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THE INTERACTION BETWEEN RELATIVE VEHICLE SECONDARY SAFETY AND DRIVER DEMOGRAPHICS

by

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**Report No. 290
September 2009**

Project Sponsored By



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REPORT DOCUMENTATION PAGE**

Report No.	Report Date	ISBN	ISSN	Pages
290	September 2009	0 7326 2360 X	1835-4815 (online)	38 + Appendices

Title and sub-title:

The interaction between relative vehicle secondary safety and driver demographics.

Author(s)

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Sponsoring Organisations - This project was funded as contract research by the following organisations:

Road Traffic Authority of NSW, Royal Automobile Club of Victoria Ltd, NRMA Motoring and Services, VicRoads, Royal Automobile Club of Western Australia Ltd, Transport Accident Commission, New Zealand Transport Agency, the New Zealand Automobile Association, Queensland Department of Transport and Main Roads, Royal Automobile Club of Queensland, Royal Automobile Association of South Australia and by grants from the Australian Government Department of Transport, Infrastructure, Regional Development and Local Government and the Road Safety Council of Western Australia.

Abstract:

Vehicle safety rating programs based on crash tests have been criticised that they use crash test dummies that represented a limited range of body shapes. Therefore, such tests may not be addressing the safety needs of occupants whose body shapes do not correspond to that of the test dummies. Similarly, vehicle safety ratings programs based on real world crash data, such as the Used Car Safety Ratings (UCSR) system (Newstead et al, 2006), may not be applicable to occupants whose body shapes do not match the body shape of the profile of drivers to which the ratings are standardised.

The data compiled for the Used Car Safety Ratings project (Newstead et al, 2006) was used in this project to identify and quantify the difference in relative vehicle market group safety depending on driver age and gender. This was done by introducing terms representing interaction between market group and age and sex of driver into the logistic regression models used to produce the Used Car Safety Ratings of Newstead et al (2006). Data limitations meant that the analysis was limited to studying how driver age and sex affect safety ratings for different market groups and not different models of vehicles. It was found that even though adding the interaction terms to the logistic models significantly affected the models, the addition of these terms did not drastically alter the relative crashworthiness rankings for market groups between different demographic groups. With a few exceptions, types of vehicles that Newstead et al (2006) ranked as being safe for a standardised set of drivers were in general safe for drivers grouped by their age and sex. The same can be said for types of vehicles that Newstead et al (2006) rated as performing poorly for a standardised set of drivers. This suggests that the vehicle safety ratings published by Newstead et al (2006) are on the whole applicable for drivers of all demographics. Incidences where market rankings did vary depending on driver demographics are identified and directions for further research have been suggested.

Key Words: (IRRDR except when marked*)

Injury, Vehicle Occupant, Collision, Passenger Car Unit, Secondary Safety, Motor Vehicle, Occupant demographic, Driver age, Driver sex, Market Category, Statistics, Logistic Regression, Odds Ratio, Chart

Disclaimer:

This Report is produced for the purposes of providing information concerning the safety of vehicles involved in crashes. It is based upon information provided to the Monash University Accident Research Centre by VicRoads, the Transport Accident Commission, the New South Wales Roads and Traffic Authority, NRMA Ltd, Queensland Transport and the Western Australian Department of Main Roads.

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EXECUTIVE SUMMARY

A common criticism of vehicle safety rating programs that are based on a finite crash-test program is that they encourage manufacturers to design vehicles so that they exhibit optimal performance on a narrow range of occupant and crash characteristics to the detriment of optimisation across a broader range of circumstances. Furthermore, many of the test programs only use crash test dummies that represent a very limited range of body shapes. This has raised concern that by optimising vehicles to perform well in the tests, vehicle manufacturers may not be addressing the safety needs of occupants whose body does not match that of the test dummy.

A similar criticism can also be made of vehicle safety rating programs that are based on real world crash data. For example, the Used Car Safety Ratings (UCSR) system provide secondary safety ratings for different groups of vehicles and for different models of vehicles using police-reported crash data from Australia and New Zealand. Newstead et al (2006) used a complex statistical analysis process to adjust for the biasing influence of non-vehicle factors so that the ratings reflected the average driver injury outcome across a standardised profile of driver demographics and crash circumstances for each make and model considered. However such ratings may not be applicable to occupants whose body shapes do not match the body shape of the profile of drivers to which the ratings are standardised. If this is the case, such rating systems derived from real world crash data should provide different ratings for different groups of occupants.

Very few studies have considered how measures of relative occupant protection for different types of vehicles are affected by non-vehicle factors, such as crash type and occupant age and gender. Just because it has been demonstrated that a vehicle provides good protection for occupants of one particular body shape does not mean that the vehicle also provides the same level of protection to all occupants. This issue was explored in this study by testing whether the relative vehicle safety performance between vehicles differs depending on the age and sex of the driver. In particular, the present study has examined whether estimates of relative vehicle secondary safety performance differ depending on driver age and gender. Although limited to examining the effect of age and gender on the UCSR system, the outcome of this study potentially has implications for the extent to which results of other vehicle safety rating programs, including those based on vehicles' performance in a range of crash tests, can be generalised across the wider driving population.

The data compiled for the Used Car Safety Ratings project (Newstead et al, 2006) was used in this project to identify and quantify how the relative safety of vehicles differed for different occupant categories defined by driver age and gender. To develop their Used Car Safety Ratings, Newstead et al (2006) built logistic regression models to estimate the risk of different injury outcomes when different types of vehicles were involved in a crash. Specifically, Newstead et al (2006) built a logistic regression model to estimate the risk of injury of any severity given a driver of a particular type of vehicle was involved in a crash and another model to estimate that an injured driver was killed or hospitalised, i.e. seriously injured. The product of the probabilities generated from these two models gave the risk that a driver involved in a police-reported crash was seriously injured. Newstead et al (2006) used the term "crashworthiness" to describe this measure. Adding variables representing the interaction between vehicle market group and driver age and sex to these logistic regression models allowed the different levels of injury risk to be estimated not only for each market category but for each market category within groups defined by driver age and sex. The analysis was limited to studying how driver age and sex affect safety ratings for different market groups and not different models of vehicles within each market group because of data limitations.

After building injury risk and injury severity models that included interaction terms between driver age and market group and driver sex and market group, odds ratios for each market group were ranked within different demographic categories. This enabled the rank that was specific to the performance of each market group in protecting female drivers from (serious) injury to be compared to the protection that the same types of vehicles provided to male drivers. It was found that Compact Four Wheel Drive vehicles and People Movers ranked better in terms of reducing injury risk for female drivers than for male drivers. Conversely, Commercial Vans and Sports Cars ranked better in terms of reduced risk of injury for male drivers when compared to the injury risk of such vehicles for female drivers. It was also found that Compact Four Wheel Drive vehicles ranked worse in terms of reducing injury risk for drivers aged 25 years or younger compared to older drivers. In terms of the odds ratio of an injured driver being seriously injured, Medium Four Wheel Drive vehicles and Commercial Vans were ranked as being safer vehicles for male drivers when compared with the ranking for these vehicles specific to female drivers. However in many cases, such differences in rankings were based on point estimates of odds ratios that weren't significantly different from each other. This was particularly true for the injury severity odds ratios where there was little difference in the point estimates between different market groups, meaning that a slight variation in the point estimate when the data were disaggregated by driver demographic characteristics could have an exaggerated effect on the relative rankings.

The logistic regression models to estimate injury risk and injury severity were also used to estimate crashworthiness odds ratios for different market groups within driver demographic categories. These crashworthiness odds ratios represented the odds of a driver being hospitalised or killed given involvement in a police-reported crash. It was found that even though adding the interaction terms to the injury risk and injury severity models significantly affected the models, the addition of these terms did not drastically affect the relative crashworthiness rankings for market groups between different demographic groups. With a few of exceptions, types of vehicles that Newstead et al (2006) ranked as being safe for a standardised set of drivers were in general safe for drivers grouped by their age and sex. The same can be said for types of vehicles that Newstead et al (2006) rated as performing poorly for a standardised set of drivers. For instance, Large Cars, Luxury Cars and Large to Medium Four Wheel Drive vehicles were found to offer good protection to older females, however these vehicles generally offered good protection to all drivers. This suggests that the safety benefits that these larger cars and Medium to Large Four Wheel Drives provide are not limited to older females. Furthermore, Small and Light Cars were poor choices in terms of crashworthiness for all demographics

Some exceptions to this general pattern of results were that Commercial Vans ranked poorly in terms of crashworthiness for all female age groups, but received neither poor nor good rankings for male drivers. Conversely, People Movers were ranked poorly for males but could not be classified as poor performers or good performers for females. For drivers aged 25 years or less, Commercial Utilities received a poor crashworthiness ranking for female drivers but a good ranking for male drivers, while the opposite was true for Compact Four Wheel Drive vehicles within this age group: achieving a poor ranking for young males and a good ranking for young females.

However, aside from these exceptions, the study showed that the relative crashworthiness of most market categories did not differ when ratings specific to different driver demographics were derived. This suggests that the vehicle safety ratings published by Newstead et al (2006) are on the whole applicable for drivers of all demographics.

Unfortunately there were insufficient data to examine the effect of driver age and gender on the crashworthiness rankings of different models of vehicles. However, based on the results of the present study, many models will probably offer a similar level of protection for all road users, but some models may offer better protection for some demographics when compared to others. It would be interesting to study whether vehicles designed to perform well in crash test programs such as the New Car Assessment Program exhibit poor crashworthiness odds ratios for occupants outside of the demographic focused on in the optimisation process. Other directions for further research have also been suggested.

ACKNOWLEDGMENTS

A project like this could not have been carried out without the help and support of a number of people. The authors particularly wish to acknowledge:

- Mr David Attwood of the Transport Accident Commission (TAC) for the provision of TAC claims data and Ms Samantha Cockfield of the TAC for her support of the project.
- VicRoads Information Services Division for the provision of data from Victorian Police crash reports.
- Mr Geoff Murray, Mr Wesley Soet and Ms Shuk Jin of the Department of Main Roads Western Australia for the provision of data from Western Australia Police crash reports.
- Mr Ken Brandis of the Western Australian Department for Planning and Infrastructure for the provision of Western Australia registration data.
- Mr Steve Lippett of the Department for Transport, Energy and Infrastructure of South Australia for the provision of data from South Australia Police crash reports and Mr Harry McDonald of the Department for Transport, Energy and Infrastructure of South Australia for the matching of registration data to South Australia crash data.
- Officers of the Data Analysis Unit of Queensland Transport for the provision of data from Queensland Police crash reports and the Queensland vehicle registration system.
- Mr Tony Kursius of Queensland Transport for assistance with facilitating the provision of data from the Queensland vehicle registration system.
- Mr Dan Leavy of the New South Wales Roads and Traffic Authority (RTA) for his support of the project and the release of data from NSW Police crash reports.
- Mr Jack Haley of NRMA Motoring and Services for his support of the project and for providing procedures to determine the models of vehicles crashing in NSW, Victoria and Queensland.
- Ms Maria Pappas of NRMA who developed and applied the procedures to determine the models of vehicles recorded in the police crash reports through decoding of Vehicle Identification Numbers.
- Mr John Goldsworthy of the Australian Federal Department of Infrastructure, Transport, Regional Development and Local Government for his support of the project.
- Mr Mike Upton of the RACWA for his support for the project and assistance with facilitating the supply of Western Australian crash data.
- Mr Ross McArthur and Chris Jones of VicRoads for their support of the project.
- Mr Michael Case and Nick Platt of the RACV for their support of the project and for advice on substantive changes in designs of specific models over the years.

- Mr John Gibson, Mr Iain Cameron, Mr Roger Farley and Teresa Rechichi of the Western Australian Office of Road Safety for their support of the project.
- Professor Caroline Finch, Mr Tri Minh Le, Mr Michael Skalova and Ms Chau My Le, all formerly of MUARC, for the development of the analysis methods in earlier years that formed the basis of the methods used in this report.
- Dr Alan Miller, formerly of the CSIRO Division of Mathematics and Statistics for suggesting analysis methods used in this report to improve the sensitivity of the results and to determine the confidence limits of the estimates.
- Officers of the Victorian, NSW, Western Australian, Queensland, South Australia and New Zealand Police Forces and of the Transport Accident Commission who diligently recorded the information on crashes and injuries which formed the basis of this report.
- Dr Barbara Bibby, Mr John White and Ms Anne Logan of Land Transport NZ for their enthusiastic support of the project.
- Mr Stuart Badger of Land Transport NZ for supply of the New Zealand crash data and advice on its use in the project.
- Mrs Carol Hewitt and Kheang Chrun of Land Transport NZ for supply of the New Zealand vehicle registration data and advice on its use in the project.
- Mr Stuart Worden of Land Transport NZ and Mr Tijs Robinson, a former contractor to the former LTSA, for their advice on specifications and sources of information on New Zealand vehicle models.
- Mr Eugene Girardin of Land Transport NZ for advice on the New Zealand used import vehicle market and the handling of these vehicles by Land Transport NZ.
- Ms Stella Stocks of AA New Zealand for her support of the project.
- Mr Steve Spalding of the Royal Automobile Club of Queensland for his support of the project.
- Mr Mark Borlace of RAA South Australia for his support of the project.
- Henry Schleimer and Mike Stapleton of Queensland Transport for their support of the project.
- Mr Davit Tarant and Ms Sujanie Peiris from MUARC for their assistance in collecting information on Vehicle Identification Numbers and dates of key vehicle model introductions.

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THE INTERACTION BETWEEN RELATIVE VEHICLE SECONDARY SAFETY AND DRIVER DEMOGRAPHICS

1. INTRODUCTION

1.1 Background, Project Motivation and Aims

Vehicle designers often claim that different vehicle design parameters are required for optimising vehicle safety for particular crash types or demographics with these optimisation profiles often differing significantly depending on the target circumstances. For example, it is sometimes claimed that a vehicle that is optimised for protection of young occupants at predominantly high impact speeds may pose a greater injury risk to older occupants at lower impact speeds than a vehicle optimised specifically to protect older occupants at low impact speed. The European Vehicle Passive Safety Network's (2003) report on *Smart Restraint Systems* provides some background on such claims. Indeed, the New Car Assessment Program (NCAP) is sometimes criticised by manufacturers on the basis that it forces optimisation of vehicle safety characteristics for too narrow a range of occupant and crash characteristics which may be detrimental to optimisation across a broader range of circumstances (e.g. Norin, Koch, Ryrberg & Svensson, 1995; O'Donnell, 2003; English, 2004). It is argued that the best optimisation of occupant protection characteristics should reflect the profile of occupant and crash characteristics associated with the fleet in which the vehicle will operate.

The broad aim of the Used Car Safety Ratings (UCSR) system (Newstead et al, 2006) is to estimate vehicle secondary safety ratings that are, as far as possible, free of the effect of non-vehicle factors. The ratings reflect the relative injury outcomes for drivers of different types of vehicles involved in real crashes. Non-vehicle factors (such as driver age, driver sex, the speed zone of the crash and the crash type) affect injury outcomes when a crash occurs and, as these factors do not have a uniform influence across different types of vehicles, these non-vehicle factors must be adjusted for if the ratings are to be considered an accurate and reliable measure of a vehicle's secondary safety. A complex statistical analysis process was developed by Cameron et al (1994) to adjust for the biasing influence of these non-vehicle factors. The UCSR estimates resulting from this process reflect the average driver injury outcome across the standardised profile of driver demographics and crash circumstances for each make and model considered.

This study aimed to use the UCSR data and methodology to investigate claims that the relative occupant protection provided by various vehicle models or market groups differs depending on the occupant characteristics (such as age and gender) and the crash characteristics. Therefore, this project aimed to test whether relative vehicle safety performance between vehicles differs depending on driver age and gender. The project investigated relative safety performance for different groups of drivers by developing extensions of the logistic regression models previously developed by Newstead et al (2006) for the UCSR project. The models developed by Newstead et al (2006) were extended by considering interactions between vehicle market group and driver demographics in determining injury outcome in terms of injury risk and severity. Testing whether such interactions have a significant influence on injury risk and injury severity is equivalent to testing the claim that injury risk and injury severity for a particular car is dependent on the occupant characteristics. The results of the analysis have been discussed in the light of claims

by some critics of the NCAP protocol that specific crash test results are not a good indication of broader safety performance.

1.2 Literature Review

A review of the literature found that few studies have sought empirical evidence as to whether the relative occupant protection provided by various vehicle models or market groups differs depending on occupant characteristics such as age and gender. A study, published in *Accident Analysis and Prevention* in 2006 (Hill and Boyle, 2006) assessed the relative risk of severe injury in automotive crashes for older female occupants. A logistic regression model was used to predict injury severity for individuals involved in a crash. This study identified female and older occupants as having a significantly higher risk of severe injuries in a crash compared with male and younger occupants. They also found that occupants of light trucks, sport utility vehicles (SUVs) and vans have a reduced risk of injury (OR=.86) with older females having an even greater reduction in risk of severe injury while occupying these vehicles. Females aged between 55 and 74 years occupying these vehicles were found to be 1.34 times less likely to be severely injured compared with this same group in passenger cars. Females aged 75 years or older had an even greater benefit, as they were 1.47 times less likely to suffer severe injuries than similarly aged females in passenger cars. The researchers concluded that when older females were in a crash they appeared to be less at risk of severe injury when they were occupants of larger vehicles.

Another study published in *Accident Analysis and Prevention* in 2003 (Kweon and Kockelman, 2003) considered overall injury risk to different drivers: combining exposure, frequency and severity models. This study found that female drivers are at higher risk of dying when compared with males under the same crash circumstances and stated that this could be explained by females being more likely to suffer severe injury from a crash's impact than males. It was also suggested that females typically have less driving experience than males (with males on average driving 50% more frequently than females) and that this may mean that they are not as adept at responding effectively to reduce the severity of the crash in circumstances where a crash is imminent. They also found that female drivers are at greater risk than males in SUVs, pickups and minivans, but young and middle-aged males are more vulnerable in passenger cars and that young drivers are at a higher risk of receiving severe injuries than middle-aged or older drivers. A study published in *Journal of Safety Research* in 2003 (Austin and Faigin, 2003) examined injury risk and differences in injuries across age groups and found that the observed increased injury risk for older occupants may be due to older occupants being more likely to travel in passenger cars than younger people who frequently use light trucks.

Many studies have considered whether injury may be attributed to driver gender or age without consideration of vehicle model or market group influence. Some of these studies have concluded that the relationship between increased injury risk and age and sex was because age and sex correlated with other physical characteristics. For example, a study published in *Accident Analysis and Prevention* in 1994 (Dischinger et al, 1994) determined that the incidence of lower extremity fractures for women drivers was a function of driver height rather than driver gender, with an increase in incidents of this injury among shorter drivers, most of whom are women. Another published in the *Journal of Traffic Medicine* in 2001 (Evans, 2001) estimated that risk of death from the same physical impact changes as people age. The study found that after age 20, the risk of death from the same impact increased at compound rates. Specifically, it was estimated that the risk of death increased by $2.52 \pm 0.08\%$ per year for males and $2.16 \pm 0.1\%$ per year for females, resulting in risk of death for

70 year old males being 250% greater than that for 20 year old males, while corresponding increase in risk for females was a 190% increase.

