -0.100 | 0.274 | 0.335 | 0.223 | 0.361 |
| FL(pds)** | -0.009 | -0.117 | 0.098 | 0.136 | -0.144 | 0.315 |
| PheadD | 0.050 | 0.133 | -0.056 | 0.126 | 0.306 | -0.140 |
| PChestD | 0.070 | -0.154 | 0.273 | 0.297 | 0.164 | 0.337 |
| PFemload | 0.073 | 0.032 | 0.083 | 0.167 | -0.007 | 0.257 |
| Pc1(full) | 0.098 | 0.054 | 0.102 | 0.240 | 0.345 | 0.023 |
| Pc2(full) | 0.093 | 0.050 | 0.099 | 0.230 | 0.322 | 0.026 |
| Mass Adj.Pc1 | 0.255 | 0.172 | 0.233 | 0.440 | [illegible] | 0.184 |
| Mass Adj.Pc2 | 0.255 | 0.172 | 0.233 | 0.435 | [illegible] | 0.190 |

### (B) OFFSET NCAP TEST RESULTS

| | All Crashes (21 Models) | | | 2 Car Head-on Crashes (15 Models) | | |
|---|---|---|---|---|---|---|
| | CWR | PR(SEV/INJ) | PR(INJ/INV) | CWR | PR(SEV/INJ) | PR(INJ/INV) |
| HIC | 0.312 | 0.233 | 0.225 | 0.292 | 0.225 | 0.274 |
| Chest G | 0.477 | 0.197 | [illegible] | 0.391 | 0.196 | 0.476 |
| FL(pds)* | 0.398 | 0.359 | 0.285 | 0.160 | 0.120 | 0.157 |
| LLI | 0.435 | 0.088 | [illegible] | 0.300 | 0.189 | 0.330 |
| PheadD | 0.364 | 0.240 | 0.288 | 0.238 | 0.243 | 0.194 |
| PChestD | 0.408 | 0.160 | 0.432 | 0.323 | 0.147 | 0.391 |
| PFemload | 0.156 | 0.307 | -0.017 | -0.027 | -0.017 | -0.033 |
| Pc1(offset) | 0.467 | 0.252 | 0.430 | 0.284 | 0.258 | 0.257 |
| Pc2(offset) | [illegible] | 0.409 | 0.383 | 0.291 | 0.265 | 0.262 |
| Preal1 | 0.321 | 0.151 | 0.317 | 0.348 | 0.372 | 0.229 |
| Preal2 | 0.376 | 0.271 | 0.304 | 0.355 | 0.378 | 0.235 |
| Mass Adj.Pc1(offset) | [illegible] | 0.332 | 0.499 | 0.394 | 0.395 | 0.338 |
| Mass Adj.Pc2(offset) | [illegible] | 0.471 | 0.449 | 0.400 | 0.402 | 0.344 |
| Mass Adj.Preal1 | [illegible] | 0.297 | 0.465 | 0.554 | [illegible] | 0.404 |
| Mass Adj.Preal2 | [illegible] | 0.404 | 0.447 | 0.557 | [illegible] | 0.408 |

### (C) FULL FRONTAL NCAP TEST RESULTS FOR VEHICLES WITH OFFSET TEST RESULTS ALSO

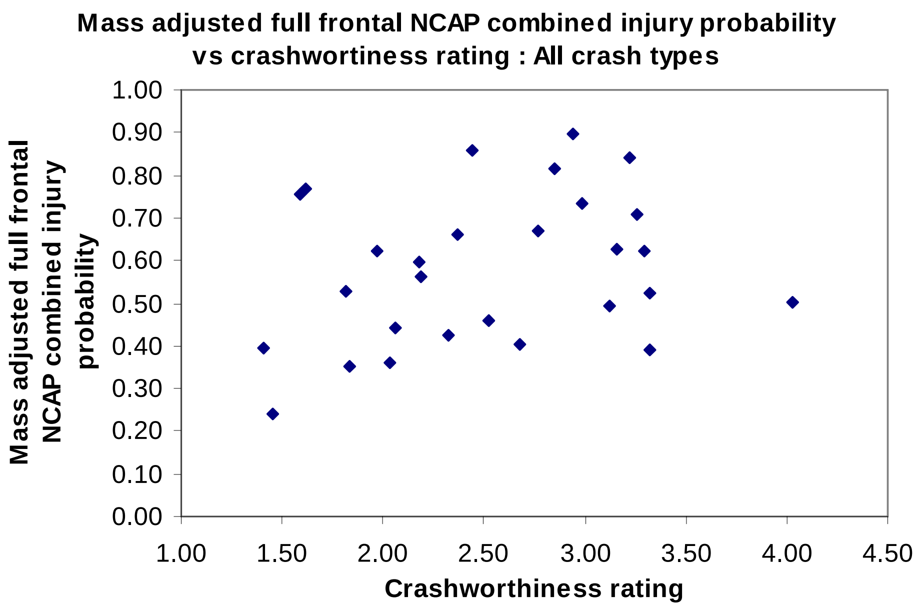
| | All Crashes (21 Models) | | | 2 Car Head-on Crashes (15 Models) | | |
|---|---|---|---|---|---|---|
| | CWR | PR(SEV/INJ) | PR(INJ/INV) | CWR | PR(SEV/INJ) | PR(INJ/INV) |
| HIC | -0.013 | 0.097 | -0.131 | 0.142 | 0.272 | -0.072 |
| Chest G | 0.133 | -0.158 | 0.374 | 0.477 | 0.351 | 0.479 |
| FL(pds)** | -0.050 | -0.079 | 0.021 | 0.192 | -0.034 | 0.339 |
| PheadD | -0.022 | 0.085 | -0.134 | 0.124 | 0.265 | -0.089 |
| PChestD | 0.086 | -0.229 | 0.373 | 0.447 | 0.289 | 0.466 |
| PFemload | 0.010 | 0.047 | -0.018 | 0.172 | 0.038 | 0.266 |
| Pc1(full) | 0.034 | -0.019 | 0.067 | 0.300 | 0.373 | 0.116 |
| Pc2(full) | 0.018 | -0.022 | 0.048 | 0.286 | 0.347 | 0.118 |
| Mass Adj. Pc1 | 0.222 | 0.126 | 0.219 | 0.522 | [illegible] | 0.305 |
| Mass Adj.Pc2 | 0.212 | 0.127 | 0.205 | 0.516 | [illegible] | 0.311 |