Similarly, a study published in *Accident Analysis and Prevention* in 2002 (Bedard et al, 2002) examined the independent contribution of driver, crash, and vehicle characteristics to driver fatalities. It was found that fatal injury risk increased with age and female vehicle occupants had higher fatality odds compared with males. As a consequence it was suggested that specific safety needs of older drivers and females may need to be addressed separately from those of men and younger drivers. Another study published in *Transportation and Research* in 2006 (Welsh et al, 2006) examined crash characteristics and injury outcomes for older passenger car occupants by comparing injury outcomes in passenger car crashes for belted occupants of different ages. It was found that older occupants were more likely to be killed or to sustain a serious injury. Female occupants were also identified as having a significantly higher risk of severe injuries. For occupants involved in frontal impacts or struck-side impacts, those aged 65 years or older had a significantly higher risk of death than younger occupants. Furthermore, when drivers received a serious chest injury in a frontal impact, the injury was more often associated with seat belt loading for older drivers while such injuries were more frequently associated with steering wheel contact for younger drivers. The study concluded that such differences in the rate and type of injury for occupants of different ages indicated a need to consider variation in injury tolerance among the car occupant population when designing restraint systems.

2. DATA

The crash data used in the present investigation of the effect of driver demographics on secondary safety ratings were the same data used to produce the 2006 update of the Used Car Safety Ratings by Newstead et al (2006). The data included police-reported crashes from five jurisdictions: Victoria, New South Wales, Queensland, Western Australia and New Zealand. The data were also restricted to crashes involving light passenger vehicles including cars, station wagons, four wheel drive vehicles, passenger vans, and light commercial vehicles manufactured over the period 1982-2004 and crashing during the years 1987-2004.

As part of the 2006 Update of the Used Car Safety Ratings, vehicles were classified into one of twelve market group classifications, comprising 7 classes of regular passenger cars (Light, Small, Medium, Large, People Movers, Sports and Luxury), 3 classes of four wheel drive (4WD) vehicles which are also known as Sports Utility Vehicles (4WD Compact, 4WD Medium and 4WD Large) and two classes of commercial vehicles (Van and Utility). The same market group classifications were adopted for the present study.

3. ANALYSIS METHODOLOGY

The effect of driver age and driver sex on the relative crashworthiness ratings of vehicles grouped by market group was analysed using the injury risk and injury severity covariate models developed by Newstead et al (2006) for their Used Car Safety Ratings. These logistic models adjusted for the effect of non-vehicle factors on injury risk and injury severity outcomes. Sections 3.1 and 3.2 briefly explain how odds ratios of outcomes for different groups of subjects can be derived from such logistic regression models, while Section 3.3 provides introduces the covariate models developed by Newstead et al (2006). Section 3.4 then explains how these covariate models were used in the present study.

3.1 The logistic model

A logistic regression equation predicts the natural log of the odds for a subject being in one category compared to another category. Thus, the general logistic model of a probability, P , can be written as:

$$\log(\text{odds}) = \log \text{it}(P) = \ln\left(\frac{P}{1-P}\right) = \beta_0 + \beta_1 X_1 + \dots + \beta_k X_k = f(X) \quad . \quad (3.1)$$

That is, the log of the odds is expressed as a linear function of k associated variables or their interactions, $X_i, i=1, \dots, k$. From this point forward, this linear function, $f(X)$, will be referred to as the logit function.

When testing the likelihood of an event occurring, for subjects that share the same value for a particular factor, the odds ratio for the event is the odds for the group of subjects compared to the odds for a reference group of subjects. For example, for subjects where the factor takes the value X , the odds ratio compared to the reference category is expressed as

$$OR_X = \left(\frac{P_X}{1-P_X}\right) \bigg/ \left(\frac{P_{ref}}{1-P_{ref}}\right) \quad (3.2)$$

where P_X is the probability of the event occurring given the factor takes the value X , while P_{ref} is the probability of the event occurring given the factor is equal to the reference value.

When using logistic regression to model the odds of the event, for other groups of subjects that have a different value for the same factor, the odds ratio is also normalised using the odds for the same reference category. Since each value in the factor that differentiates between the groups is normalised using the odds from the same reference category, it is not actually necessary to know the odds for the reference category to compare the odds for the non-reference groups: the odds ratios are a relative measure of risk which allow the risk between the different categories to be compared against each other.

The regression coefficients in a logistic regression equation can be used to estimate odds ratios for each of the independent variables or their interactions. Estimates of the parameter coefficients of the logit function can be obtained by maximum likelihood estimation (Hosmer & Lemeshow, 1989). Where no interaction exists, the odds ratio (OR) for an independent variable can be computed by raising e to the power of the logistic coefficient,

$$OR = e^{\hat{\beta}_i} \quad (3.3)$$

The exponent of the logistic coefficient gives the effect of the independent variable on the odds ratio. For example if $e^{\hat{\beta}_i} = 2$, then a one unit change in the independent variable X_i would make the event twice as likely to occur. The following section provides an example of how odds ratios can be derived from the parameter coefficients of the logit function where there is an interaction between two factors.

Confidence limits for odds ratios are obtained by computing the confidence limits for the logs odds ratio (the logistic regression coefficient) and then taking raising the exponential constant

to the power of these limits to obtain limits for the odds ratio. The limits for the coefficient are of the form:

$$\hat{\beta}_i \pm z_{1-\alpha/2} \times \text{SE}\left(\hat{\beta}_i\right)$$

and so the corresponding limits for the odds ratio can be expressed as:

$$\exp\left[\hat{\beta}_i \pm z_{1-\alpha/2} \times \text{SE}\left(\hat{\beta}_i\right)\right]. \quad (3.4)$$

3.2 Odds ratio estimates in the presence of interaction

When there is interaction between two independent variables, the estimate of the odds ratio for each of the variables depends on the value of the other variable with which it is interacting. The odds ratio in this situation is not the exponential of the estimated coefficient as in equation 3.3 but is the exponential of the difference of the logit functions. Consider two covariate variables, one denoted F and the other X and their interaction $F \times X$. If we are interested in the odds ratio comparing two levels of F (e.g. $F = f_1$ versus $F = f_0$ at $X = x$) we evaluate equation 3.1 for the two levels of F and subtract as follows:

$$\begin{aligned} \ln[OR(F = f_1, F = f_0, X = x)] &= f(f_1, x) - f(f_0, x) \\ &= (\hat{\beta}_0 + \hat{\beta}_1 f_1 + \hat{\beta}_2 x + \hat{\beta}_3 f_1 \times x + \dots) - (\hat{\beta}_0 + \hat{\beta}_1 f_0 + \hat{\beta}_2 x + \hat{\beta}_3 f_0 \times x + \dots) \\ &= \hat{\beta}_1(f_1 - f_0) + \hat{\beta}_3 x(f_1 - f_0). \end{aligned} \quad (3.5)$$

The odds ratio is equal to the exponential of equation 3.5, giving

$$OR = \exp\left[\hat{\beta}_1(f_1 - f_0) + \hat{\beta}_3 x(f_1 - f_0)\right]. \quad (3.6)$$

Equation 3.6 involves two coefficients, the difference in the values of the covariate F and X , the variable with which the covariate F interacts.

Confidence limits for odds ratios are obtained by computing the exponential of the confidence limits for the log odds ratio.

The limits for the log-odds ratio of equation 3.5 are of the form:

$$\left[\hat{\beta}_1(f_1 - f_0) + \hat{\beta}_3 x(f_1 - f_0)\right] \pm z_{1-\alpha/2} \times \text{SE}\left(\hat{\beta}_1(f_1 - f_0) + \hat{\beta}_3 x(f_1 - f_0)\right) \quad (3.7)$$

where the standard error in equation 3.7 is the positive square root of the variance estimator

$$\text{Var}[\hat{\beta}_1(f_1 - f_0) + \hat{\beta}_3 x(f_1 - f_0)] = (f_1 - f_0)^2 \times \text{Var}(\hat{\beta}_1) + [x(f_1 - f_0)]^2 \times \text{Var}(\hat{\beta}_3)$$

$$+ 2x(f_1 - f_0)^2 \times \widehat{Cov}(\hat{\beta}_1, \hat{\beta}_3). \quad (3.8)$$

3.3 Covariate models

Extensions of the logistic regression models used to derive the Used Car Safety Ratings of Newstead et al (2006) were used to consider interactions between vehicle market group and driver demographics in determining injury outcome in terms of injury risk (R) and injury severity (S). Injury risk was defined as the probability that a driver involved in a crash was injured, while injury severity was defined as the probability that an injured driver was hospitalised or killed. Crashworthiness (C) was defined as the product of injury severity and injury risk, i.e. $C = R \times S$.

A thorough description of the logistic covariate regression models used to produce the Used Car Safety Ratings can be found in Newstead et al (2006). These logistic regression models adjust simultaneously for the effect of a number of factors on probabilities of injury risk and injury severity. Such factors include driver age and sex, number of vehicles involved and the speed zone in which the crash occurred. Separate logistic covariate models are derived for injury risk and injury severity. Each model enables identification of possible factors, other than vehicle design, that might have influenced driver injury risk or driver injury severity. It is important to derive separate logistic regression models for injury risk and injury severity as it was likely that the various non-vehicle factors would have different levels of influence on each of the two outcome variables. A stepwise procedure was used to identify which factors had an important influence in each model.

In addition to the factors mentioned above, the jurisdiction of crash was also included in the logistic covariate models because each jurisdiction had its own level of general road safety performance and some models are driven more in some jurisdictions than others. Including the jurisdiction factor also controlled for reporting biases caused by differences between jurisdictions in the criteria for a crash to be included in police-reported data. It was also necessary to include the year of crash indicator in the logistic covariate models to adjust for the different trends in crash severity over time.

The logistic covariate modelling was done without considering the influence of vehicle-related factors such as model, year of manufacture and market group, as these models were designed to determine which non-vehicle factors were most likely to have had an influence on crash outcomes. Including vehicle-related variables in the covariate models would have made it difficult to include non-vehicle-related variables in the covariate models in the stepwise procedure.

For both the injury risk and injury severity covariate models, a stepwise procedure was used to identify which factors and their interactions made a significant contribution to each model. All possible first and higher order interactions were considered between all factors in the model. A hierarchical structure was imposed so that interaction between two variables was included in the model only when the corresponding main effects were also included.

The following covariates and interaction terms were significantly associated with injury risk and were included by Newstead et al (2006) in their covariate logistic model for injury risk:

Base effect terms: passenger vehicle driver sex (sex), passenger vehicle driver age (age), speed zone of crash (speedzone),

number of vehicles involved (nveh), state of crash (state), year of crash (year).

First order interaction terms: speedzone*nveh, sex*nveh, sex*age, age*nveh, speedzone*age, state*year, nveh*state, nveh*year, age*state, age*year, speedzone*year, speedzone*state, sex*speedzone.

Second order interaction terms: age*speedzone*nveh, sex*speedzone*nveh, speedzone*year*nveh, speedzone*year*state, speedzone*nveh*state, state*year*nveh, age*state*nveh, age*speedzone*state.

No other variable or interaction term significantly improved the fit of the logistic model.

Newstead et al (2006) found that the following terms were significantly associated with injury severity and were included in their covariate logistic model for injury severity:

Base effect terms: passenger vehicle driver sex (sex), passenger vehicle driver age (age), speed zone of crash (speedzone), number of vehicles involved (nveh), state of crash (state), year of crash (year).

First order interaction terms: sex*state, speedzone*nveh, sex*age, age*nveh, speedzone*age, state*year, nveh*state, nveh*year, age*state, age*year, speedzone*year, speedzone*state, sex*speedzone.

Second order interaction terms: age*state*year, speedzone*year*nveh, speedzone*year*state, speedzone*nveh*state, state*year*nveh, age*state*nveh, age*speedzone*state.

Third order interaction terms: speedzone*state*year*nveh.

No other term significantly improved the fit of the logistic model.

3.4 Assessing vehicle market group and driver demographic interaction effects

The previous section describes how Newstead et al (2006) developed two covariate models: one to measure injury risk and the other to measure injury severity.

It is at this point that the methodology of the present study deviates from that of Newstead et al (2006). Once both covariate models had been finalised, Newstead et al (2006) added a variable differentiating each model of vehicle to each covariate model. This allowed estimation of the crashworthiness of different models of vehicles. To model crashworthiness for different market groups, a variable differentiating the twelve market groups was added to each covariate model. Newstead et al (2006) applied the same procedure to model crashworthiness of vehicles grouped by year of manufacture.

When Newstead et al (2006) added one of the three vehicle-related variables to the covariate models, the vehicle-related variables were only added as main effect variables because it was

not considered appropriate to allow interaction between vehicle-related variables and non-vehicle-related factors as this would give relative vehicle crashworthiness estimates between models or market groups that were dependent on crash circumstance and occupant characteristics. Only the average crashworthiness across a standardised set of crash circumstances and occupant characteristics was of interest. By contrast, to fulfil the aim of the present study it was necessary to differentiate between different occupant characteristics when estimating the crashworthiness of vehicles.

Therefore, in the present study, a term representing car market group was added to each of the two covariate models along with another term that represented the first order interaction between market group and the age of the driver as well as a term that represented the first order interaction between market group and the sex of the driver. Therefore, the logistic regression model for injury risk now included all the base effects and interaction terms that were found to be statistically significantly related to the outcome variable in the stepwise modelling procedure described in Section 3.3, as well as a market group base-effect and two first order interaction terms: one between market group and driver age and the other between market group and driver sex. The logistic regression model for injury severity also included the non-vehicle-related base effects and interaction terms mentioned in the previous section as well as the market group base-effect and the two terms representing the first order interaction between market group and driver age and market group and driver sex. Coefficients for individual market groups along with coefficients for interaction terms between these market categories and age and sex were computed.

Each of the variables included in the injury risk and injury severity logistic regression models were defined in such a way that each estimated coefficient of the two models represented the log of the odds ratio of one variable level relative to another chosen level. For each variable, each level was compared against a particular reference level. The reference level to which other levels are compared is sometimes termed the baseline of the variable. The reference level for each variable was chosen in a purely arbitrary manner. In this analysis, males, the age group 26-59 years and Compact Four Wheel Drives were chosen as the reference level for factors sex, age and market group respectively.

Odds ratio estimates of the interaction terms for injury risk and injury severity relative to the reference categories were obtained by computing the exponential of the difference of the logit equations for the non-reference category and the reference category (see equations 3.5 and 3.6). The precision of the odds ratio estimates of the interaction terms for injury risk and injury severity was measured by the width of 95% confidence intervals calculated using equations 3.7 and 3.8.

All data were analysed using the logistic regression procedure of the SAS statistical package (SAS, 1989). Each factor in the model, including year of crash, was treated as categorical to allow maximum flexibility in the relationship between each factor and the outcome measure. Estimates of the coefficients of the logit function, $\hat{\beta}_i, i = 1, \dots, k$, together with their associated standard errors, were obtained by maximum likelihood estimation.

4. RESULTS

The following sections provide results of estimating how estimates of the safety of vehicles grouped by market category changes for drivers of different demographic groups. Section 4.1 provides estimates of driver injury risk for different market groups and for different groups of drivers defined by age or sex, while Section 4.2 provides estimates of the risk that an injured

driver is seriously injured for different market groups and for drivers of different demographic groups. Finally Section 4.3 uses the results of the sections that preceded it to estimate the crashworthiness of different market groups when they are driven by drivers belonging to demographic groups defined by age or sex.

4.1 Injury Risk

Injury risk was estimated from the data on 2,106,456 drivers involved in tow-away crashes in NSW, Queensland and Western Australia during 1987-2004. These data were compiled for the Used Car Safety Ratings project (Newstead et al, 2006). This data set is referred to as the "involved drivers". Missing values in one or more of the factors driver sex, driver age, speed zone and the number of vehicles involved in the crash, meant that 1,231,772 of the 2,106,456 involved drivers were included in the final dataset used to build the injury risk model. Of these drivers, 219,185 were injured.

When the term representing passenger vehicle market group was added to the injury risk covariate model described in Section 3.3, it was found that the market group variable was significant. Adding the market group variable to the injury risk covariate model enabled comparison of the odds that the driver of a vehicle was injured for vehicles of different market groups. As the category of Compact Four Wheel Drive vehicles was selected as the reference category, the odds for each of the remaining market group were compared against the odds for Compact Four Wheel Drive vehicles. The 95% confidence interval of each market group was calculated using equation 3.4. Figure 1 shows the relative odds of driver injury for each market category compared to Compact Four Wheel Drive vehicles. An odds ratio of one indicated that the odds of driver injury did not differ to the odds for drivers of Compact Four Wheel Drive vehicles.

The odds ratios presented in Figure 1 represent the relative odds for a driver being injured for vehicles differentiated by market group. The odds ratios presented in Figure 1 do not distinguish between drivers of different demographic groups. Odds ratios for different market groups disaggregated by age and gender can be derived by adding first order interaction terms between market group and driver age and market group and the sex of the driver to the model used to derive the odds ratios presented in Figure 1. When these two terms were added to the injury risk model it was found that they were both significant. The Type 3 analysis of effects are included in Table A1 of Appendix A, while Table A2 gives the estimated coefficients, standard errors, Wald Chi-square test statistic, p-values and 95% confidence intervals for the estimated coefficients used to derive results presented in this section, which included the market group, sex and age main effects variables, as well as the market group and sex of driver interaction variable and the market group and age of driver interaction variable.

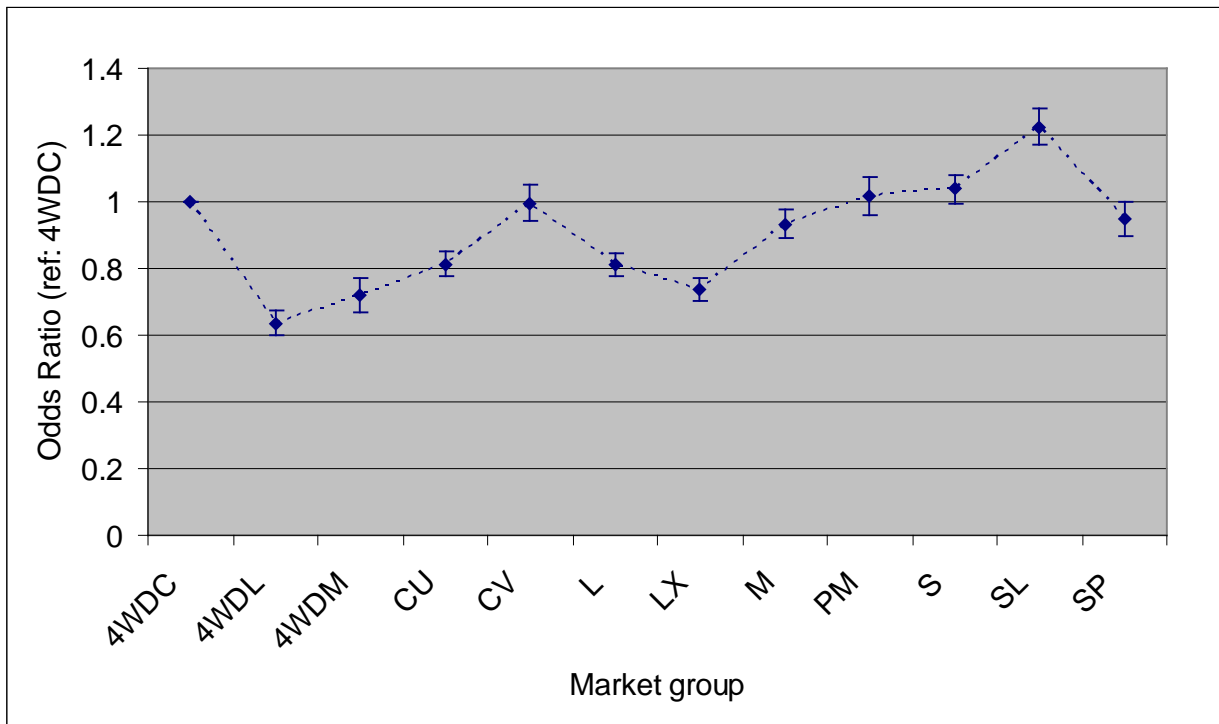


Figure 1: Estimated injury risk odds ratios by market group

The following section describes how estimates of injury risk for vehicles of different market categories change depending on the sex of the driver. This is followed by a section that describes the extent to which the age of the driver affects the estimate of injury risk for each market group.