### (D) FULL FRONTRAL NCAP TEST RESULTS FOR VEHICLES WITH NO OFFSET TEST RESULTS

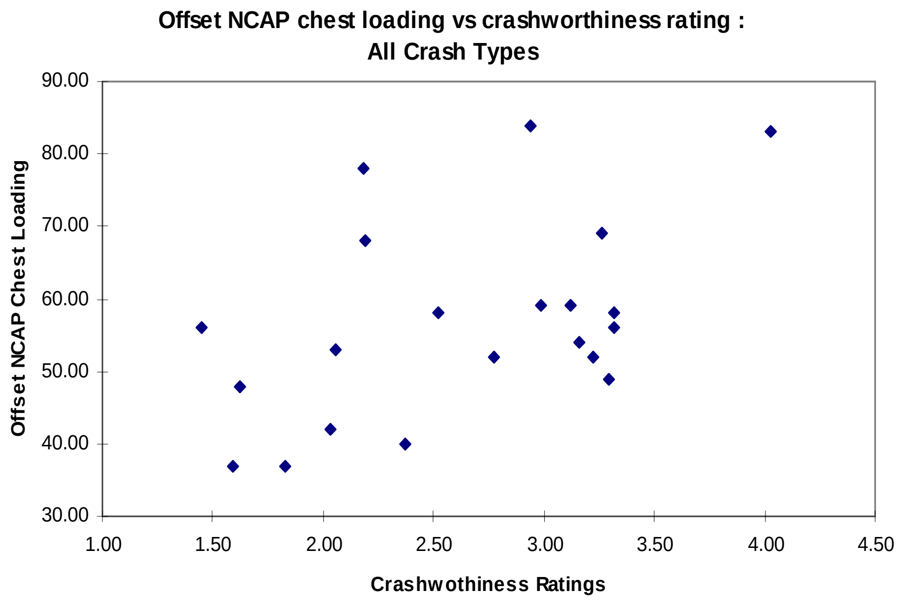
| | All Crashes (7 Models) | | | 2 Car Head-on Crashes (7 Models) | | |
|---|---|---|---|---|---|---|
| | CWR | PR(SEV/INJ) | PR(IN/INV) | CWR | PR(SEV/INJ) | PR(INJ/INV) |
| HIC | 0.442 | 0.341 | 0.420 | 0.165 | 0.459 | -0.559 |
| Chest G | 0.235 | 0.141 | 0.307 | -0.304 | -0.236 | -0.165 |
| FL(pds)** | -0.461 | -0.392 | -0.411 | -0.679 | -0.744 | 0.156 |
| PheadD | 0.452 | 0.343 | 0.435 | 0.178 | 0.465 | -0.548 |
| PChestD | 0.208 | 0.118 | 0.283 | -0.289 | -0.227 | -0.157 |
| PFemload | -0.335 | -0.229 | -0.333 | -0.873 | -0.821 | -0.069 |
| Pc1(full) | 0.431 | 0.324 | 0.431 | 0.009 | 0.279 | -0.523 |
| Pc2(full) | 0.426 | 0.320 | 0.426 | -0.004 | 0.267 | -0.523 |
| Mass Adj.Pc1 | 0.461 | 0.357 | 0.450 | 0.077 | 0.359 | -0.548 |
| Mass Adj.Pc2 | 0.456 | 0.353 | 0.446 | 0.064 | 0.346 | -0.549 |

NNN = Statistically significant at the 1% level
NNN = Satistically significant at the 5% level
NNN = Statistically significant at the 10% level