4.1.1 The effect of driver gender on injury risk estimates for each market group

Recalling Section 3.2, when there is an interaction between two independent variables, the estimate of the odds ratio for one of the variables depends on the value of the other variable with which it shares an interaction term in the logit. The odds ratio for the variable is the exponential of the difference between the two logit functions. In the first of the logit functions, the category for which the odds ratio is being estimated is substituted, while for the second logit function, the reference category is substituted. All other values remain constant between the two logit functions. The exponential of this difference will give the odds ratio of injury risk for the first category compared to the reference category. This process is described in equations 3.5 and 3.6 of Section 3.2.

Section 3.3 described how the covariate model for injury risk devised by Newstead et al (2006) included six main effects, thirteen first order interactions and eight second order interactions. This meant that the logit function for the covariate model was a linear function of 27 sets of terms. Adding the market group main effect and the two first order interactions (between market group and driver sex and market group and driver age) increases to thirty the number of sets of terms in the logit function used to estimate injury risk for different market categories within different groups of drivers. However, since the injury risk odds ratios for different market groups and for different driver groups are estimated by taking the exponential of the difference of two logit functions that differ from each with respect to the market group variable only, for present purposes, the logit function can be simplified as

$$\begin{aligned}
& f(X_{mktgrp}, X_{mktgrp*sex}, X_{mktgrp*age}, Y) \\
& = \beta_{mktgrp} X_{mktgrp} + \beta_{mktgrp*sex} X_{mktgrp*sex} + \beta_{mktgrp*age} X_{mktgrp*age} + g(Y) \quad (4.1)
\end{aligned}$$

where $g(Y)$ is a linear function of parameters and variables that do not include market group either as a main effect term or as a member of an interaction term. For each combination of driver age, driver sex and market group, the values of each term in the sum represented in equation 4.1 can be read from Table A2 of Appendix A.

Therefore, following equation 3.5, the difference of the two logit functions used to estimate the injury risk odds ratio for a particular market group compared to the reference market group (Compact Four Wheel Drive vehicles) for drivers grouped by age and sex can be written as:

$$\begin{aligned}
& f(X_{mktgrp}, X_{mktgrp*sex}, X_{mktgrp*age}, Y) - f(X_{4WDC}, X_{4WDC*sex}, X_{4WDC*age}, Y) \\
& = \beta_{mktgrp} X_{mktgrp} + \beta_{mktgrp*sex} X_{mktgrp*sex} + \beta_{mktgrp*age} X_{mktgrp*age} + g(Y) \\
& \quad - (\beta_{4WDC} X_{4WDC} + \beta_{4WDC*sex} X_{4WDC*sex} + \beta_{4WDC*age} X_{4WDC*age} + g(Y)) \\
& = \beta_{mktgrp} X_{mktgrp} + \beta_{mktgrp*sex} X_{mktgrp*sex} + \beta_{mktgrp*age} X_{mktgrp*age} \\
& \quad - (\beta_{4WDC} X_{4WDC} + \beta_{4WDC*sex} X_{4WDC*sex} + \beta_{4WDC*age} X_{4WDC*age}) \quad (4.2)
\end{aligned}$$

Furthermore, as the Compact Four Wheel Drive category was chosen as the reference level for the market group variable, the following hold:

$$X_{4WDC} = 0; \quad (4.3a)$$

$$X_{4WDC*sex} = 0; \quad (4.3b)$$

$$X_{4WDC*age} = 0 \quad (4.3c)$$

for all levels of driver age and sex.

Substituting equations 4.3a, 4.3b and 4.3c into equation 4.2 gives

$$\begin{aligned}
& f(X_{mktgrp}, X_{mktgrp*sex}, X_{mktgrp*age}, Y) - f(X_{4WDC}, X_{4WDC*sex}, X_{4WDC*age}, Y) \\
& = \beta_{mktgrp} X_{mktgrp} + \beta_{mktgrp*sex} X_{mktgrp*sex} + \beta_{mktgrp*age} X_{mktgrp*age} \cdot \quad (4.4)
\end{aligned}$$

Equation 4.4 can be used to estimate the odds ratio of injury risk for male drivers for each market group compared to the injury risk for male drivers of Compact Four Wheel Drive vehicles by substituting $\beta_{mktgrp*sex} X_{mktgrp*sex} = 0$ as males were previously chosen as the reference category for the sex main effect variable and for interaction variables involving the sex of the driver. Therefore, from equation 3.6 in Section 3.2, the odds ratio for injury risk for

male drivers of a particular market group compared to male drivers of Compact Four Wheel Drive vehicles is

$$OR_{males} = \exp[\beta_{mktgrp} X_{mktgrp} + \beta_{mktgrp*age} X_{mktgrp*age}] \quad (4.5)$$

and the 95% confidence interval is equal to

$$\exp[\beta_{mktgrp} X_{mktgrp} + \beta_{mktgrp*age} X_{mktgrp*age} \pm z_{1-\alpha/2} \times SE(\beta_{mktgrp} X_{mktgrp} + \beta_{mktgrp*age} X_{mktgrp*age})] \quad (4.6)$$

where $SE(\beta_{mktgrp} X_{mktgrp} + \beta_{mktgrp*age} X_{mktgrp*age})$

$$= \sqrt{Var(\beta_{mktgrp}) + Var(\beta_{mktgrp*age}) + 2 \times Cov(\beta_{mktgrp}, \beta_{mktgrp*age})}. \quad (4.7)$$

The values of all the terms in equation 4.5 are listed in the second column of Table A2 of Appendix A. This table also provides estimates of the standard error of each term, which can be squared to derive the variance terms to be substituted into equation 4.7. The SAS program also provides a feature that gives the covariance of each pair of terms used in the model. Since many terms were used to construct the injury risk by market group and driver sex model, only covariance terms relevant to the present analysis have been listed in Table A3 of Appendix A.

Equation 4.4 can also be used to estimate the odds ratio of injury risk for female drivers for each market group compared to the injury risk for female drivers of Compact Four Wheel Drive vehicles. However, as the female category was not the reference category for the driver gender variable, the $\beta_{mktgrp*sex} X_{mktgrp*sex}$ in equation 4.4 is not equal to zero. Therefore, the odds ratio for injury risk for female drivers of a particular market group compared to females of Compact Four Wheel Drive vehicles is

$$OR_{females} = \exp[\beta_{mktgrp} X_{mktgrp} + \beta_{mktgrp*female} X_{mktgrp*female} + \beta_{mktgrp*age} X_{mktgrp*age}] \quad (4.8)$$

and the 95% confidence interval is equal to

$$\exp[\beta_{mktgrp} X_{mktgrp} + \beta_{mktgrp*female} X_{mktgrp*female} + \beta_{mktgrp*age} X_{mktgrp*age} \pm z_{1-\alpha/2} \times SE(\beta_{mktgrp} X_{mktgrp} + \beta_{mktgrp*female} X_{mktgrp*female} + \beta_{mktgrp*age} X_{mktgrp*age})] \quad (4.9)$$

where $SE(\beta_{mktgrp} X_{mktgrp} + \beta_{mktgrp*female} X_{mktgrp*female} + \beta_{mktgrp*age} X_{mktgrp*age})$

$$= \sqrt{Var(\beta_{mktgrp}) + Var(\beta_{mktgrp*female}) + Var(\beta_{mktgrp*age}) + 2 \times Cov(\beta_{mktgrp}, \beta_{mktgrp*female}) + 2 \times Cov(\beta_{mktgrp}, \beta_{mktgrp*age}) + 2 \times Cov(\beta_{mktgrp*female}, \beta_{mktgrp*age})}. \quad (4.10)$$

The values of the terms in equations 4.9 and 4.10 can be derived using Tables A2 and A3 of Appendix A.

Equations 4.5 and 4.8 both contain an interaction term between market group and age. This means that injury risk odds ratios for different vehicle market groups and for male and female drivers are estimated at each of the three driver age levels (i.e. less than or equal to 25 years,

26 to 59 years, greater or equal to 60 years). Table 1 presents the estimates of the injury risk odds ratios for market groups within each sex category for drivers aged 26 to 59 years. These estimates of odds ratios were derived by applying equation 4.5 (for males) and equation 4.8 (for females). The table also shows the 95% confidence interval for each odds ratio, which were estimated using equations 4.6 and 4.7 (for males) and equations 4.9 and 4.10 (for females). Analogous results for the 25 years or younger age group and the 60 years or greater age groups are presented in Tables A4 and A5 of Appendix A.

Table 1: *Estimated injury risk odds ratios for market group within driver sex and 95% confidence intervals (for drivers aged 26-59 years only)*

Driver sex	Market group	Odds Ratio	95% Confidence interval	
Male	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	0.58	0.53	0.63
	Medium Four Wheel Drive	0.69	0.61	0.77
	Commercial - Ute	0.74	0.68	0.80
	Commercial - Van	0.88	0.81	0.96
	Large	0.76	0.70	0.81
	Luxury	0.73	0.67	0.79
	Medium	0.88	0.82	0.95
	People Mover	1.05	0.96	1.15
	Small	0.98	0.91	1.05
	Light	1.21	1.12	1.31
	Sports	0.87	0.80	0.96
	Female	Compact Four Wheel Drive	1.00	
Large Four Wheel Drive		0.69	0.63	0.76
Medium Four Wheel Drive		0.76	0.68	0.85
Commercial - Ute		0.99	0.92	1.08
Commercial - Van		1.29	1.16	1.44
Large		0.94	0.88	1.00
Luxury		0.83	0.77	0.90
Medium		1.08	1.00	1.15
People Mover		1.05	0.96	1.15
Small		1.20	1.12	1.28
Light		1.41	1.32	1.51
Sports		1.13	1.03	1.23

Odds ratio estimates for market groups within each driver sex category that are significantly ($p < 0.05$) different to that for Compact Four Wheel Drive vehicles have been highlighted

It is also possible to estimate the injury risk odds ratios for market groups within each sex category for drivers of all ages by not including the interaction between market group and age in the injury risk logistic model. The injury risk odds ratios for market group categories for all ages are presented in Table A6 of Appendix A.

The estimated injury risk odds ratios for market groups within each sex category for each age category and for all age categories combined are presented graphically in Figure 2. The value of one on the y-axis represents the odds ratio of the reference group, i.e. drivers of Compact Four Wheel Drive vehicles within each demographic category. Within each driver sex category, the odds ratio for a market category is significantly different from the reference group if the 95% confidence interval of the odds ratio does not include the odds ratio of one, while the odds ratio for two different market categories within the same demographic are significantly different from each other if their confidence intervals do not overlap.

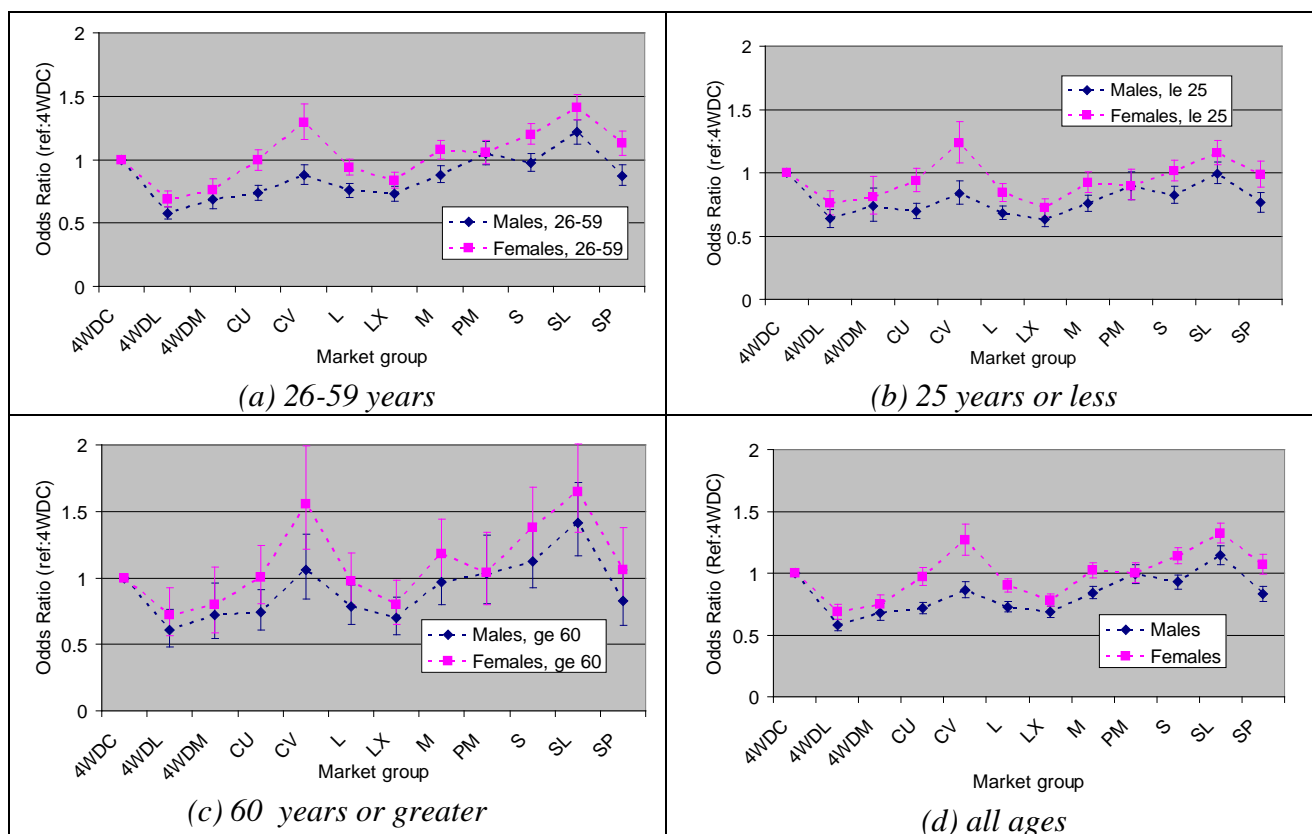


Figure 2: Estimated injury risk odds ratios for market group within driver sex and 95% confidence intervals

The reader should be aware that the odds for each market group for female drivers are being compared against the injury risk odds for female drivers of Compact Four Wheel Drive vehicles while the odds for male drivers are being compared against the odds for male drivers of Compact Four Wheel Drive vehicles. This means that when the confidence intervals for male and female drivers of a particular market category overlap, this does not necessarily mean that the difference between the injury risk odds for females and males who drive the particular market group is not significant. The male and female odds ratios represented in Figure 2 are being normalised using two different odds: i.e. the odds of injury for male drivers of Compact Four Wheel Drive vehicles and the odds for female drivers of Compact Four Wheel Drive vehicles.

It can be seen from Figure 2 that the general pattern of results for age categories 26-59 years (Figure 2.a) and 25 years or less (Figure 2.b) are similar to those when all age groups were aggregated (Figure 2.d). However, the confidence intervals for the male and female drivers belonging to the 60 years or greater age group are in general much wider than those of the younger age categories and when drivers were not grouped by age.

In order to aid interpretation of the odds ratios displayed in Figure 2, Table 2 ranks the odds ratio of each market group within each age and sex category. This enables comparison of the relative injury risk of market groups for female drivers compared to male drivers. Vehicles that have a ranking of 1 represent the market groups with the lowest injury risk odds ratio, while vehicles with a ranking of 12 represent market categories with the greatest injury risk. Cells that are highlighted represent market categories where the difference in the injury risk ranking for female drivers compared to male drivers in the same age and market categories is three or greater. It can be seen that for all age categories, including when drivers of all ages

are grouped together, Compact Four Wheel Drive vehicles rank better in terms of injury risk for female drivers than male drivers. For example, when all age categories are aggregated, Compact Four Wheel Drive vehicles had the seventh lowest injury risk odds ratio for female drivers but the same market category was the second worst category for male drivers (ranking 11th).

Table 2: *Rankings of estimated injury risk odds ratios for market group within driver sex and age categories (1=least risk; 1= greatest risk)*

Driver Age	All Ages		25 years or less		26-59 years		60 years or more	
Driver Sex	Male	Female	Male	Female	Male	Female	Male	Female
Compact Four Wheel Drive	11	7	12	9	10	6	8	5
Large Four Wheel Drive	1	1	2	2	1	1	1	1
Medium Four Wheel Drive	2	2	5	3	2	2	3	3
Commercial - Ute	4	5	4	7	4	5	4	6
Commercial - Van	8	11	9	12	7	11	10	11
Large	5	4	3	4	5	4	5	4
Luxury	3	3	1	1	3	3	2	2
Medium	7	8	6	6	8	8	7	9
People Mover	10	6	10	5	11	7	9	7
Small	9	10	8	10	9	10	11	10
Light	12	12	11	11	12	12	12	12
Sports	6	9	7	8	6	9	6	8

Highlighted cells represent market categories where the difference in rank for female drivers compared to male drivers is three or greater within each age category

Interestingly, vehicles belonging to the Large Four Wheel Drive category were ranked as being the most safe or the second safest (in terms of injury risk) category of vehicles for all age categories for both male and females. Conversely, drivers of Light Cars were most at risk of being injured for all driver demographic groups except drivers aged 25 years or less, in which the Light Car category had the second-highest injury risk odds ratio, behind Compact 4WD vehicles for males and Commercial Vans for females. Commercial Vans were the least safe type of vehicle (in terms of injury risk) for females aged 25 years or less, but were ranked three places higher (i.e. less risk) for males in this age category. This trend was also exhibited for the 26-59 year age category (a ranking of 11 for females and 7 for males) and when drivers of all ages were examined together (11 to 8).

Another interesting result was that when drivers were not categorised by age, Sports Cars were ranked ninth in terms of injury risk for female drivers but sixth for male drivers. Conversely, People Movers were ranked sixth in terms of injury risk for female drivers and tenth for male drivers. These results suggest that if a change from Sports Car to a People Mover would, on average, reduce the risk of injury for a female driver (with all other factors remaining constant), while for male drivers such a change in vehicles would increase injury risk.

4.1.2 The effect of driver age on injury risk estimates for each market group

The previous section described how a logistic regression model was used to describe how estimates of injury risk for vehicles of different market categories changes depending on the sex of the driver. The same model can be used to describe how estimates of injury risk for different market groups changes depending on the age of the driver. In Figure 2 of the previous section, the odds ratios of injury risk for male drivers of different market groups were compared with the odds ratios for female drivers. Figure 3 shows the same estimated odds ratio for injury risk except that instead of comparing males with females across different

age group, odds ratios for different age groups are compared for males only (Figure 3.a) and then for females only (Figure 3.b). The estimated injury risk odds ratios on which Figures 3.a and 3.b are based can be read from Table 1 of the previous section and Tables A4 and A5 of Appendix A.

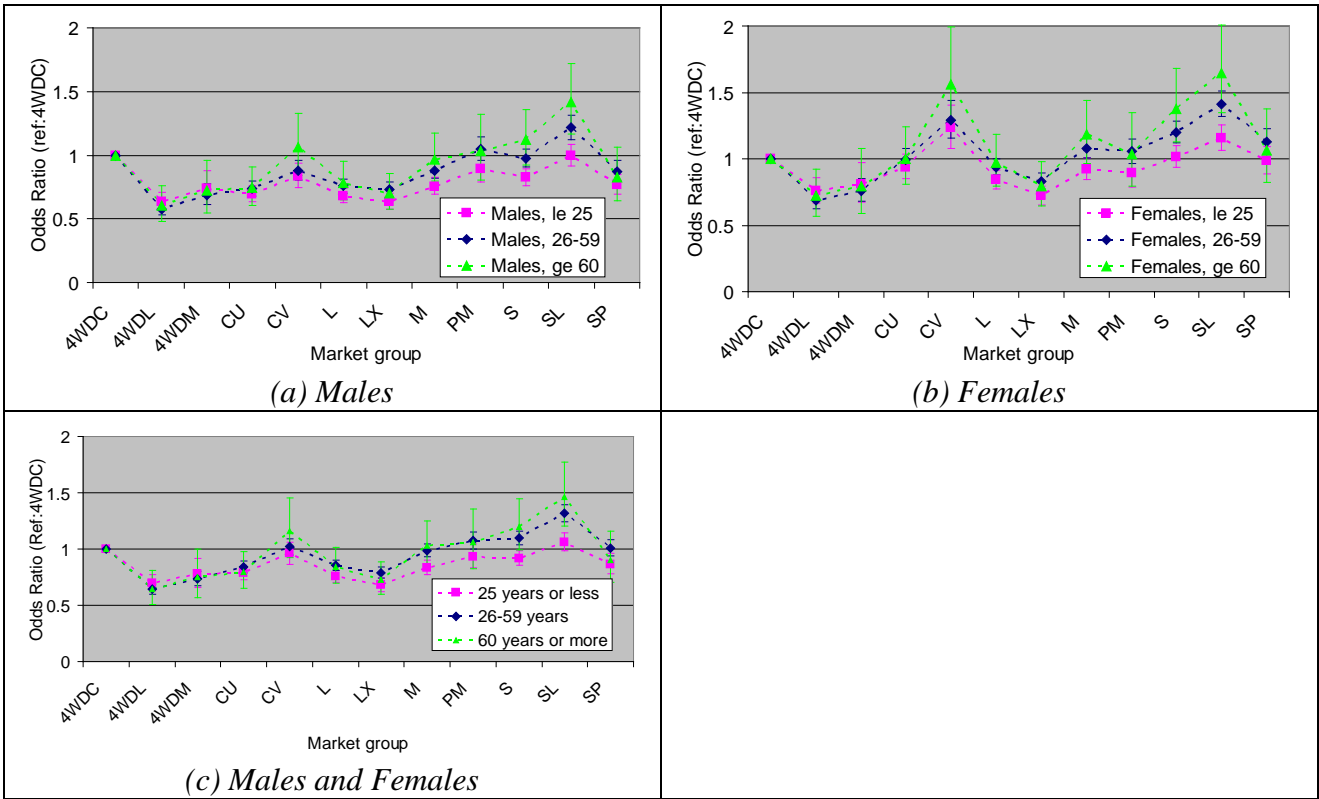


Figure 3: Estimated injury risk odds ratios for market group within driver age and 95% confidence intervals

Figure 3 also shows the estimated injury risk odds ratios for market groups within each age category for male and female drivers combined. These estimates were made by not including the interaction between market group and sex in the injury risk logistic model. The injury risk odds ratios for market group categories for males and females combined are presented in Table A7 of Appendix A.

As before, to aid interpretation of the odds ratios displayed in Figure 3, Table 3 ranks the odds ratio of each market group within each sex and age category. Table 3 contains the same data as Table 2, but columns of data have been rearranged so that different age groups are now adjacent to each other, allowing them to be compared. In Table 3, highlighted cells represent groups of drivers defined by market group and gender in which two of the three age categories differed in rank by three places or more. It can be seen that for all driver gender categories, including when all drivers are grouped together irrespective of gender, Compact Four Wheel Drive vehicles ranked better in terms of injury risk for older drivers than for younger drivers. For example, when male and female drivers were grouped together, Compact Four Wheel Drive vehicles had the seventh lowest injury risk odds ratio for 26-59 year old drivers and for drivers aged sixty or greater. However, the same market category was the second worst category for drivers aged 25 years or less (ranking 11th). When only male drivers were considered, Compact Four Wheel Drive vehicles were the least safe (in terms of injury risk), while these vehicles were the third-least safe (i.e. a ranking of 10) for male drivers aged 26 to 59 years and were the fifth-least safe for male drives aged 60 or more.

Table 3: *Rankings of estimated injury risk odds ratios for market group within driver age and sex categories (1=least risk; 12=greatest risk)*

Driver Sex	Males			Females			Males and Females		
Driver Age	≤25	26-59	≥60	≤25	26-59	≥60	≤25	26-59	≥60
Compact Four Wheel Drive	12	10	8	9	6	5	11	7	7
Large Four Wheel Drive	2	1	1	2	1	1	2	1	1
Medium Four Wheel Drive	5	2	3	3	2	3	4	2	3
Commercial - Ute	4	4	4	7	5	6	5	4	4
Commercial - Van	9	7	10	12	11	11	10	9	10
Large	3	5	5	4	4	4	3	5	5
Luxury	1	3	2	1	3	2	1	3	2
Medium	6	8	7	6	8	9	6	6	8
People Mover	10	11	9	5	7	7	9	10	9
Small	8	9	11	10	10	10	8	11	11
Light	11	12	12	11	12	12	12	12	12
Sports	7	6	6	8	9	8	7	8	6

Highlighted cells represent market categories where the difference in rank for two of the three age categories is three or greater within each sex category

For female drivers aged 25 years or less, 26 to 59 years and 60 years or older, the Compact Four Wheel Drive vehicles were ranked ninth, sixth and fifth safest for injury risk respectively, while for the same demographic, Medium Cars were ranked the sixth, eighth and ninth safest. This can be interpreted as suggesting that a change from a Compact Four Wheel Drive vehicle to a Medium Car would reduce the risk of injury for a female driver aged 25 years or less, but would increase the risk of injury for female drivers aged 60 years or more.

Another interesting result is that Commercial Vans were ranked the seventh safest (in terms of injury risk) market group for males aged 26 to 59 years but only the tenth safest for males aged 60 years or more.

4.2 Injury Severity

The data on "injured drivers" covered 443,284 drivers of 1982-2004 model vehicles who were injured in crashes in Victoria, NSW, Western Australia, Queensland or New Zealand during 1987-2004 compiled for the Used Car Safety Ratings project (Newstead et al, 2006). Because of missing values in one or more of the covariates amongst the 443,284 injured drivers, the final file used for analysis consisted of the 252,141 drivers for which all the covariate data was complete. Of these drivers 53,526 were seriously injured.

When the term representing passenger vehicle market group was added to the injury severity covariate model described in Section 3.3, it was found that the market group variable was significant. This model enabled comparison of the odds that an injured driver was seriously injured for vehicles of different market groups. Figure 4 shows the relative odds of an injured driver being seriously injured for each market category compared to the reference category of Compact Four

Wheel Drive vehicles. The 95% confidence intervals for each odds ratio were estimated in the same way that the confidence intervals for the estimates of injury risk by market group were estimated in Figure 1 of Section 4.1, i.e. substituting the standard errors of the coefficients of the model into equation 3.4 of Section 3.1.

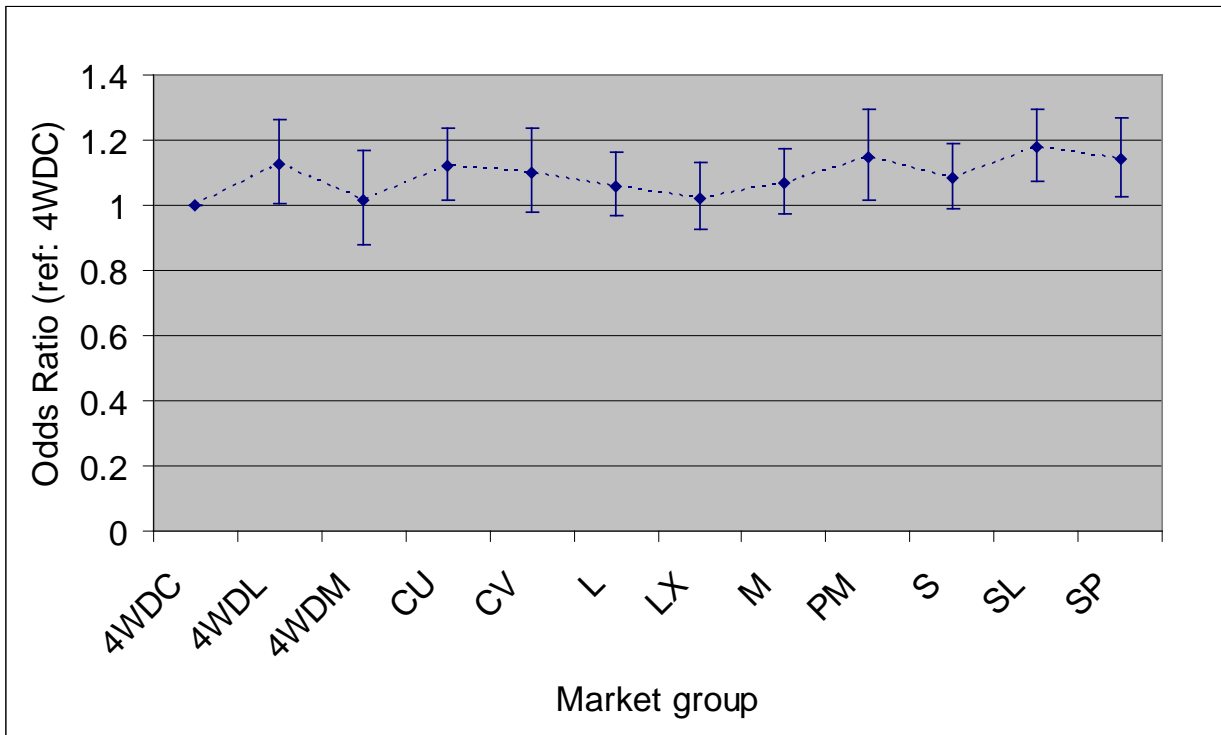


Figure 4: Estimated injury severity odds ratios by market group

The odds ratios presented in Figure 4 represent the relative odds for an injured driver being seriously injured for vehicles differentiated by market group. These odds ratios do not distinguish between drivers of different demographic groups. To estimate separate odds ratios for demographic groups, first order interaction terms between market group and driver age and market group and the sex of the driver were added to the model that was used to derive the odds ratios presented in Figure 4. It was found that both these interaction terms were significant.

The Type 3 analysis of effects for the injury severity model that included the first order interaction terms between market group and driver age and market group and driver sex are included in Table B1 of Appendix B, while Table B2 gives the estimated coefficients, standard errors, Wald Chi-square test statistic, p-values and 95% confidence intervals for the estimated coefficients used to derive results presented in this section.

The following section describes how estimates of injury severity for vehicles of different market categories change depending on the sex of the driver. This is followed by a section that describes the extent to which the age of the driver affects the estimate of injury risk for each market group.

4.2.1 The effect of driver gender on injury severity estimates for each market group

The injury severity odds ratios for different market groups and for different driver groups were estimated in the same manner that analogous injury risk odds ratios were estimated in Section 4.1. That is, the difference of two logit functions that differ from each other with respect to the market group variable only was calculated and then the exponential function was applied. As these two logit functions only differ with respect to the market group main effect variable and first order interactions involving the main effect variable, the odds ratio for injury severity for injured males of a particular market group compared to injured male drivers of Compact Four Wheel Drive vehicles is also represented by equation 4.5 from

Section 4.1.1, except that the parameters from Table B2 in Appendix B are substituted instead of the parameters from Table A2. Furthermore, the confidence interval for each estimated injury severity odds ratio for injured male drivers can be estimated using equations 4.6 and 4.7 of Section 4.1.1. Table B3 of Appendix B contains the relevant covariance terms.

Similarly, for injured female drivers, the injury severity odds ratio for a particular market group compared to injured female drivers of Compact Four Wheel Drive vehicles can be estimated by substituting the parameters from Table B2 in Appendix B into equation 4.8 of Section 4.1.1 and the confidence interval for each estimate can be found using equations 4.9 and 4.10.

Table 4 presents the estimates of the injury severity odds ratios for market groups within each sex category for drivers aged 26 to 59 years. The table also shows the 95% confidence interval for each odds ratio. Analogous results for the 25 years or younger age group and the 60 years or greater age groups are presented in Tables B4 and B5 of Appendix B.

Table 4: *Estimated injury severity odds ratios for market group within driver sex and 95% confidence intervals (for drivers aged 26-59 years only)*

Driver sex	Market group	Odds Ratio	95% Confidence interval	
Male	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	1.09	0.91	1.31
	Medium Four Wheel Drive	0.88	0.70	1.10
	Commercial - Ute	1.06	0.90	1.24
	Commercial - Van	1.10	0.92	1.32
	Large	1.03	0.88	1.20
	Luxury	0.98	0.82	1.16
	Medium	1.04	0.89	1.23
	People Mover	1.17	0.97	1.42
	Small	1.07	0.92	1.26
	Light	1.15	0.97	1.35
	Sports	1.21	1.00	1.45
Female	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	1.10	0.90	1.34
	Medium Four Wheel Drive	1.20	0.96	1.50
	Commercial - Ute	1.19	1.00	1.42
	Commercial - Van	1.30	1.05	1.62
	Large	1.02	0.88	1.18
	Luxury	1.00	0.85	1.18
	Medium	1.04	0.89	1.21
	People Mover	1.06	0.87	1.28
	Small	1.04	0.90	1.20
	Light	1.16	1.00	1.35
	Sports	1.14	0.95	1.36

Odds ratio estimates for market groups within each driver sex category that are significantly ($p < 0.05$) different to that for Compact Four Wheel Drive vehicles have been highlighted

By not including the interaction between market group and age in the injury severity model, it was possible to estimate the injury severity odds ratios for market groups within each sex category for drivers of all ages. The injury severity odds ratios for market group categories for all ages are presented in Table B6 of Appendix B.

Figure 5 shows the injury severity odds ratios for market groups within each sex category for each age category and for all age categories combined. Comparing Figures 2 and 5, it appears

that for most market groups there is less of a sex difference for risk of serious injury given a driver is injured than the risk of receiving an injury of any severity. The confidence intervals of the injury severity odds ratios also appear to be wider than those for injury risk odds ratios (see Figure 2). In fact, from Table 4, among male drivers aged 26 to 59 years, the Sports Car market category was the only category for which the injury severity odds estimate was significantly different to that for Compact Four Wheel Drive vehicles. Returning to Table 1, many of the market categories exhibited significantly different injury risk odds to the odds for Compact Four Wheel Drive vehicles. Similarly, among 26 to 59 year old female drivers, there were only two market categories (Commercial Vans and Utes) with an injury severity odds estimate that was significantly different to that for Compact Four Wheel Drive vehicles.

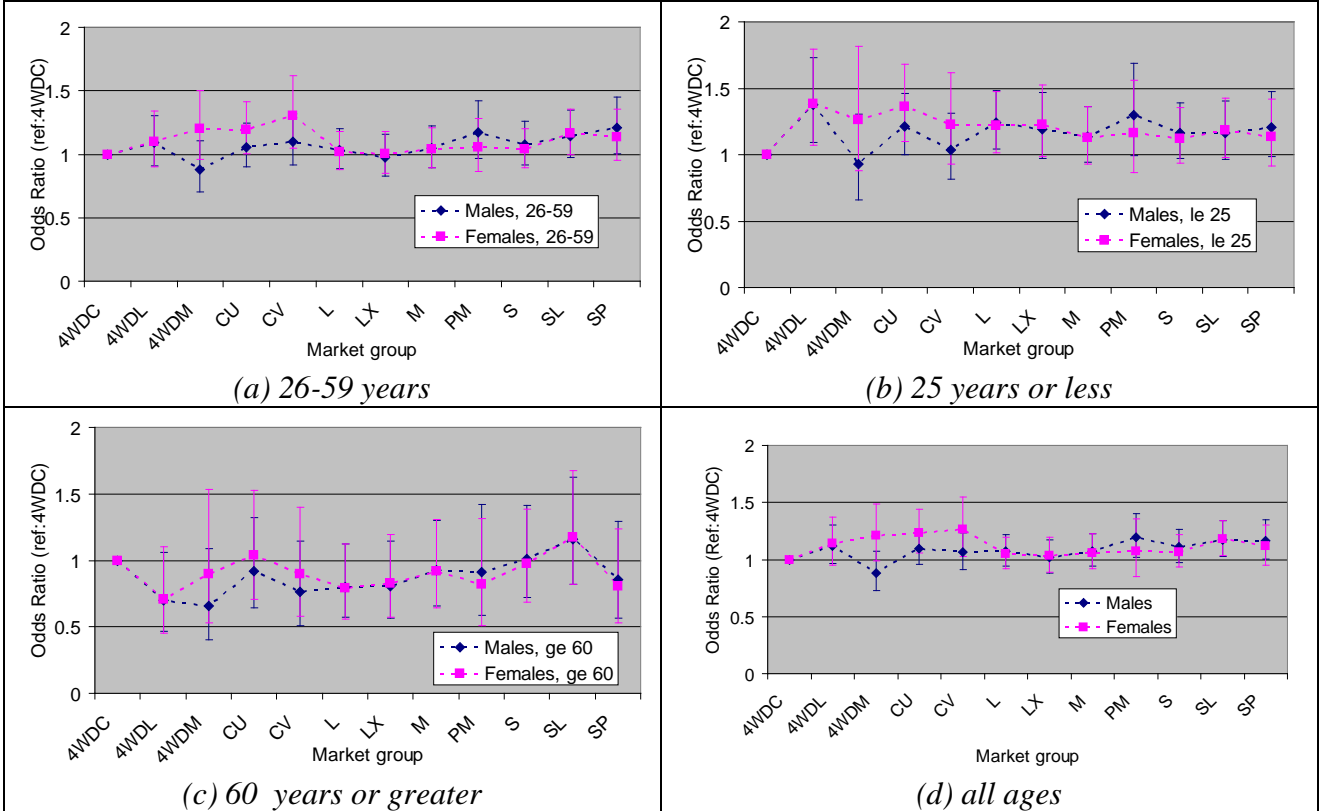


Figure 5: Estimated injury severity odds ratios for market group within driver sex and 95% confidence intervals

Table 5 ranks the point estimates of the injury severity odds ratios of the twelve market groups within each age and sex category. This enables the relative risk of serious injury for injured female drivers of different market groups to be compared against the relative risk by market group for injured male drivers. Vehicles that have a ranking of 1 represent the market groups with the lowest injury severity odds ratio within the specified demographic category, while vehicles with a ranking of 12 represent the market category with the greatest injury severity odds ratio. Highlighted cells represent market categories where the difference in the injury severity ranking for injured female drivers compared to injured male drivers in the same age and market categories is three or greater.

The reader should be aware that the rankings within each demographic group are based on non-significant ($p > 0.05$) differences between the point estimates of the injury severity odds ratios of each market category. It is expected that the rankings of market categories for injured male drivers would differ to those for injured female drivers if very few of the point estimates on which the rankings are based significantly differed from each other: a small variation in

point estimate for a market category could lead to large a relatively large change in rank. However, it is still worth commenting on a few market categories where the injury severity rankings for injured drivers differ markedly for males and females. For example, it can be seen that for all age categories, including when drivers of all ages are grouped together, Medium Four Wheel Drive vehicles rank better in terms of injury severity for male drivers than for female drivers. For example, when all age categories are aggregated, Medium Four Wheel Drive vehicles had the third highest injury severity odds ratio for female drivers but the same market category was the best injury severity estimate for male drivers. A similar pattern of results exists for the Commercial Van market category.