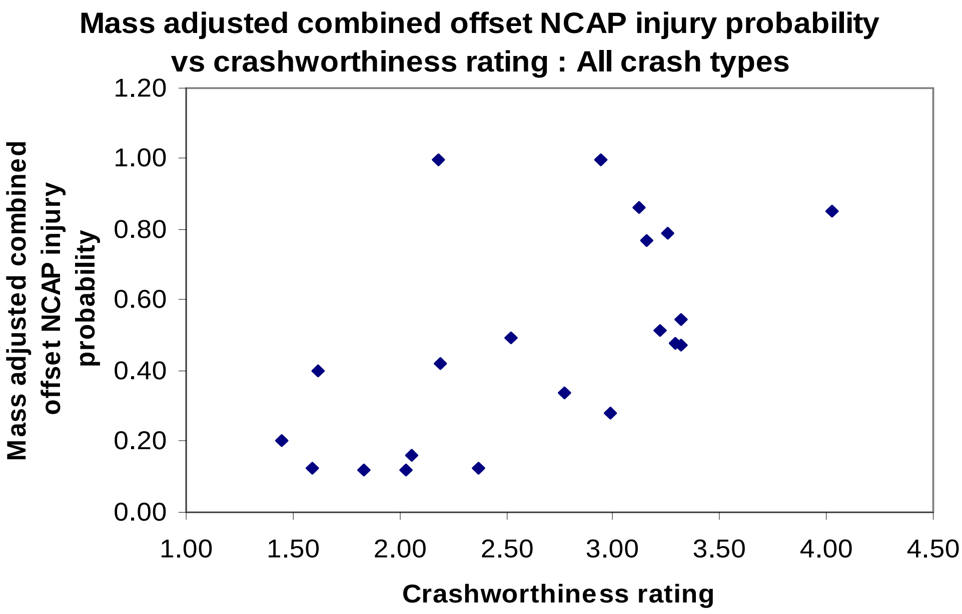
3/31/99



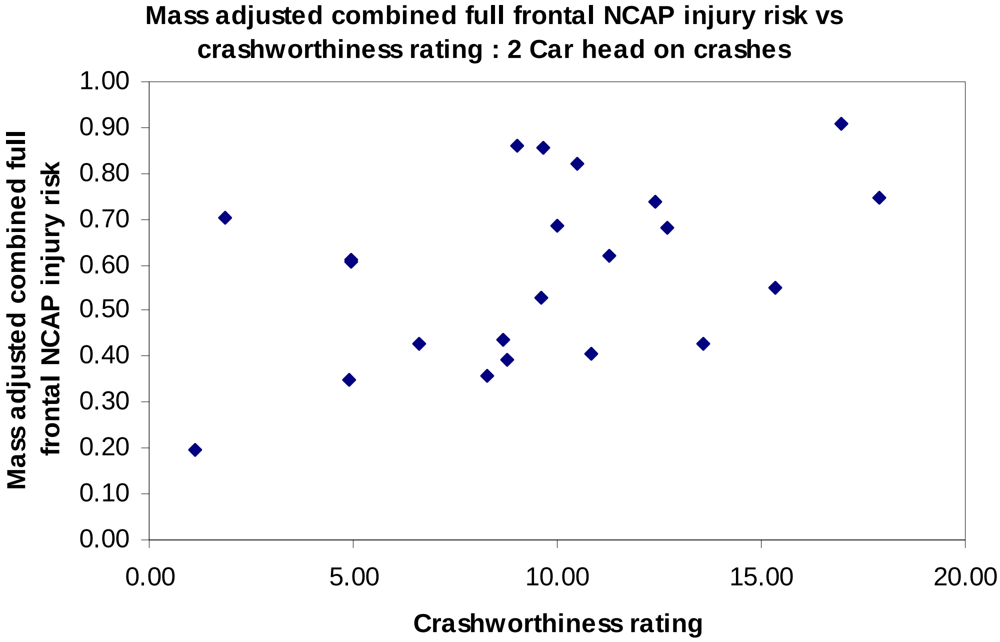
Mass adjusted full frontal NCAP combined injury probability vs crashwortiness rating : All crash types
Mass adjusted full frontal NCAP combined injury probability
Crashworthiness rating
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50