Table 5: *Rankings of estimated injury severity odds ratios for market group within driver sex and age categories (1=least risk of a severe injury; 12=greatest risk)*

Driver Age	All Ages		25 years or less		26-59 years		60 years or more	
Driver Sex	Male	Female	Male	Female	Male	Female	Male	Female
Compact Four Wheel Drive	2	1	2	1	3	1	10	10
Large Four Wheel Drive	9	8	12	12	8	7	2	1
Medium Four Wheel Drive	1	10	1	10	1	11	1	6
Commercial - Ute	7	11	9	11	6	10	8	11
Commercial - Van	4	12	3	9	9	12	3	7
Large	5	3	10	7	4	3	4	2
Luxury	3	2	7	8	2	2	5	5
Medium	6	4	4	3	5	5	9	8
People Mover	12	6	11	5	11	6	7	4
Small	8	5	5	2	7	4	11	9
Light	11	9	6	6	10	9	12	12
Sports	10	7	8	4	12	8	6	3

Highlighted cells represent market categories where the difference in rank for female drivers compared to male drivers is three or greater within each age category

In contrast, when all age categories were aggregated, People Movers were ranked as being the sixth safest market category for female drivers (in terms of injury severity), while for males they were ranked as being the least safe market category. Furthermore, a similar pattern of results holds within individual age groups for the People Mover market category as well as for the Sports Car category and the Small Car category (except for drivers aged 60 years or more for Sports Cars).

4.2.2 The effect of driver age on injury severity estimates for each market group

The logistic regression model described in the previous section can also be used to describe how injury severity odds ratios for different market categories changes depending on the age of the driver. Figure 6 shows the same estimated injury severity odds ratios as depicted in Figure 5 except that instead of comparing males with females across different age group, odds ratios for different age groups are compared for males only (Figure 6.a) and then for females only (Figure 6.b). The estimated injury risk odds ratios on which Figures 6.a and 6.b are based can be read from Table 4 of the previous section and Tables B4 and B5 of Appendix B.

Figure 6 also shows the estimated injury severity odds ratios for market groups within each age category for male and female drivers combined. These estimates were made by not including the interaction between market group and sex in the injury severity logistic model. The injury severity odds ratios for market group categories for males and females combined are presented in Table B7 of Appendix B.

As in previous sections, to aid interpretation of the odds ratios displayed in Figure 6, Table 6 ranks the odds ratio of each market group within each sex and age category. Table 6 contains the same data as Table 5 except that columns of data have been rearranged so that different age groups are now adjacent to each other allowing them to be compared. As before, highlighted cells represent groups of drivers defined by market group and gender in which two of the three age categories differed in rank by three places or more. It can be seen that for nearly all market categories there was variation of three units or more in the rankings of relative injury severity odds ratios for different age groups. This is a reflection of the confidence intervals of many of the injury severity odds ratios being quite wide (in particular for drivers aged 60 years or more). It is worth noting however that some market groups of vehicles ranked favourably with respect to the risk of serious injury given driver injury while for other age groups they ranked poorly. For example, Compact Four Wheel Drive vehicles were ranked as being the most-safe (in terms of injury severity) for drivers in the 25 years or less age group and second in the 26-59 age group but second worst (11th) in the 60 years or greater age group.

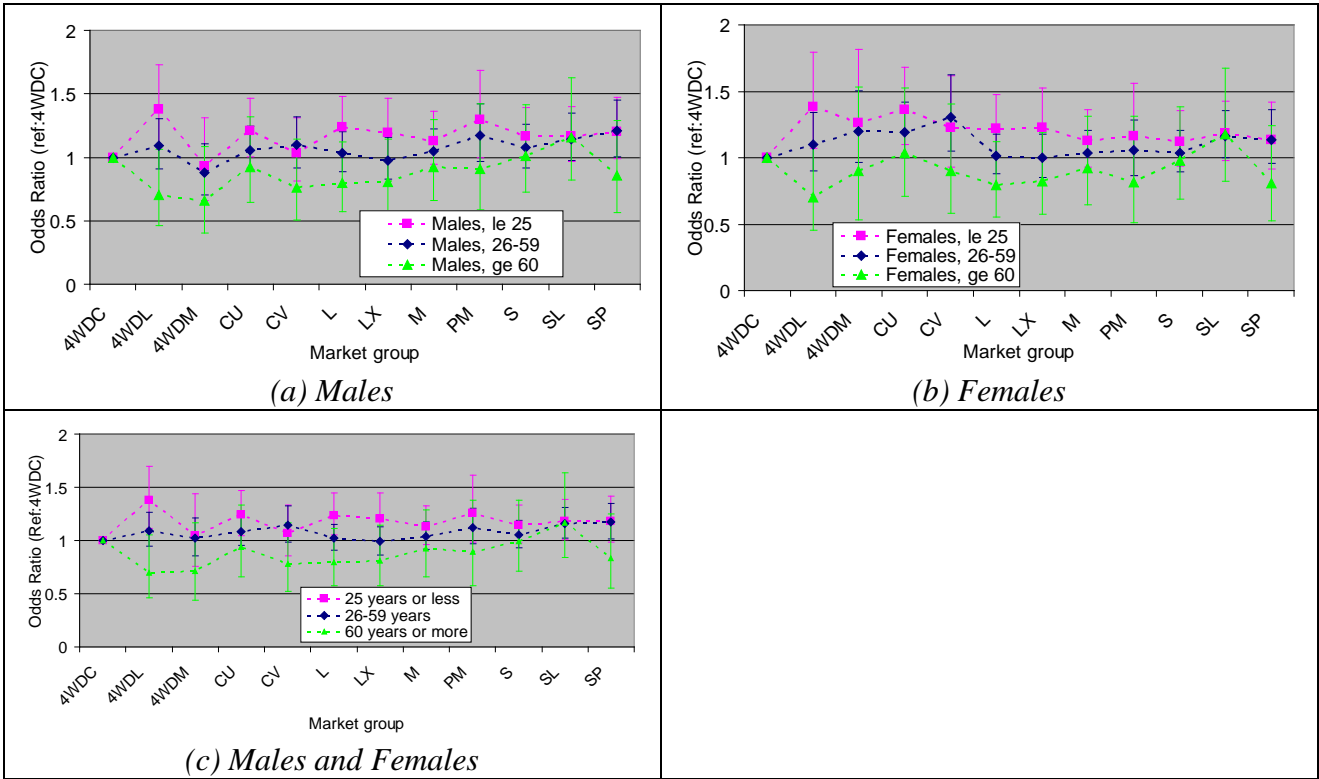


Figure 6: Estimated injury severity odds ratios for market group within driver age and 95% confidence intervals

Again, the reader should be aware that the rankings within each demographic group that are depicted in Table 6 are based on non-significant ($p > 0.05$) differences in the point estimates of the injury severity odds ratios between market groups.

Table 6: *Rankings of estimated injury severity odds ratios for market group within driver age and sex categories (1=least risk of severe injury; 12=greatest risk)*

Driver Sex	Males			Females			Males and Females		
	≤25	26-59	≥60	≤25	26-59	≥60	≤25	26-59	≥60
Compact Four Wheel Drive	2	3	10	1	1	10	1	2	11
Large Four Wheel Drive	12	8	2	12	7	1	12	8	1
Medium Four Wheel Drive	1	1	1	10	11	6	2	3	2
Commercial - Ute	9	6	8	11	10	11	10	7	9
Commercial - Van	3	9	3	9	12	7	3	10	3
Large	10	4	4	7	3	2	9	4	4
Luxury	7	2	5	8	2	5	8	1	5
Medium	4	5	9	3	5	8	4	5	8
People Mover	11	11	7	5	6	4	11	9	7
Small	5	7	11	2	4	9	5	6	10
Light	6	10	12	6	9	12	6	11	12
Sports	8	12	6	4	8	3	7	12	6

Highlighted cells represent market categories where the difference in rank for two of the three age categories is three or greater within each sex category

4.3 Crashworthiness

This section estimates the odd of a driver being hospitalised or killed given involvement in a police-reported crash for drivers of different demographic groups. As was the case when injury risk and injury severity odds were reported in Section 4.1 and 4.2 respectively, odds for drivers driving different market groups will be normalised using the analogous odds for drivers of Compact Four Wheel Drive vehicles. The odds ratios estimated in this section will be referred to as crashworthiness odds ratios because they are a measure the relative crashworthiness of different market groups within each demographic group. Newstead et al. (2006) defined crashworthiness as “the measure of the risk of serious injury to a driver of that vehicle when it is involved in a crash” (p.2). Before presenting results, it is worth describing the process used to derive these estimates.

The crashworthiness probability is equal to the product of the risk of a driver receiving an injury of any severity given they are involved in a crash and the probability that an injured driver is seriously injured (i.e. hospitalised or killed). The injury risk and injury severity odds ratios derived in Section 4.1 and 4.2 can be thought as odds that have been normalised using analogous odds for drivers of Compact Four Wheel Drive vehicles. As explained in Section 3.1, when estimating the odds ratios of being injured or seriously injured, the odds for different groups of drivers defined by the market group variable are all compared against the analogous odds for a reference group of drivers (in this case drivers of Compact Four Wheel Drive vehicles). Since the injury risk and injury severity odds for each market category are normalised using the odds from the same reference category, it is not actually necessary to know the odds for the reference category to compare the odds ratios for the non-reference groups: the odds ratios are a relative measure of risk which allow the risk between the different categories to be compared against each other. In the present analysis, the odds for injury risk and injury severity for the reference category were calculated using the overall average injury risk and injury severity probabilities from Newstead et al. (2006). Assuming these odds for the market group reference category enabled the odds ratios reported in the previous sections to be expressed as odds.

Once the injury risk and injury severity odds for each market category within each demographic group were estimated in this way, they were transformed into probabilities using the inverse logistic transform given by

$$L(X) = \frac{X}{1+X} \quad (4.11)$$

The injury risk and injury severity probabilities can then be multiplied to give an estimate of crashworthiness probability for each market group within each demographic group. From the crashworthiness probability, the crashworthiness odds for each market group, within each driver demographic group was calculated. The average crashworthiness rating from Newstead et al (2006) was then used to normalise the crashworthiness odds for each market group using equation 3.2 of Section 3.1, which gave crashworthiness odds ratios for each market group within different driver demographic categories.

Newstead et al (2006) provide details of how the confidence limits of each crashworthiness odds ratios can be estimated by calculating the variance of the natural logarithm of the crashworthiness probability, which can be approximated by

$$\text{Var}(\log_e C_j) \approx \frac{\text{Var}(\alpha_j)}{(1+e^\alpha)^2} + \frac{\text{Var}(\beta_j)}{(1+e^\beta)^2} \quad (4.12)$$

where C_j is the crashworthiness probability for market group j and α_j and β_j are the respective values of the logistic function for injury risk and injury severity for the drivers of market group j that belong to demographic group being analysed.

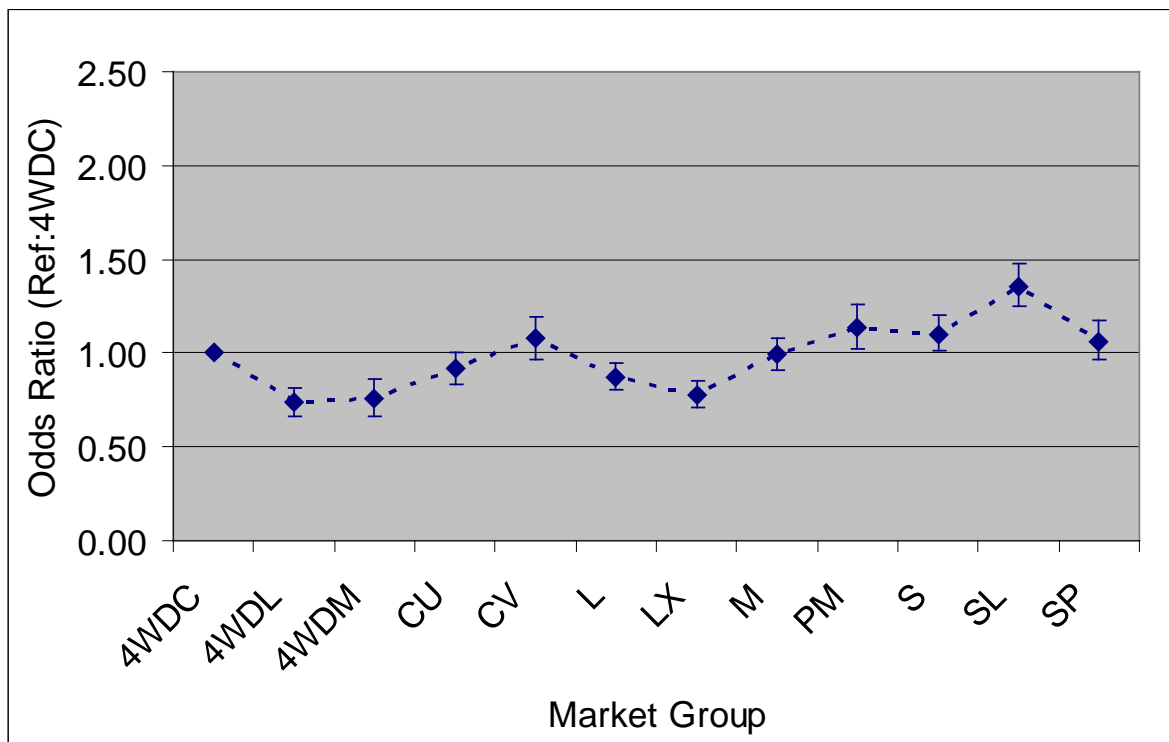


Figure 7: Estimated crashworthiness odds ratios by market group

Figure 7 shows the relative crashworthiness odds compared to the reference category of Compact Four Wheel Drive vehicles for all drivers. In the following section, the methodology described above is used to estimate how crashworthiness odds ratios for different market categories change depending on the sex of the driver. This is followed by a section that

describes the extent to which the age of the driver affects the estimate of crashworthiness odds ratios for each market group.

4.3.1 The effect of driver gender on crashworthiness estimates for each market group

Table 7 presents the estimates of crashworthiness odds ratios for market groups within each sex category for drivers aged 26 to 59 years. The table also shows the 95% confidence interval for each odds ratio. For each driver sex category, these odds ratios represent the odds that a driver of a particular market group is seriously injured when they are involved in a crash relative to the odds that a driver of the same sex who is driving a Compact Four Wheel Drive vehicle is seriously injured when involved in a crash. These odds ratios were estimated using the method described at the start of Section 4.3 using injury risk odds ratios derived in Section 4.1.1 (see Table 1) and injury severity odds ratios derived in Section 4.2.1 (see Table 4). Table C1 in Appendix C presents the injury risk odds ratios and the injury severity odds ratios that were used to estimate the crashworthiness odds ratios for this group of drivers. Table C1 also shows the variance estimates required to estimate the 95% confidence intervals presented in Table 7. Furthermore, Tables C2 and C3 provide estimates of the crashworthiness odds ratios for males and females aged 25 years or younger and males and females aged 60 years or older respectively.

Table 7: *Estimated crashworthiness odds ratios for market group within driver sex and 95% confidence intervals (for drivers aged 26-59 years only)*

Driver sex	Market group	Odds Ratio	95% Confidence interval	
Male	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	0.66	0.56	0.78
	Medium Four Wheel Drive	0.65	0.53	0.80
	Commercial - Ute	0.80	0.69	0.93
	Commercial - Van	0.97	0.82	1.14
	Large	0.81	0.70	0.93
	Luxury	0.75	0.64	0.87
	Medium	0.93	0.80	1.07
	People Mover	1.19	1.00	1.41
	Small	1.04	0.90	1.20
	Light	1.32	1.14	1.52
	Sports	1.03	0.88	1.22
Female	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	0.78	0.65	0.93
	Medium Four Wheel Drive	0.91	0.75	1.12
	Commercial - Ute	1.15	0.98	1.34
	Commercial - Van	1.53	1.27	1.86
	Large	0.96	0.84	1.10
	Luxury	0.85	0.74	0.99
	Medium	1.10	0.96	1.26
	People Mover	1.09	0.92	1.30
	Small	1.20	1.05	1.37
	Light	1.50	1.32	1.72
	Sports	1.23	1.05	1.44

Odds ratio estimates for market groups within each driver sex category that are significantly (p<0.05) different to that for Compact Four Wheel Drive vehicles have been highlighted

Table C4 of Appendix C shows the estimated crashworthiness odds ratios for market groups within each sex category for drivers of all ages. These crashworthiness odds ratios were derived using injury risk and injury severity odds ratios that were estimated using logistic models that did not include an interaction between market group and driver age.

Figure 8.a shows the crashworthiness odds ratios for market groups within each sex category for drivers aged 26 to 59 years, while Figure 8b and 8c show analogous results for drivers aged 25 years or less and 60 years or older respectively. Figure 8d shows the same results for all age categories combined.

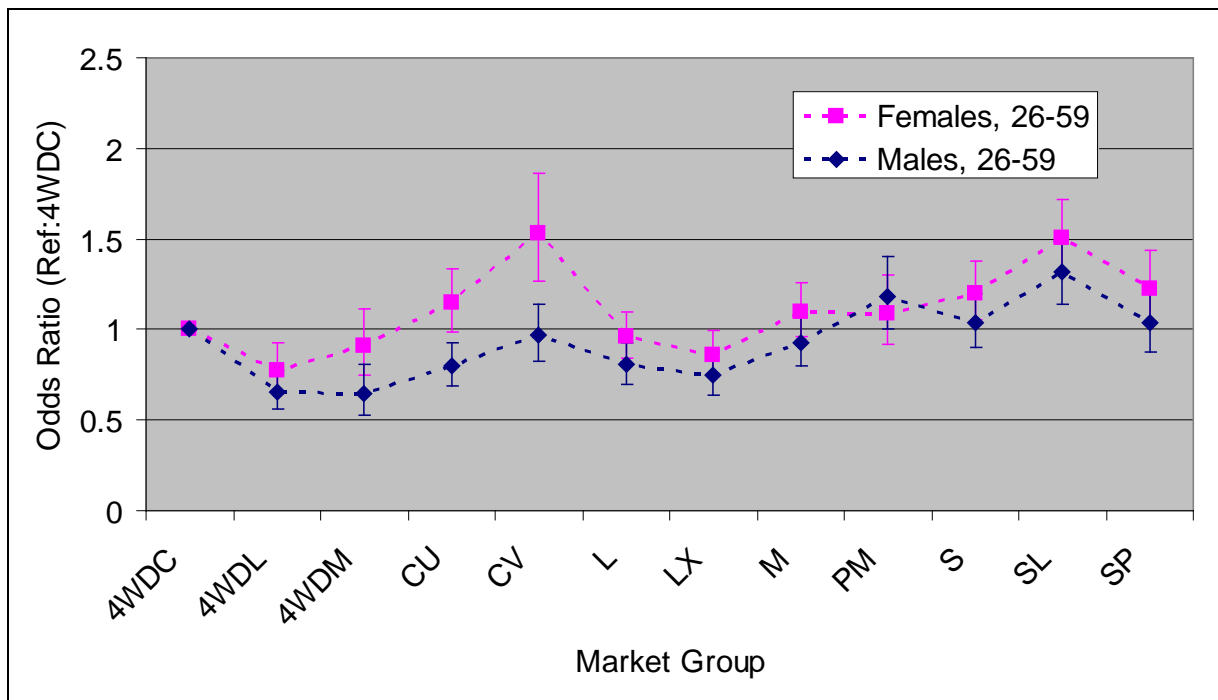


Figure 8a: Estimated crashworthiness odds ratios for market group within driver sex and 95% confidence intervals (26-59 year olds only)

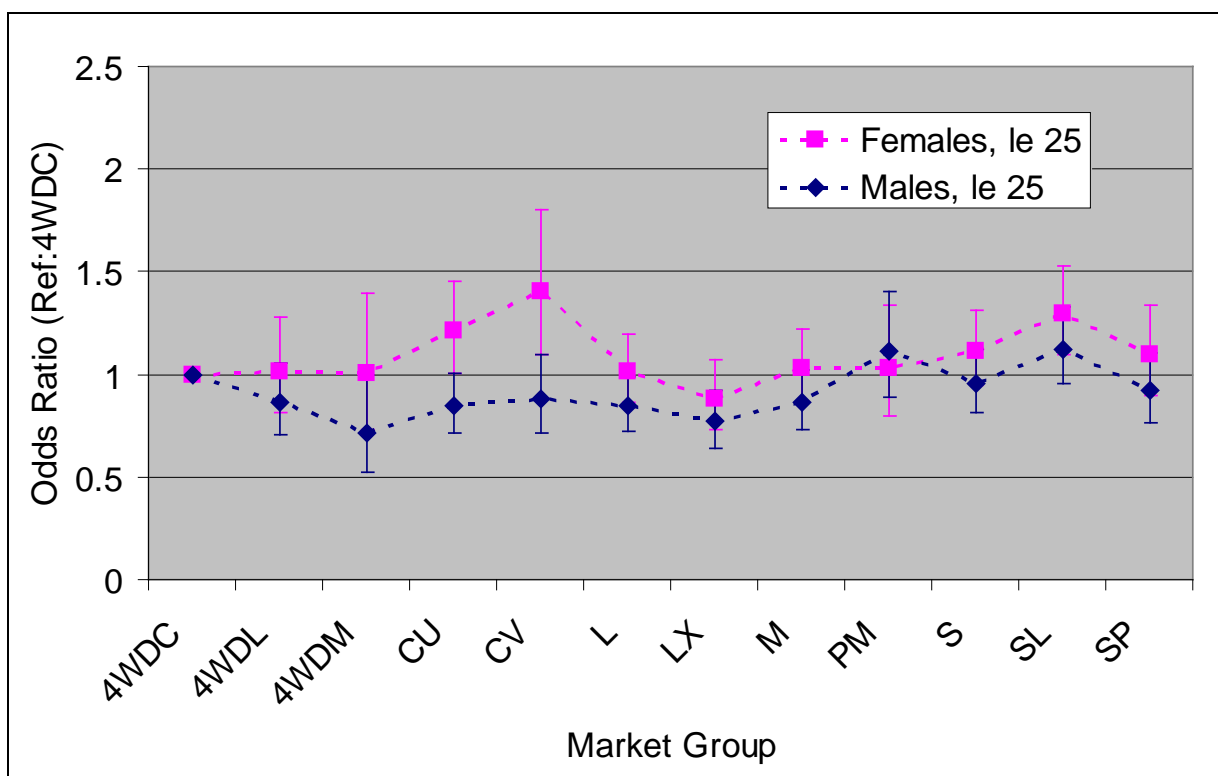


Figure 8b: Estimated crashworthiness odds ratios for market group within driver sex and 95% confidence intervals (25 years or less only)

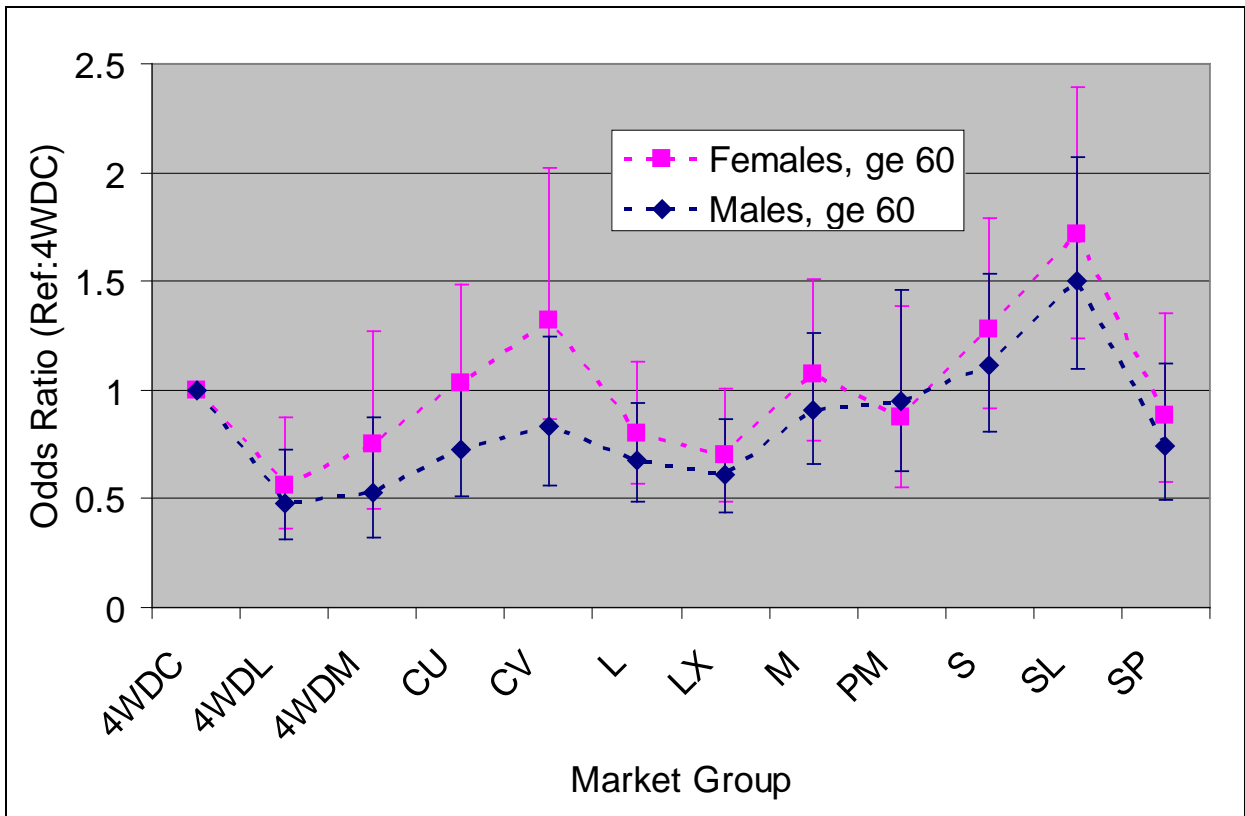


Figure 8c: Estimated crashworthiness odds ratios for market group within driver sex and 95% confidence intervals (60 years or greater only)

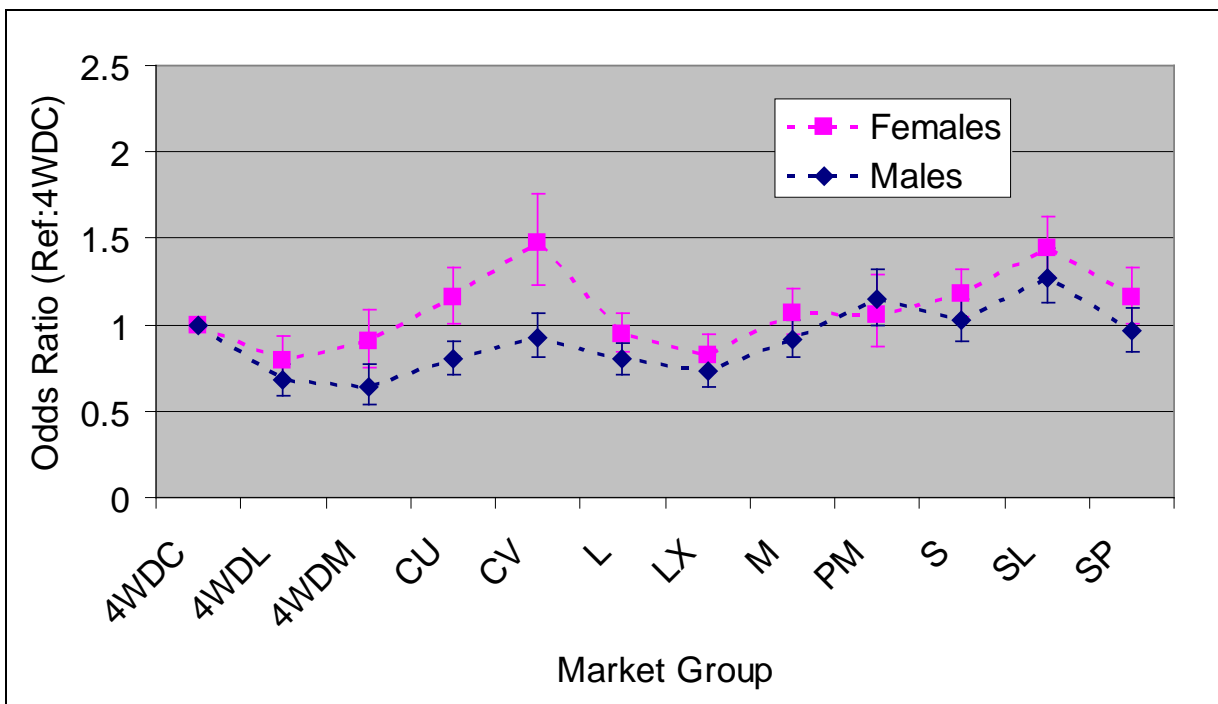


Figure 8d: Estimated crashworthiness odds ratios for market group within driver sex and 95% confidence intervals (all ages)

It can be seen from Figure 8c that many of the confidence intervals of the crashworthiness odds ratios for drivers aged sixty years or older are wider than those for the other age groups and for when data from all age groups were aggregated. This is not surprising given that the

injury risk and injury severity odds ratios for this age group were in general wider than corresponding confidence intervals for other age groups (see Figures 2 and 5 to compare).

From Figure 8a it can be seen that within the 26-59 year age group, the crashworthiness odds for female drivers of Commercial Vans was significantly higher than the odds for female drivers of Compact Four Wheel Drive vehicles (i.e. the crashworthiness odds ratio for female drivers of Commercial Vans was significantly greater than one). By comparison, the best estimate of the crashworthiness odds for male drivers of Commercial Vans was almost equal to the odds for male drivers of Compact Four Wheel Drives. These results could be interpreted as suggesting that if a male driver changed from driving a Commercial Van to a Compact Four Wheel Drive vehicle, their risk of serious injury would not change. However if a female driver decided to drive a Compact Four Wheel Drive vehicle instead of a Commercial Van, driving the Compact Four Wheel Drive vehicle would improve their safety.

To assist in interpreting of the odds ratios displayed in Figures 8a to 8d, Table 8 ranks the odds ratio of each market group within each age and sex category. Similar to tables displayed in previous sections, a ranking of 1 represents the market groups with the lowest (safest) crashworthiness odds ratio, while a ranking of 12 represent market categories with the highest (least safe) crashworthiness odds ratio. Cells where the difference in the crashworthiness ranking for female drivers compared to male drivers in the same age and market category is three or greater have been highlighted. It can be seen that for all age categories, including when drivers of all ages are grouped together, Compact Four Wheel Drive vehicles rank better in terms of crashworthiness for female drivers than male drivers. The superior crashworthiness ranking of Compact Four Wheel Drive vehicles for female drivers compared to male drivers is mostly due to this type of vehicle ranking better for females in the injury risk rankings (see Table 2 of Section 4.1.2). These vehicles provided good protection from serious injury for both males and females, ranking first in terms of injury severity for female drivers and second for males (see Table 5 of Section 4.2.1), however Compact Four Wheel drive vehicles ranked only 11th safest (or second worst) in terms of injury risk for male drivers and 7th safest first female drivers (see Table 2 of Section 4.1.1).

Table 8: *Rankings of estimated crashworthiness odds ratios for market group within driver age and sex categories (1=least risk of severe injury; 12=greatest risk)*

Driver Age	All Ages		25 years or less		26-59 years		60 years or more	
	Male	Female	Male	Female	Male	Female	Male	Female
Compact Four Wheel Drive	9	5	10	2	8	5	10	7
Large Four Wheel Drive	2	1	5	5	2	1	1	1
Medium Four Wheel Drive	1	3	1	3	1	3	2	3
Commercial – Ute	5	8	3	10	4	8	5	8
Commercial – Van	7	12	7	12	7	12	7	11
Large	4	4	4	4	5	4	4	4
Luxury	3	2	2	1	3	2	3	2
Medium	6	7	6	6	6	7	8	9
People Mover	11	6	11	7	11	6	9	5
Small	10	10	9	9	10	9	11	10
Light	12	11	12	11	12	11	12	12
Sports	8	9	8	8	9	10	6	6

Highlighted cells represent market categories where the difference in rank for two of the three age categories is three or greater within each sex category

People Movers are another market category that rank poorly for men in terms of crashworthiness (11th for all age categories except 60 years or older) but comparatively well for female drivers (ranking between fifth and seventh depending on the age category).

Conversely, Commercial Vans and Commercial Utes rank poorly in terms of crashworthiness for female drivers but better for male drivers. For example when data from all age groups are aggregated, Commercial Vans were on average the least crashworthy market category for female drivers, while they were the 7th most-crashworthy category for male drivers. As before, one way of interpreting such results is to consider the scenario of a male and female who both drive Commercial Vans. If both drivers changed their vehicle of choice to a People Mover, Table 8 suggests that such a change would reduce the risk of serious injury for the female driver but increase the risk for the male driver. However, the reader should be aware that the rankings depicted in Table 8 are based on the point estimates of the relevant crashworthiness odds ratios only and that just because one market group ranks higher than another within a driver sex category, this does not mean that the former market group offers significantly better safety than the latter market group. For example, although People Movers were ranked the sixth most-crashworthy market category for female drivers compared to Commercial Vans which were ranked the least-crashworthy for female drivers, the crashworthiness estimates on which the rankings for these two vehicle types were based were not significantly different from each other: the female-specific crashworthiness odds ratio of Commercial Vans ranged from 1.23 to 1.76 with 95% certainty, while the analogous estimate for People Movers ranged from 0.87 to 1.30 with 95% certainty (see Table C4 of Appendix C).

4.3.2 The effect of driver age on crashworthiness estimates for each market group

This section compares the estimates of crashworthiness odds ratios for each market group for drivers grouped by age. Figures 9.a and 9.b show the same estimated crashworthiness odds ratios as depicted in Figures 8.a to 8.c except that instead of comparing males with females across different age groups, odds ratios for different age groups are compared for males only (Figure 9.a), then for females only (Figure 9.b). Finally Figure 9.c compares crashworthiness odds ratios for males and females grouped together. The injury risk odds ratios and the injury severity odds ratios that were used to estimate the crashworthiness odds ratios in Figures 9.a and 9.b are shown in Tables C1, C2 and C3 of Appendix C, while those used to in Figure 9.c are presented in Table C5.

From Figures 9.a to 9.c it can be seen that the 95% confidence intervals for the 60 year or older age group are quite wide for all driver gender categories. There appears to be some variation between the relative crashworthiness of vehicles from the same market group for the remaining two age categories. To assist in the identification of market groups that deliver different relative crashworthiness odds ratios for different driver age groups, Table 9 shows the ranking of the crashworthiness odds ratio of each market group within each sex and age category. Table 9 is identical to Table 8 except that columns of data have been rearranged so that different age groups are now adjacent to each other, allowing them to be compared. Where there is a difference of three ranking places or more for the three different driver age groups within each market group and sex category, the cells have been highlighted.

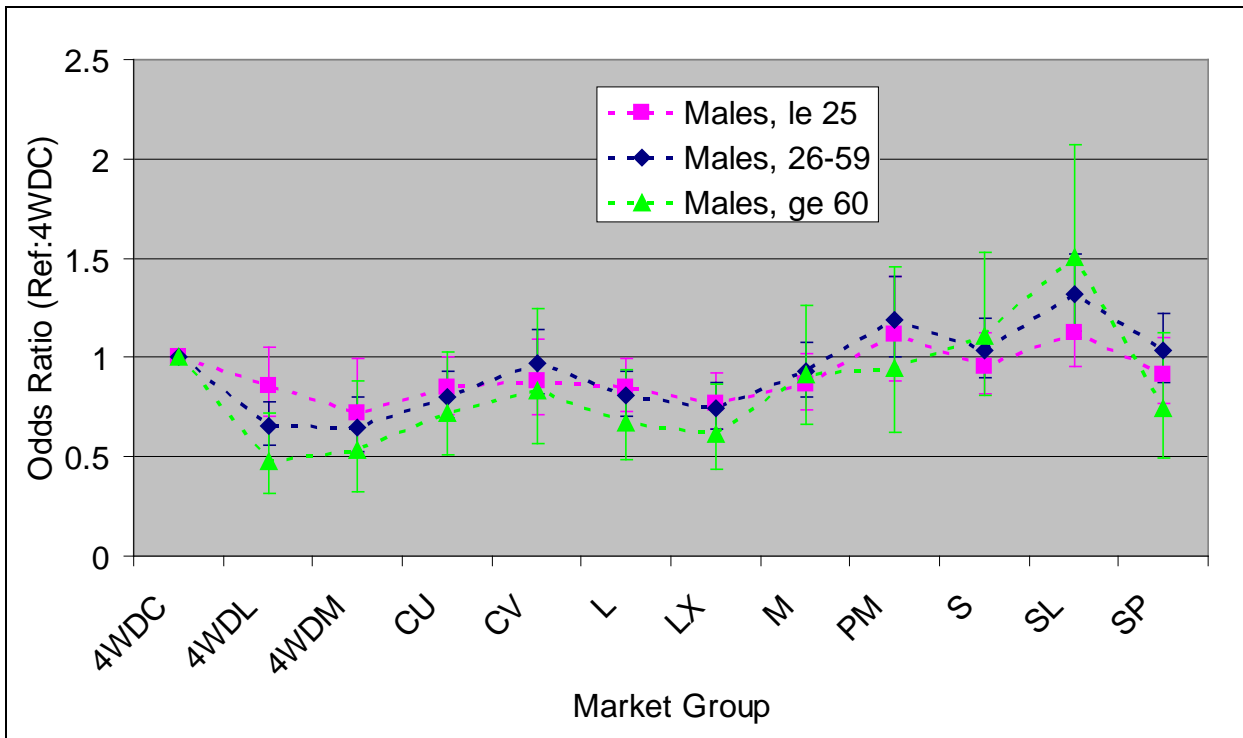


Figure 9a: Estimated crashworthiness odds ratios for market group within driver age and 95% confidence intervals (males only)

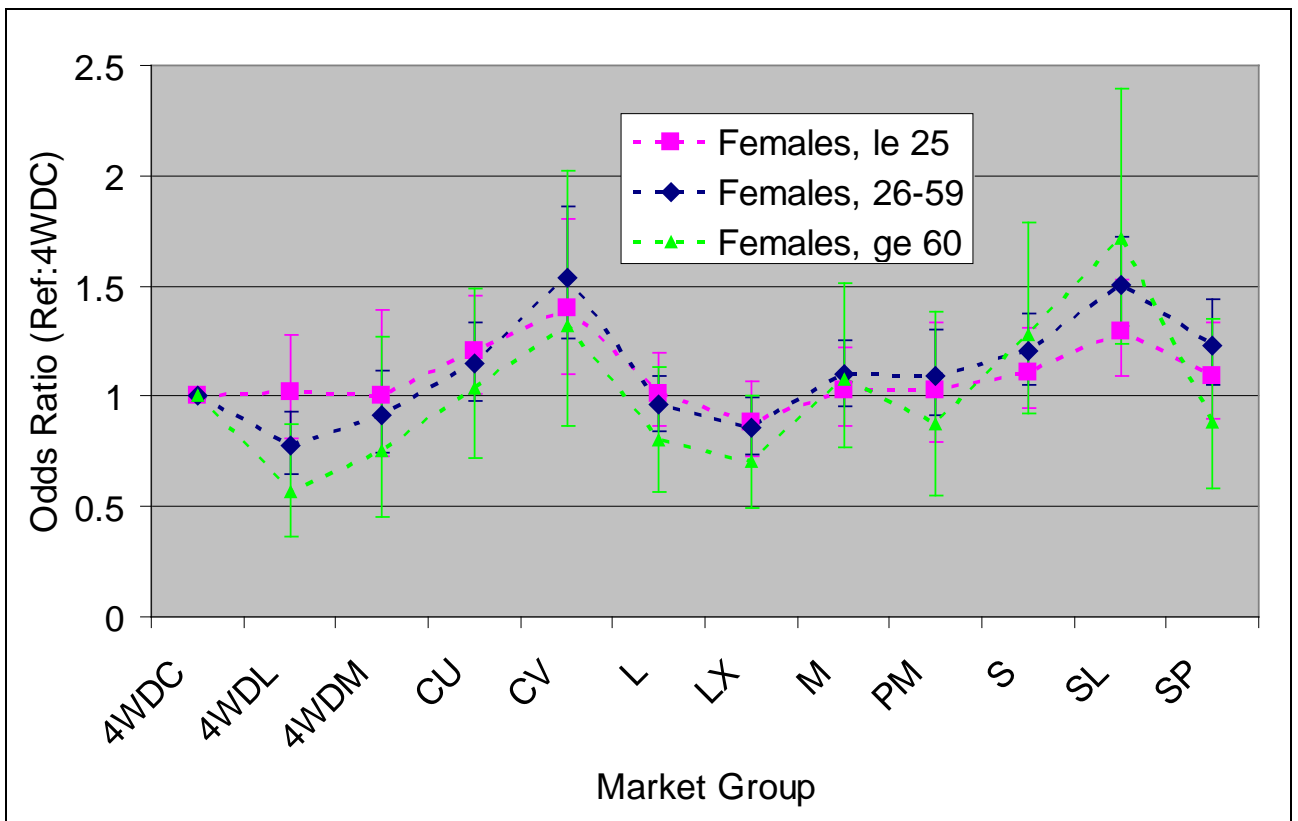


Figure 9b: Estimated crashworthiness odds ratios for market group within driver age and 95% confidence intervals (females only)