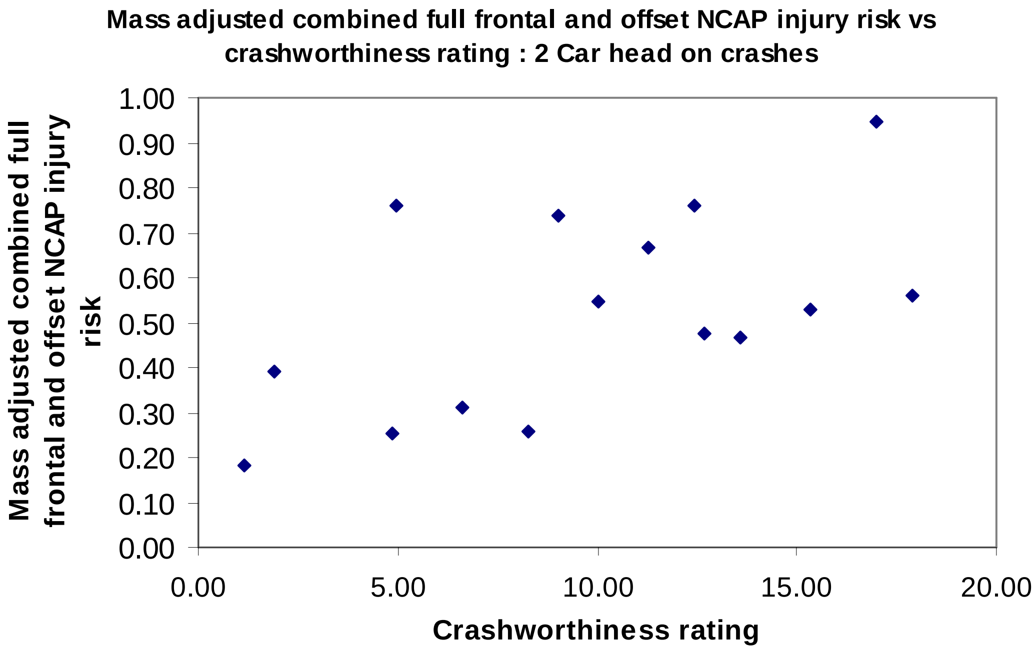
Offset NCAP chest loading vs crashworthiness rating : All Crash Types
Offset NCAP Chest Loading
Crashwothiness Ratings
90.00
80.00
70.00
60.00
50.00
40.00
30.00
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50

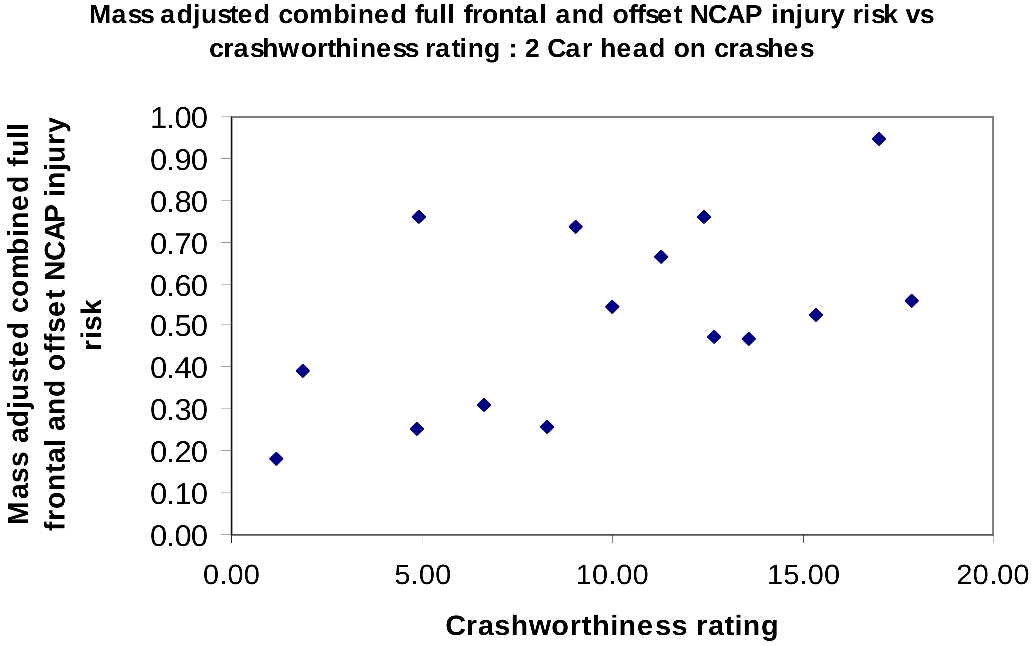
Mass adjusted combined offset NCAP injury probability vs crashworthiness rating : All crash types
Mass adjusted combined offset NCAP injury probability
Crashworthiness rating
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50



Mass adjusted combined full frontal NCAP injury risk vs crashworthiness rating : 2 Car head on crashes
Mass adjusted combined full frontal NCAP injury risk
Crashworthiness rating

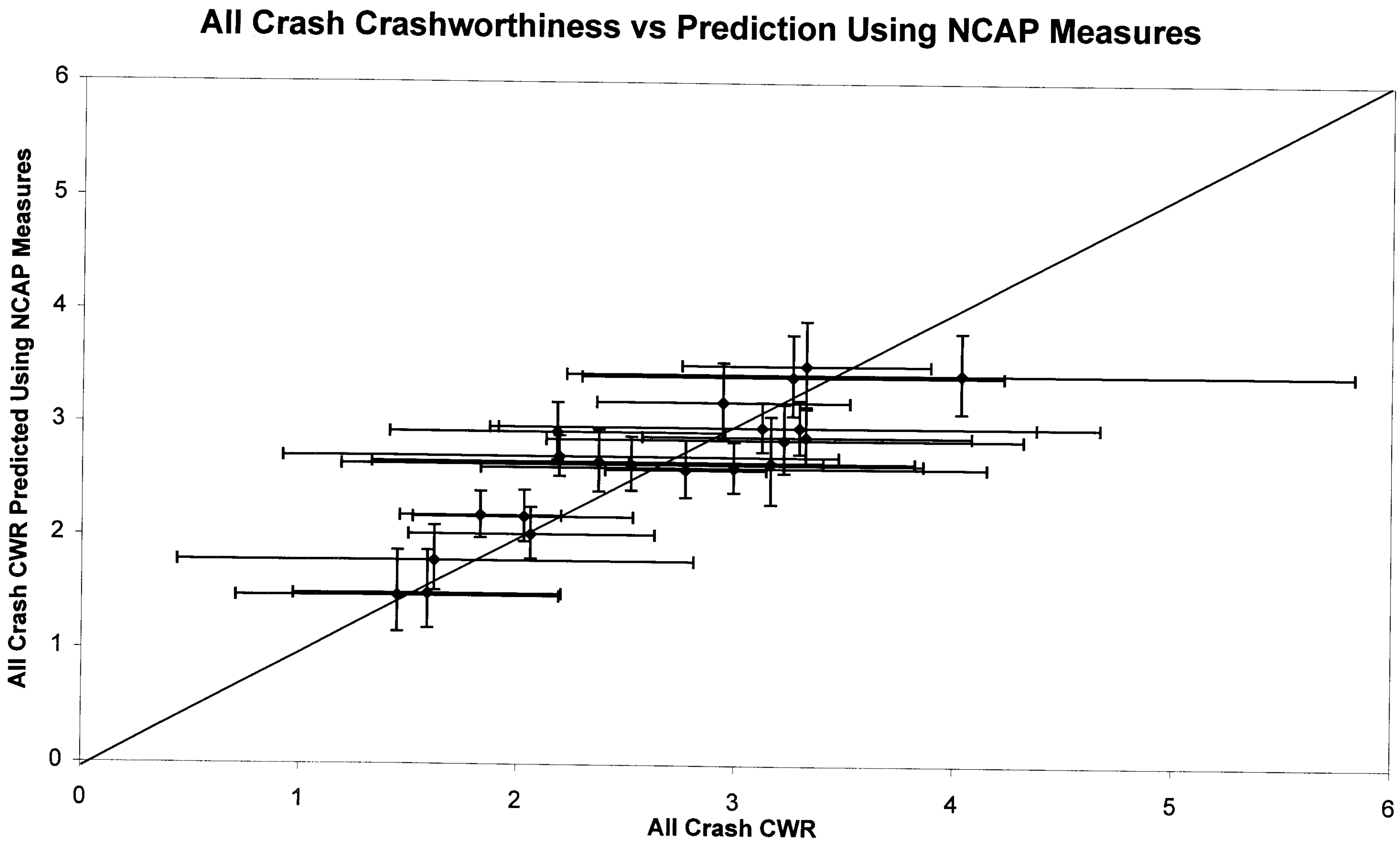
Mass adjusted combined full frontal and offset NCAP injury risk vs crashworthiness rating : 2 Car head on crashes
Mass adjusted combined full frontal and offset NCAP injury risk
Crashworthiness rating

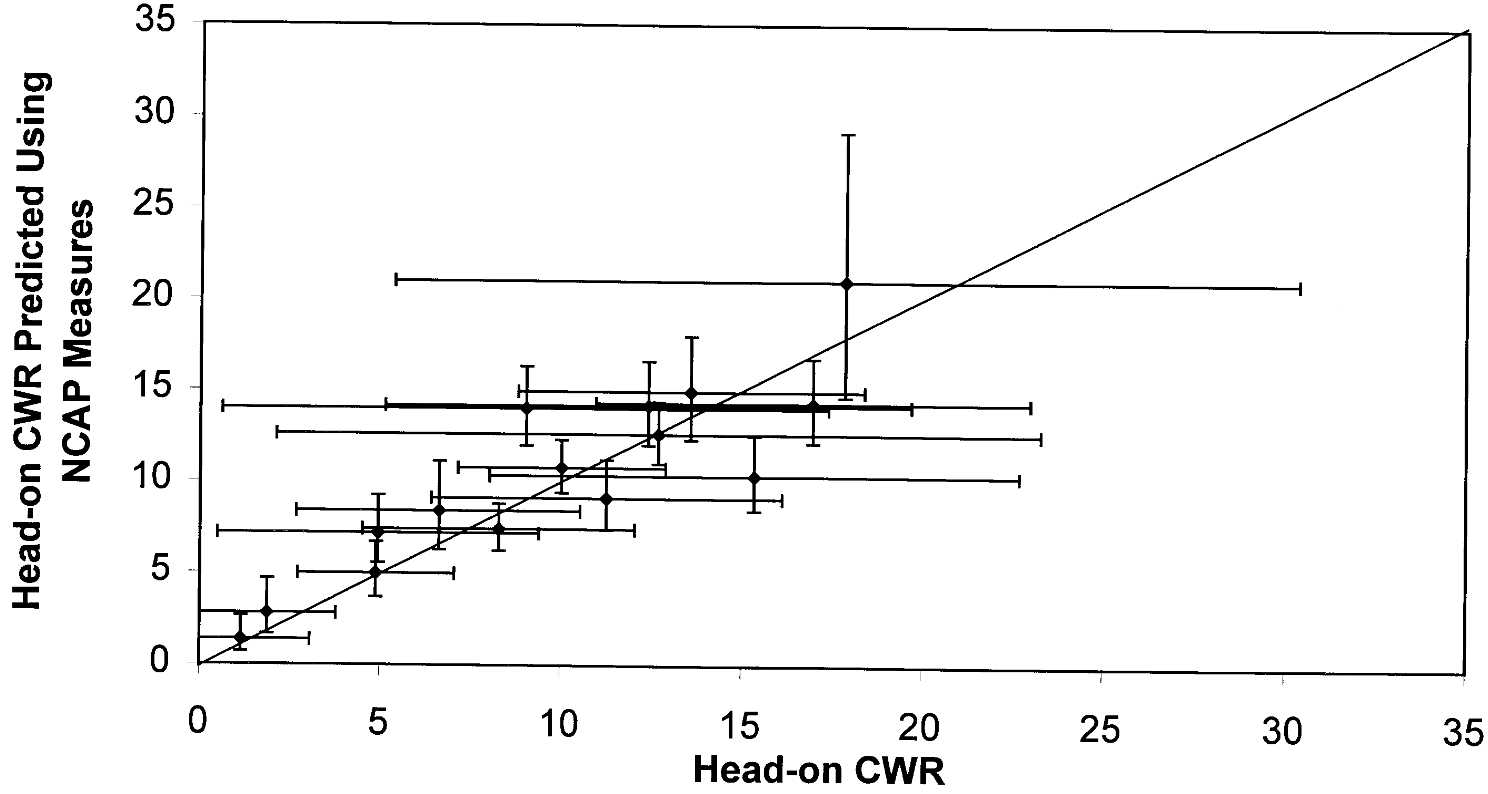
Mass adjusted combined full frontal and offset NCAP injury risk vs crashworthiness rating : 2 Car head on crashes
Mass adjusted combined full frontal and offset NCAP injury risk
Crashworthiness rating