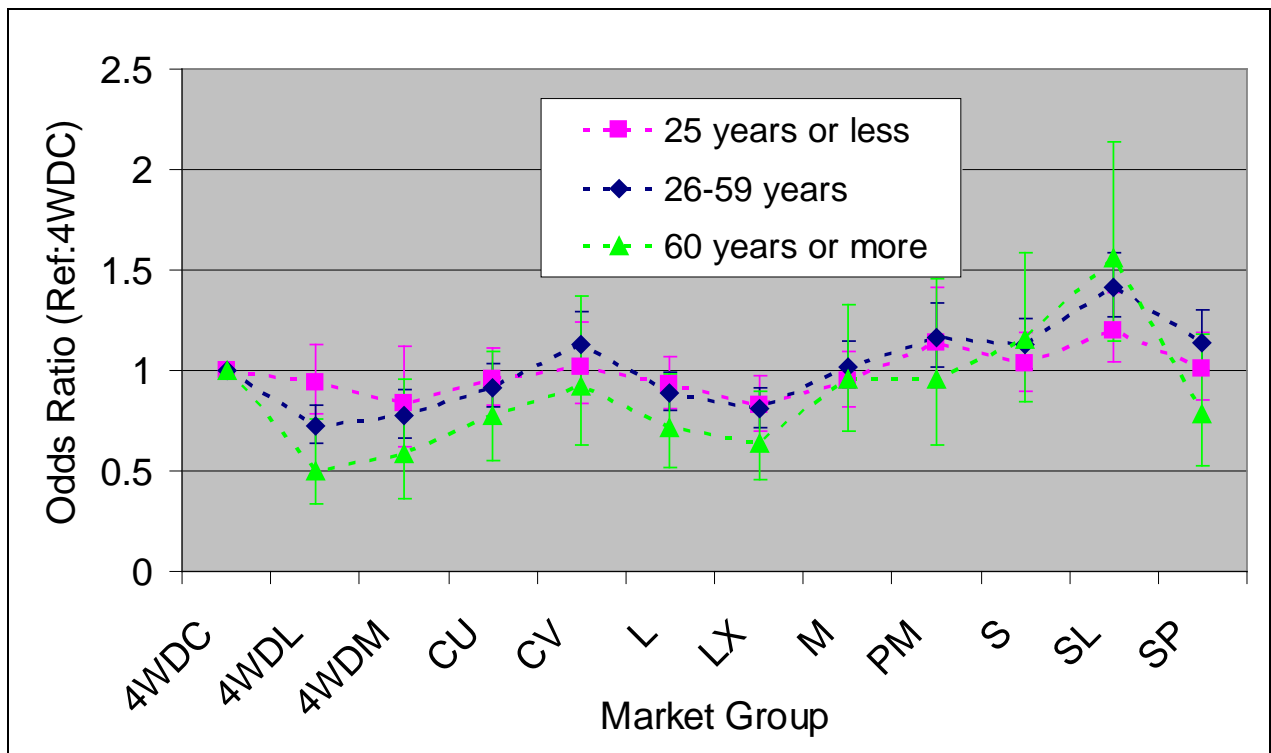


Figure 9c: Estimated crashworthiness odds ratios for market group within driver age and 95% confidence intervals (females and males)

Again, the reader should be aware that the rankings depicted in Table 9 are based on non-significant ($p > 0.05$) differences in the point estimates of the injury severity odds ratios for injured male and female drivers within each age category and market category.

Table 9: Rankings of estimated crashworthiness odds ratios for market group within driver age and sex categories (1=least risk of severe injury; 12=greatest risk)

Driver Sex	Males			Females			Males and Females		
	≤25	26-59	≥60	≤25	26-59	≥60	≤25	26-59	≥60
Compact Four Wheel Drive	10	8	10	2	5	7	7	6	10
Large Four Wheel Drive	7	2	1	7	1	1	5	1	1
Medium Four Wheel Drive	1	1	2	3	3	3	1	2	2
Commercial - Ute	3	4	5	10	8	8	6	5	5
Commercial - Van	6	7	7	12	12	11	9	9	7
Large	4	5	4	4	4	4	3	4	4
Luxury	2	3	3	1	2	2	2	3	3
Medium	5	6	8	5	7	9	4	7	9
People Mover	11	11	9	6	6	5	11	11	8
Small	9	9	11	9	9	10	10	8	11
Light	12	12	12	11	11	12	12	12	12
Sports	8	10	6	8	10	6	8	10	6

Highlighted cells represent market categories where the difference in rank for two of the three age categories is three or greater within each sex category

5. DISCUSSION

Very few studies have considered whether the relative occupant protection provided by various vehicle models or market groups differs depending on occupant characteristics such as age and gender or with crash characteristics.

The data compiled for the Used Car Safety Ratings Program (Newstead et al, 2006) was used in this report to identify and quantify the difference in relative vehicle market group safety depending on driver age and gender. This was done by introducing terms representing interactions between market group and age and sex of driver into the logistic regression models used to produce the Used Car Safety Ratings of Newstead et al (2006). Interaction effects represent the difference in increasing risk for two populations as they move from one condition to another. The analysis was based only on market group differences because of data limitations for individual vehicle models when classifying by age and gender.

After building injury risk and injury severity models that included interaction terms between driver age and market group and driver sex and market group, odds ratios for each market group were ranked within different demographic categories. This enabled the rank that was specific to the performance of each market group in protecting female drivers from (serious) injury to be compared to the protection that the same types of vehicles provided to male drivers. Table 2 of Section 4.1.1 suggested that Compact Four Wheel Drive vehicles and People Movers ranked better in terms of reducing injury risk for female drivers than for male drivers. Conversely, Commercial Vans and Sports Cars ranked better in terms of reduced risk of injury for male drivers when compared to the injury risk of such vehicles for female drivers.

When injury risk rankings of market groups for drivers classified into different age groups were compared in Table 3, it was found that Compact Four Wheel Drive vehicles ranked worse in terms of reducing injury risk for drivers in the 25 years or younger category than drivers in older categories, while Small Cars ranked better for younger drivers (25 years or less) than for drivers in the older age categories. However the reader is reminded that such differences in rankings were based on point estimates of injury risk odds ratios that weren't necessarily significantly different from each other.

Figure 4 demonstrated that there was little variation in the injury severity odds ratios between different market groups compared to the variation exhibited for injury risk odds ratios between different market groups (Figure 1). This meant that when injury severity odds ratios were estimated for male drivers and female drivers separately, slight variations in the point-estimates for each market group could have a disproportionate effect on the gender-specific rankings of a particular market category. This is evidenced in Table 5 where Medium Four Wheel Drive vehicles were ranked as being the safest in terms of injury severity for male drivers but tenth safest for female drivers, despite the point estimates for Medium Four Wheel Drive vehicles specific to male drivers not being significantly different to that for female drivers.

Section 4.3 described how the logistic model to estimate injury risk and the model to estimate injury severity could be used to estimate crashworthiness odds ratios for different market groups within driver demographic categories. Table 10 below is provided to assist in the interpretation of the crashworthiness rankings derived in Section 4.3. For each driver demographic category, market groups that ranked in positions 1 to 4 in terms of crashworthiness have been labelled "good" vehicle choices for the demographic, while the four least-crashworthy market groups have been labelled "poor" choices for the demographic. It can be seen that Small and Light Cars are poor choices for all demographics, while Medium Four Wheel Drive vehicles and Luxury Cars are Good choices for all demographics.

Table 10: *Categorisation of market groups into Good (crashworthiness ranking of 1 to 4) and Poor (9-12) categories for driver demographic groups defined by age and sex*

Driver age	25 years or less		26-59 years		60 years or more	
Driver sex	Male	Female	Male	Female	Male	Female
Compact Four Wheel Drive	Poor	Good			Poor	
Large Four Wheel Drive			Good	Good	Good	Good
Medium Four Wheel Drive	Good	Good	Good	Good	Good	Good
Commercial – Ute	Good	Poor	Good			
Commercial – Van		Poor		Poor		Poor
Large	Good	Good		Good	Good	Good
Luxury	Good	Good	Good	Good	Good	Good
Medium						Poor
People Mover	Poor		Poor		Poor	
Small	Poor	Poor	Poor	Poor	Poor	Poor
Light	Poor	Poor	Poor	Poor	Poor	Poor
Sports			Poor	Poor		

“Good” indicates a ranking of 1 to 4; “Poor” indicates a ranking of 9-12

Appendix D shows the distribution of the data used to produce the 2006 update of the Used Car Safety Ratings by Newstead et al (2006) by market group, driver age and driver sex for drivers that were injured in crashes that occurred in the period 2001-2005. The relatively poor secondary safety provided by light cars and small cars when compared to other market categories is of concern because, as Table D1 of Appendix D demonstrates, for vehicles manufactured since 1981, at least 25% of injured drivers were driving small or light cars.

This study is one of a few to identify and quantify the interaction between driver demographics and the level of safety of different market groups in this way. A previous study (Hill and Boyle, 2006) found that older females appear better off in vehicles which are larger and protect better in severe crashes and another study (Kweon and Kockelman, 2003) found that female drivers are at greater risk than males in SUVs, pickups and minivans, but young and middle-aged males are more vulnerable in passenger cars. To some extent the present report confirms the findings of Hill and Boyle’s (2006) study. For instance, in the present study, it was found that Large Cars and Luxury Cars offered good protection to older females, however these vehicles generally offered good protection to all drivers. Along with Large Cars and Luxury Cars, Large to Medium Four Wheel Drive vehicles also offered good protection to older female drivers, but these vehicles also provided good protection to most other demographic groups, suggesting that the safety benefits that these larger cars and Medium to Large Four Wheel Drives provide are not limited to older females.

Kweon and Kockelman’s (2003) finding that middle aged men are more vulnerable in passenger cars is partly supported by the current study. The least-crashworthy market category for males aged 26 to 59 years were Light Cars, People Movers, Small Cars and then Sports Cars. However three of these four market categories were also the four least-crashworthy types of vehicles for females in this age category, with Commercial Vans replacing People Movers in the “Poor” crashworthiness group for female drivers aged 26 to 59 years.

Another interesting result is that Commercial Vans ranked poorly in terms of crashworthiness for all female age groups, but received a ranking in neither the good nor poor categories for

males. Table D2 of Appendix D shows that only 20% of drivers of Commercial Vans who were injured were female, and that female drivers of Commercial Vans represented only 0.2% of all injured drivers. It is possible that because females represent such a low proportion of the demographic that drives Commercial Vans, these types of vehicles are less inclined to be designed with the safety of female drivers in mind. It is also possible that it is just a fortuitous coincidence the relatively few females are involved in crashes in Commercial Vans. Should the exposure of females in this vehicle type increase in the future this may become more of a significant injury problem.

The opposite was true for People Movers, with this category ranking poorly for males in all three age groups; but for female drivers, People Movers were ranked neither poor nor good in terms of crashworthiness. However unlike Commercial Vans and female drivers, a small majority (53%) of injured drivers of People Movers were males. There is no obvious explanation for why People Movers would rank as less safe types of vehicles for males than for females with further research being required to investigate possible reasons.

For drivers aged 25 years or less, Compact Four Wheel Drive vehicles received a good crashworthiness ranking for female drivers, but a poor ranking for male drivers. Only seven percent of injured drivers of Compact Four Wheel Drive vehicles were males aged 25 years or less compared with 15% for females in the same age group. Again, low prevalence of young male drivers in this vehicle type has mitigated a potential injury problem, a problem which may grow if exposure of young males increases in this vehicle type in the future.

Conversely, Commercial Utes received a poor ranking for female drivers aged 25 years or less and a good ranking for male drivers in the same age group. Only six percent of injured drivers of Commercial Utes were females aged 25 years or less, while males aged 25 years or less represented 23% of drivers of Commercial Utes. Again, the overall size of the injury problem represented by young female drivers in Commercial Utes is small because of their limited crash exposure, a situation that could change if exposure increases in the future.

Each of the variations in market group rankings between different driver demographic groups described above was derived by comparing the point-estimates of crashworthiness odds ratios only. The differences between these point estimates were quite often not significant. Where several market groups had similar crashworthiness estimates for one demographic group, a slight variation could have an exaggerated effect on the rankings for another demographic group. In such cases it is difficult to confidently say that one market group is a “safe” purchasing option for one demographic over another.

What is possible to say is that market categories that Newstead et al (2006) identified as being at either end of the crashworthiness spectrum performed as expected for most driver demographic groups. For example, Newstead et al (2006) ranked Large and Medium Four Wheel Drive vehicles as being the most-crashworthy and second most-crashworthy market groups respectively, while the present study showed that these two market categories ranked in the three most-crashworthy categories for all demographic groups except drivers aged 25 years or less in which Large Four Wheel Drive vehicles were ranked as being the fifth safest. Similarly, Newstead et al (2006) identified Light Cars as being the least-crashworthy market group; this category was ranked either the least-crashworthy or the second least crashworthy for every demographic.

5.1 Repercussions for the Used Car Safety Ratings

The Used Car Safety Ratings produce estimates of injury risk that reflect the average driver injury outcome across the standardised profile of driver demographics and crash circumstances for each make and model considered. If it is considered that age and sex interact significantly with vehicle market group or vehicle model the implication for vehicle rating systems may be that different rating sets would be required for different age and gender combinations.

Sections 4.1 and 4.2 showed that when market group by age and market group by sex interaction terms were added to the injury risk and injury severity models, these terms were significant. However adding these terms did not drastically affect the relative crashworthiness rankings for market groups between different demographic groups. With a couple of exceptions, types of vehicles that Newstead et al (2006) ranked as being safe for a standardised set of drivers were in general safe for drivers grouped by their age and sex. The same can be said for types of vehicles that Newstead et al (2006) rated as performing poorly for a standardised set of drivers.

6. RECOMMENDATIONS FOR FURTHER RESEARCH

- This study has only considered the interaction between driver age and gender and relative vehicle secondary safety performance. It is also possible that relative vehicle secondary safety performance varies with crash circumstances. It is recommended the analysis be extended to consider different crash configuration types.
- The interpretation of results was complex in this study because of the separate analysis of injury risk and injury severity. A less complex analysis using crash data with details on non-injury, injury and severe injury would allow prediction of injury severity for drivers involved in a crash thus simplifying the interpretation of results.
- Further research is required to understand the physical causes of the interaction effects measured in this study.
- This study showed that the relative crashworthiness of most market categories did not differ when ratings specific to different driver demographics were derived. However there were a few interesting exceptions such as Commercial vehicles, People Movers and Compact Four Wheel Drive vehicles, for which there was some evidence that crashworthiness varied across different demographic groups. It is also quite possible that such a trend would also be exhibited if different models of vehicles were analysed instead of different market groups. Based on the results of the present study, many models will probably offer a similar level of protection for all road users, but some models may offer better protection for some demographics when compared to others. It is possible that vehicles designed to perform well in crash test programs such as the New Car Assessment Program will exhibit poor crashworthiness odds ratios for occupants outside of the demographic focused on in the optimisation process. Such an outcome would support recent criticism of such programs. Unfortunately, at present there are insufficient data to complete an analysis at the model level.

7. CONCLUSIONS

- This report identified significant interaction effects between vehicle market group and driver age and gender.
- The interactive effects were relatively small compared to the gross effects of vehicle market group.
- Vehicles that rate high in terms of crashworthiness for a standardised set of drivers also tend to rate favourably for most groups of drivers. Similarly, vehicles identified as having poor crashworthiness for a standardised set of drivers also rate poorly for most groups of drivers.
- There is some evidence that compared to other market categories; Commercial vehicles offer poor protection to female drivers, but average protection to male drivers. Conversely, People Movers appear to be a poor choice in terms of safety for male drivers but offer average protection to female drivers. Compact Four Wheel Drive vehicles also appeared to be a poor choice for male drivers but not necessarily so for female drivers.

8. ASSUMPTIONS AND QUALIFICATIONS

The results and conclusions presented in this report are based on a number of assumptions and warrant a number of qualifications that the reader should note. These are as follows.

8.1 Assumptions

It has been assumed that:

- New South Wales, Victorian, Western Australian and Queensland Police crash reports accurately recorded driver injury, hospitalisation and death and that there was no bias in reporting injury at any level.
- Crashed vehicle registration numbers were recorded accurately on Police crash reports and that they correctly identified the crashed vehicles in the Victorian, NSW, Western Australian and Queensland vehicle registers. Further, it was also assumed that vehicle identification numbers and make and model details were accurately recorded in the vehicle registers.

8.1 Qualifications

The results and conclusions warrant at least the following qualification:

- Only light passenger vehicle driver crash involvements and injuries have been considered. Passengers occupying the same vehicle may have different injury outcomes.