# APPENDIX D

# PLOTS OF CRASHWORTHINESS RATINGS AGAINST PREDICTIONS FROM LOGISTIC MODELLING INCLUDING 95% CONFIDENCE LIMITS

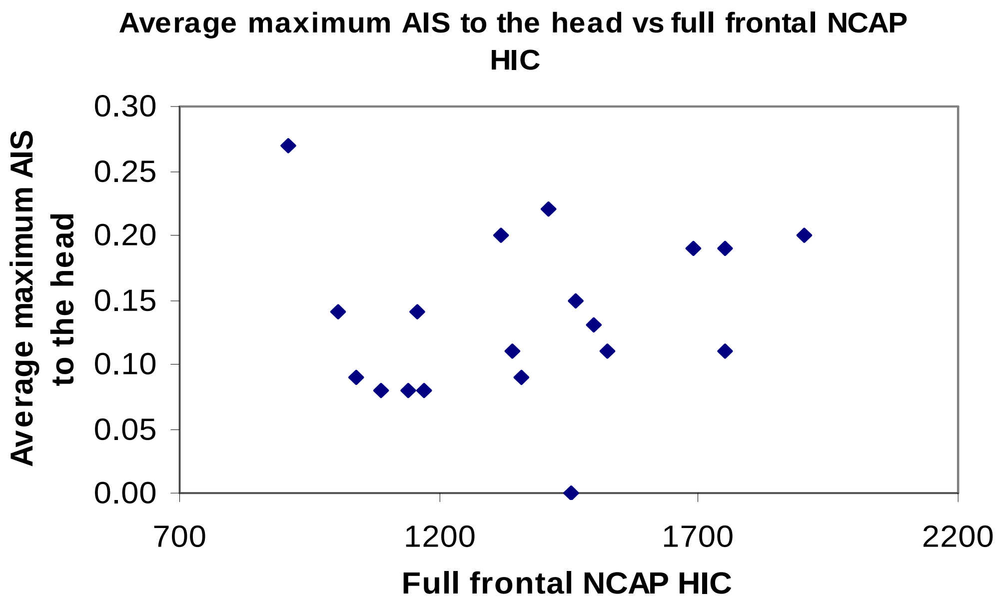

All Crash Crashworthiness vs Prediction Using NCAP Measures
All Crash CWR Predicted Using NCAP Measures
All Crash CWR
0
1
2
3
4
5
6

## Head-on Crash CWR vs Prediction From NCAP Scores

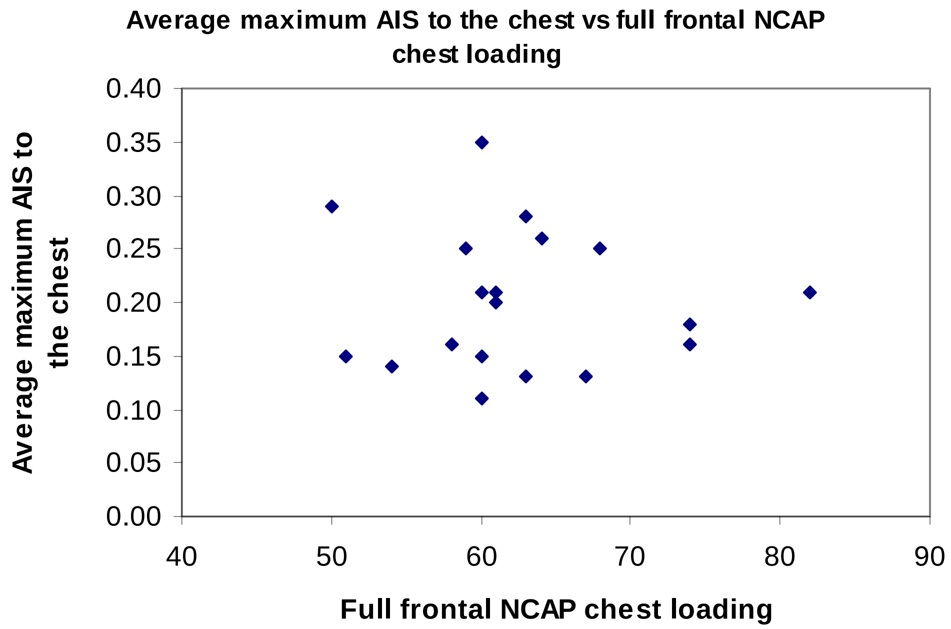


# APPENDIX E

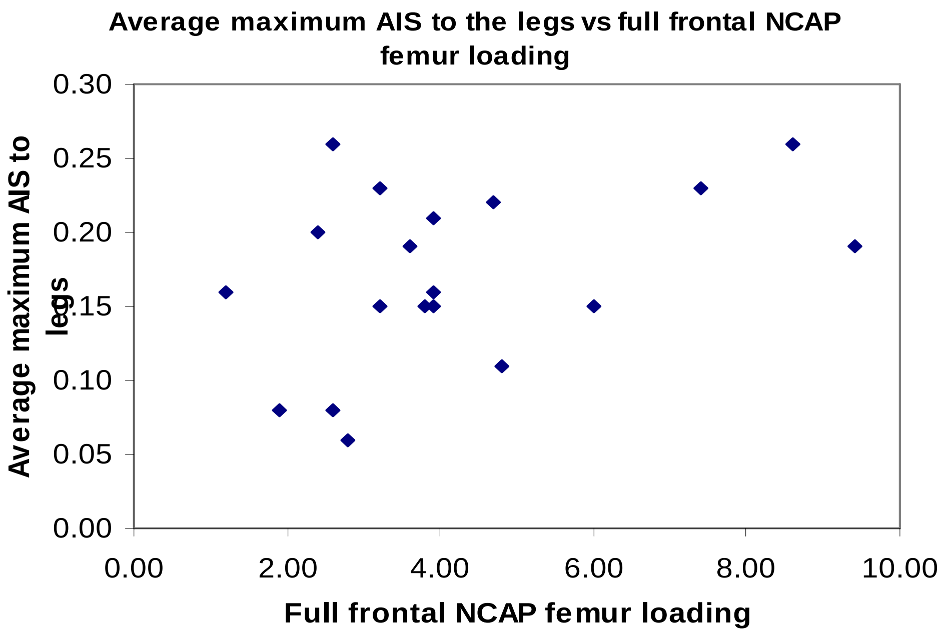
# PLOTS OF AVERAGE MAXIMUM AIS AGAINST ANCAP SCORE BY BODY REGION



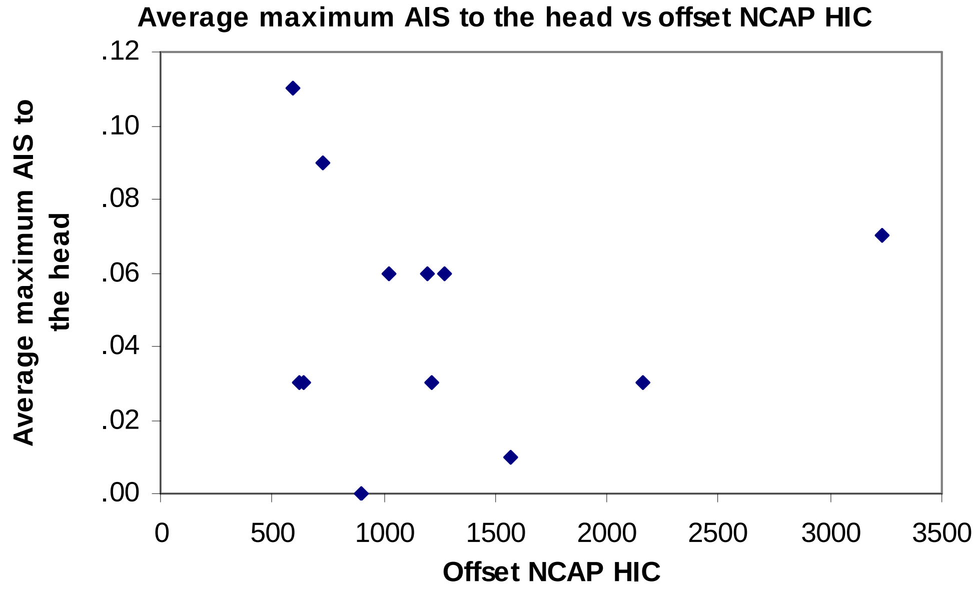
Average maximum AIS to the head vs full frontal NCAP HIC
Average maximum AIS to the head
0.30
0.25
0.20
0.15
0.10
0.05
0.00
700
1200
1700
2200
Full frontal NCAP HIC

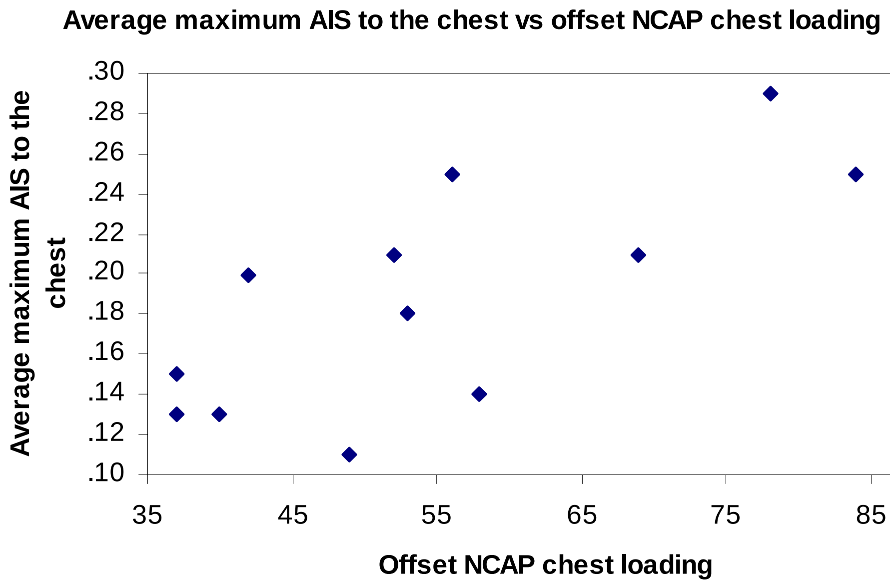
Average maximum AIS to the chest vs full frontal NCAP chest loading
Average maximum AIS to the chest
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
40
50
60
70
80
90
Full frontal NCAP chest loading

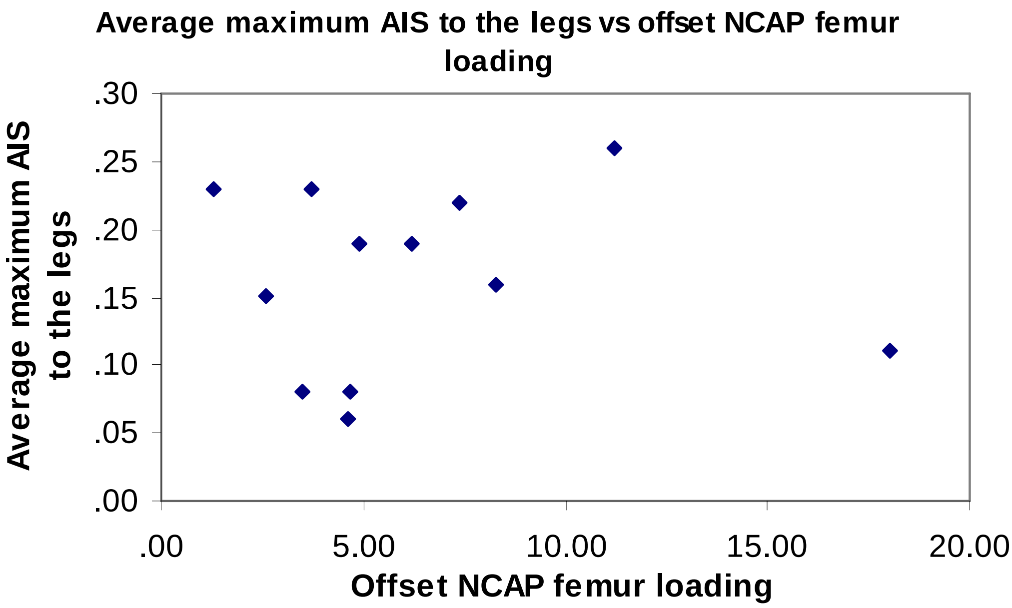
Average maximum AIS to the legs vs full frontal NCAP femur loading
Average maximum AIS to legs
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.00
2.00
4.00
6.00
8.00
10.00
Full frontal NCAP femur loading



Average maximum AIS to the head vs offset NCAP HIC
Average maximum AIS to the head
.12
.10
.08
.06
.04
.02
.00
0
500
1000
1500
2000
2500
3000
3500
Offset NCAP HIC

Average maximum AIS to the chest vs offset NCAP chest loading
Average maximum AIS to the chest
.30
.28
.26
.24
.22
.20
.18
.16
.14
.12
.10
35
45
55
65
75
85
Offset NCAP chest loading

Average maximum AIS to the legs vs offset NCAP femur loading
Average maximum AIS to the legs
.30
.25
.20
.15
.10
.05
.00
.00
5.00
10.00
15.00
20.00
Offset NCAP femur loading