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**LOGISTIC REGRESSION MODELS
USED TO ESTIMATE
INJURY RISK**

Table A1: *Type 3 Analysis of Effects when market group and the interactions between market group and driver age and market group and driver sex were added to the covariate model for injury risk*

Effect	DF	Chi-Square	Pr > ChiSq
AGE3	2	43.4333	<.0001
SEX1	1	28.7794	<.0001
ZONE1	1	255.4280	<.0001
NVEH1	1	174.2626	<.0001
FILEFLAG	2	228.4371	<.0001
YCRASH	17	216.9315	<.0001
AGE3*SEX1	2	195.2336	<.0001
AGE3*ZONE1	2	2.8560	0.2398
AGE3*NVEH1	2	180.7924	<.0001
ZONE1*NVEH1	1	116.3432	<.0001
FILEFLAG*YCRASH	26	256.0107	<.0001
SEX1*NVEH1	1	39.3139	<.0001
AGE3*ZONE1*NVEH1	2	21.7206	<.0001
FILEFLAG*NVEH1	2	16.0333	0.0003
YCRASH*NVEH1	17	139.0594	<.0001
AGE3*FILEFLAG	4	116.8179	<.0001
AGE3*YCRASH	34	176.1214	<.0001
ZONE1*YCRASH	17	42.6796	0.0005
ZONE1*YCRASH*NVEH1	17	109.4475	<.0001
ZONE1*FILEFLAG	2	209.0075	<.0001
ZONE1*FILEFLAG*NVEH1	2	672.8184	<.0001
ZONE1*FILEFLA*YCRASH	26	67.1439	<.0001
SEX1*ZONE1	1	20.9434	<.0001
SEX1*ZONE1*NVEH1	1	62.7855	<.0001
FILEFLAG*YCRASH*NVEH1	26	174.8970	<.0001
AGE3*FILEFLAG*NVEH1	4	152.0865	<.0001
AGE3*ZONE1*FILEFLAG	4	32.8032	<.0001
MKTGRP	11	1578.2685	<.0001
SEX1*MKTGRP	11	105.9695	<.0001
AGE3*MKTGRP	22	165.7865	<.0001

Table A2: *Estimated parameter coefficients, standard errors, Wald Chi-Square, p value and 95% confidence interval.*

Independent Variable / Risk factor	Parameter estimate	Standard error	Wald Chi-square	p-value	95% Confidence Interval	
					Lower limit	Upper limit
Age (Le 25 years)	0.3729	0.0573	42.3116	<.0001	0.2605	0.4853
Age (Ge 60 years)	0.0244	0.1174	0.0430	0.8357	-0.2058	0.2545
Sex (Female)	0.2434	0.0454	28.7794	<.0001	0.1545	0.3323
Market group						
4WDL	-0.5509	0.0447	152.1512	<.0001	-0.6385	-0.4634
4WDM	-0.3727	0.0588	40.1193	<.0001	-0.488	-0.2574
CU	-0.3056	0.0391	60.9299	<.0001	-0.3823	-0.2289
CV	-0.1295	0.044	8.6751	0.0032	-0.2157	-0.0433
L	-0.2779	0.0371	55.9934	<.0001	-0.3506	-0.2051
LX	-0.3127	0.041	58.1475	<.0001	-0.3931	-0.2323
M	-0.1271	0.0385	10.8807	0.001	-0.2027	-0.0516
PM	0.0479	0.0458	1.0952	0.2953	-0.0418	0.1377
S	-0.0246	0.0379	0.422	0.5159	-0.0989	0.0497
SL	0.1943	0.0391	24.6741	<.0001	0.1176	0.271
SP	-0.1352	0.0468	8.3625	0.0038	-0.2269	-0.0436
Market group, sex interaction						
Female, 4WDL	0.1780	0.0583	9.3242	0.0023	0.0638	0.2923
Female, 4WDM	0.0981	0.0749	1.7135	0.1905	-0.0488	0.2449
Female, CU	0.2998	0.0501	35.7465	<.0001	0.2015	0.3981
Female, CV	0.3854	0.0633	37.0409	<.0001	0.2613	0.5095
Female, L	0.2134	0.0435	24.0296	<.0001	0.1281	0.2987
Female, LX	0.1292	0.0488	7.0088	0.0081	0.0336	0.2249
Female, M	0.1999	0.045	19.7719	<.0001	0.1118	0.288
Female, PM	0.00424	0.0577	0.0054	0.9414	-0.1088	0.1173
Female, S	0.2062	0.0439	22.0362	<.0001	0.1201	0.2924
Female, SL	0.1494	0.0451	10.9761	0.0009	0.061	0.2377
Female, SP	0.2539	0.055	21.316	<.0001	0.1461	0.3617
Market group, age interaction						
Le 25 years, 4WDL	0.0972	0.0636	2.3404	0.1261	-0.0273	0.2218
Le 25 years, 4WDM	0.0645	0.0949	0.4621	0.4966	-0.1214	0.2504
Le 25 years, CU	-0.0585	0.0504	1.3508	0.2451	-0.1572	0.0402
Le 25 years, CV	-0.0484	0.0634	0.5827	0.4452	-0.1727	0.0759
Le 25 years, L	-0.1055	0.0459	5.2801	0.0216	-0.1955	-0.0155
Le 25 years, LX	-0.1452	0.0549	6.9979	0.0082	-0.2528	-0.0376
Le 25 years, M	-0.1535	0.0479	10.2836	0.0013	-0.2473	-0.0597
Le 25 years, PM	-0.1614	0.0686	5.5421	0.0186	-0.2957	-0.027
Le 25 years, S	-0.1685	0.0461	13.3701	0.0003	-0.2588	-0.0782
Le 25 years, SL	-0.2009	0.047	18.2663	<.0001	-0.2931	-0.1088
Le 25 years, SP	-0.1340	0.0576	5.4122	0.02	-0.2468	-0.0211
Ge 60 years, 4WDL	0.0500	0.1226	0.1664	0.6833	-0.1903	0.2904
Ge 60 years, 4WDM	0.0484	0.1524	0.1008	0.7509	-0.2503	0.3471
Ge 60 years, CU	0.00783	0.1081	0.0052	0.9423	-0.2041	0.2197
Ge 60 years, CV	0.1876	0.1210	2.4019	0.1212	-0.0496	0.4248
Ge 60 years, L	0.0360	0.1009	0.1274	0.7212	-0.1617	0.2337
Ge 60 years, LX	-0.0440	0.1054	0.1740	0.6766	-0.2506	0.1627
Ge 60 years, M	0.0939	0.1020	0.8473	0.3573	-0.1061	0.2939
Ge 60 years, PM	-0.0174	0.1314	0.0175	0.8947	-0.2748	0.2401
Ge 60 years,S	0.1387	0.1013	1.8753	0.1709	-0.0598	0.3372
Ge 60 years,SL	0.1533	0.1027	2.2296	0.1354	-0.0479	0.3546
Ge 60 years,SP	-0.0571	0.1318	0.1875	0.665	-0.3153	0.2012

The parameter estimates of the shaded independent variables are significant.

Table A3: *Covariance matrix of relevant variables from the injury risk model*

Market group	β_{mktgrp} , $\beta_{mktgrp*female}$	β_{mktgrp} , $\beta_{mktgrp*age_le25}$	β_{mktgrp} , $\beta_{mktgrp*age_ge60}$	$\beta_{mktgrp*female}$, $\beta_{mktgrp*age_le25}$	$\beta_{mktgrp*female}$, $\beta_{mktgrp*age_ge60}$
4WDL	-0.00156	-0.00135	-0.0016	0.000240	0.000806
4WDM	-0.00288	-0.00218	-0.0027	0.000393	0.001430
CU	-0.00114	-0.00101	-0.0012	0.000099	0.000515
CV	-0.00145	-0.00135	-0.0016	0.000124	0.000564
L	-0.00105	-0.00086	-0.0011	0.000119	0.000477
LX	-0.00130	-0.00106	-0.0013	0.000153	0.000567
M	-0.00113	-0.00093	-0.0011	0.000125	0.000503
PM	-0.00170	-0.00141	-0.0017	0.000393	0.000906
S	-0.00109	-0.00089	-0.0011	0.000115	0.000481
SL	-0.00116	-0.00092	-0.0011	0.000105	0.000489
SP	-0.00164	-0.00143	-0.0016	0.000268	0.000474

Table A4: *Estimated injury risk odds ratios for market group within driver sex and 95% confidence intervals (for drivers aged 25 years or less only)*

Driver sex	Market group	Odds Ratio	95% Confidence interval	
Male	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	0.64	0.57	0.71
	Medium Four Wheel Drive	0.73	0.62	0.88
	Commercial - Ute	0.69	0.64	0.76
	Commercial - Van	0.84	0.75	0.94
	Large	0.68	0.63	0.74
	Luxury	0.63	0.57	0.70
	Medium	0.76	0.69	0.82
	People Mover	0.89	0.79	1.01
	Small	0.82	0.76	0.90
	Light	0.99	0.91	1.08
	Sports	0.76	0.69	0.85
Female	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	0.76	0.67	0.86
	Medium Four Wheel Drive	0.81	0.67	0.97
	Commercial - Ute	0.94	0.85	1.03
	Commercial - Van	1.23	1.08	1.41
	Large	0.84	0.78	0.92
	Luxury	0.72	0.65	0.80
	Medium	0.92	0.85	1.01
	People Mover	0.90	0.78	1.03
	Small	1.01	0.93	1.10
	Light	1.15	1.06	1.25
	Sports	0.98	0.89	1.10

Odds ratio estimates for market groups within each driver sex category that are significantly ($p < 0.05$) different to that for Compact Four Wheel Drive vehicles have been highlighted

Table A5: *Estimated injury risk odds ratios for market group within driver sex and 95% confidence intervals (for drivers aged 60 years or greater only)*

Driver sex	Market group	Odds Ratio	95% Confidence interval	
Male	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	0.61	0.48	0.76
	Medium Four Wheel Drive	0.72	0.54	0.96
	Commercial - Ute	0.74	0.61	0.91
	Commercial - Van	1.06	0.84	1.33
	Large	0.79	0.65	0.95
	Luxury	0.70	0.57	0.85
	Medium	0.97	0.80	1.17
	People Mover	1.03	0.80	1.32
	Small	1.12	0.93	1.36
	Light	1.42	1.17	1.72
	Sports	0.83	0.64	1.06
Female	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	0.72	0.57	0.93
	Medium Four Wheel Drive	0.80	0.59	1.08
	Commercial - Ute	1.00	0.81	1.24
	Commercial - Van	1.56	1.22	1.99
	Large	0.97	0.80	1.18
	Luxury	0.80	0.65	0.98
	Medium	1.18	0.97	1.44
	People Mover	1.04	0.80	1.34
	Small	1.38	1.13	1.68
	Light	1.64	1.34	2.01
	Sports	1.06	0.82	1.37

Odds ratio estimates for market groups within each driver sex category that are significantly ($p < 0.05$) different to that for Compact Four Wheel Drive vehicles have been highlighted

Table A6: *Estimated injury risk odds ratios for market group within driver sex and 95% confidence intervals (for all ages)*

Driver sex	Market group	Odds Ratio	95% Confidence interval	
Male	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	0.58	0.54	0.62
	Medium Four Wheel Drive	0.68	0.61	0.75
	Commercial - Ute	0.72	0.67	0.76
	Commercial - Van	0.87	0.81	0.93
	Large	0.73	0.68	0.77
	Luxury	0.68	0.64	0.73
	Medium	0.84	0.79	0.90
	People Mover	0.99	0.92	1.07
	Small	0.93	0.87	0.99
	Light	1.14	1.07	1.22
Sports	0.83	0.77	0.90	
Female	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	0.68	0.63	0.75
	Medium Four Wheel Drive	0.74	0.67	0.83
	Commercial - Ute	0.97	0.90	1.05
	Commercial - Van	1.27	1.15	1.40
	Large	0.90	0.85	0.95
	Luxury	0.78	0.73	0.84
	Medium	1.02	0.96	1.09
	People Mover	1.00	0.92	1.08
	Small	1.14	1.07	1.21
	Light	1.32	1.24	1.40
Sports	1.07	0.99	1.15	

Odds ratio estimates for market groups within each driver sex category that are significantly ($p < 0.05$) different to that for Compact Four Wheel Drive vehicles have been highlighted

Table A7: *Estimated injury risk odds ratios for market group within driver age and 95% confidence intervals (for males and females)*

Age	Market group	Odds Ratio	95% Confidence interval	
25 years or less	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	0.70	0.63	0.77
	Medium Four Wheel Drive	0.78	0.66	0.92
	Commercial - Ute	0.78	0.73	0.85
	Commercial - Van	0.96	0.87	1.06
	Large	0.76	0.71	0.81
	Luxury	0.68	0.62	0.74
	Medium	0.84	0.78	0.90
	People Mover	0.94	0.83	1.05
	Small	0.92	0.85	0.98
	Light	1.06	0.99	1.14
	Sports	0.86	0.78	0.96
26-59 years	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	0.64	0.60	0.69
	Medium Four Wheel Drive	0.73	0.67	0.80
	Commercial - Ute	0.84	0.79	0.89
	Commercial - Van	1.02	0.95	1.09
	Large	0.85	0.81	0.90
	Luxury	0.79	0.74	0.84
	Medium	0.99	0.93	1.05
	People Mover	1.07	1.00	1.15
	Small	1.10	1.04	1.16
	Light	1.31	1.24	1.39
	Sports	1.01	0.94	1.08
60 years or more	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	0.64	0.51	0.81
	Medium Four Wheel Drive	0.75	0.57	1.00
	Commercial - Ute	0.80	0.65	0.98
	Commercial - Van	1.16	0.93	1.45
	Large	0.84	0.69	1.01
	Luxury	0.73	0.60	0.89
	Medium	1.03	0.85	1.25
	People Mover	1.06	0.83	1.36
	Small	1.20	0.99	1.45
	Light	1.46	1.21	1.77
	Sports	0.90	0.71	1.16

Odds ratio estimates for market groups within each driver age category that are significantly ($p < 0.05$) different to that for Compact Four Wheel Drive vehicles have been highlighted

**LOGISTIC REGRESSION MODELS
USED TO ESTIMATE
INJURY SEVERITY**

Table B1: *Type 3 Analysis of Effects when market group and the interactions between market group and driver age and market group and driver sex were added to the covariate model for injury severity*

Effect	DF	Chi-Square	Pr > ChiSq
AGE3	2	7.0734	0.0291
SEX1	1	6.8103	0.0091
ZONE1	1	2.1466	0.1429
NVEH1	1	0.3764	0.5395
FILEFLAG	4	78.4481	<.0001
YCRASH	17	28.2167	0.0425
FILEFLAG*NVEH1	4	24.9638	<.0001
ZONE1*NVEH1	1	9.4733	0.0021
FILEFLAG*YCRASH	49	146.3313	<.0001
AGE3*SEX1	2	68.1668	<.0001
AGE3*NVEH1	2	13.6819	0.0011
ZONE1*FILEFLAG	4	10.6598	0.0307
ZONE1*YCRASH	17	14.1887	0.6537
AGE3*FILEFLAG	8	19.3728	0.0130
SEX1*FILEFLAG	4	27.5294	<.0001
AGE3*ZONE1	2	6.0163	0.0494
ZONE1*FILEFLAG*NVEH1	4	3.4790	0.4811
ZONE1*FILEFLAG*YCRASH	49	68.4736	0.0344
AGE3*YCRASH	34	47.8056	0.0584
SEX1*ZONE1	1	6.9846	0.0082
AGE3*FILEFLAG*YCRASH	98	137.8046	0.0050
YCRASH*NVEH1	17	26.2350	0.0703
AGE3*FILEFLAG*NVEH1	8	30.2918	0.0002
FILEFLAG*YCRASH*NVEH1	49	86.8519	0.0007
AGE3*ZONE1*FILEFLAG	8	16.9439	0.0307
ZONE1*YCRASH*NVEH1	17	16.9769	0.4559
ZONE*FILEFLAG*YCRASH*NVEH1	49	87.4296	0.0006
MKTGRP	11	30.0616	0.0015
SEX1*MKTGRP	11	22.0052	0.0243
AGE3*MKTGRP	22	94.6849	<.0001

Table B2: *Estimated parameter coefficients, standard errors, Wald Chi-Square, p value and 95% confidence intervals.*

Independent Variable / Risk factor	Parameter estimate	Standard error	Wald Chi-square	p-value	95% Confidence Interval	
					Lower limit	Upper limit
Age (Le 25 years)	-0.171	0.1749	0.9552	0.3284	-0.5138	0.1719
Age (Ge 60 years)	0.5276	0.2449	4.6428	0.0312	0.0477	1.0076
Sex (Female)	-0.2515	0.0964	6.8103	0.0091	-0.4403	-0.0626
Market group						
4WDL	0.0864	0.0923	0.8772	0.3490	-0.0945	0.2673
4WDM	-0.1277	0.1151	1.2308	0.2673	-0.3532	0.0979
CU	0.0564	0.0828	0.4634	0.4960	-0.1059	0.2186
CV	0.0967	0.0932	1.0765	0.2995	-0.0860	0.2794
L	0.0313	0.0789	0.1578	0.6912	-0.1233	0.1860
LX	-0.0229	0.0865	0.0700	0.7914	-0.1924	0.1466
M	0.0435	0.0815	0.2849	0.5935	-0.1162	0.2031
PM	0.1605	0.0972	2.7252	0.0988	-0.0301	0.3511
S	0.0723	0.0804	0.8069	0.3690	-0.0854	0.2299
SL	0.1355	0.0837	2.6237	0.1053	-0.0285	0.2995
SP	0.1866	0.0936	3.9723	0.0463	0.0031	0.3701
Market group, sex interaction						
Female, 4WDL	0.00664	0.1217	0.0030	0.9565	-0.2319	0.2452
Female, 4WDM	0.3117	0.1459	4.5647	0.0326	0.0258	0.5977
Female, CU	0.1185	0.1053	1.2667	0.2604	-0.0879	0.3249
Female, CV	0.1683	0.1296	1.6875	0.1939	-0.0856	0.4222
Female, L	-0.0142	0.0937	0.0231	0.8793	-0.1978	0.1693
Female, LX	0.025	0.1037	0.0582	0.8093	-0.1782	0.2282
Female, M	-0.00581	0.0961	0.0037	0.9518	-0.1942	0.1826
Female, PM	-0.1065	0.1253	0.7215	0.3957	-0.3521	0.1392
Female, S	-0.035	0.0943	0.1374	0.7109	-0.2198	0.1499
Female, SL	0.0149	0.0972	0.0236	0.8780	-0.1756	0.2054
Female, SP	-0.0571	0.1111	0.2639	0.6074	-0.2749	0.1607
Market group, age interaction						
Le 25 years, 4WDL	0.2326	0.1306	3.1723	0.0749	-0.0234	0.4886
Le 25 years, 4WDM	0.0518	0.1869	0.0767	0.7818	-0.3146	0.4181
Le 25 years, CU	0.1343	0.1090	1.5192	0.2177	-0.0793	0.3479
Le 25 years, CV	-0.0623	0.1361	0.2099	0.6468	-0.3290	0.2043
Le 25 years, L	0.1843	0.1008	3.3391	0.0677	-0.0134	0.3819
Le 25 years, LX	0.2002	0.1163	2.9613	0.0853	-0.0278	0.4282
Le 25 years, M	0.0803	0.1043	0.5931	0.4412	-0.1241	0.2848
Le 25 years, PM	0.0986	0.1484	0.4414	0.5065	-0.1923	0.3894
Le 25 years, S	0.0794	0.1015	0.6126	0.4338	-0.1195	0.2783
Le 25 years, SL	0.0168	0.1040	0.0262	0.8715	-0.1870	0.2206
Le 25 years, SP	-0.00015	0.1180	0	0.9990	-0.2315	0.2311
Ge 60 years, 4WDL	-0.4417	0.2226	3.9380	0.0472	-0.8780	-0.00545
Ge 60 years, 4WDM	-0.2890	0.2675	1.1670	0.2800	-0.8132	0.2353
Ge 60 years, CU	-0.1374	0.1933	0.5051	0.4772	-0.5163	0.2415
Ge 60 years, CV	-0.3693	0.2186	2.8523	0.0912	-0.7978	0.0593
Ge 60 years, L	-0.2518	0.1798	1.9607	0.1614	-0.6042	0.1006
Ge 60 years, LX	-0.1934	0.1884	1.0536	0.3047	-0.5626	0.1759
Ge 60 years, M	-0.1213	0.1816	0.4458	0.5043	-0.4773	0.2347

The parameter estimates of the shaded independent variables are significant.

Table B3: *Covariance matrix of relevant variables from the injury severity model*

Market group	β_{mktgrp} , $\beta_{mktgrp*female}$	β_{mktgrp} , $\beta_{mktgrp*age_le25}$	β_{mktgrp} , $\beta_{mktgrp*age_ge60}$	$\beta_{mktgrp*female}$, $\beta_{mktgrp*age_le25}$	$\beta_{mktgrp*female}$, $\beta_{mktgrp*age_ge60}$
4WDL	-0.00650	-0.00596	-0.00668	0.001048	0.002677
4WDM	-0.01086	-0.00863	-0.01003	0.001848	0.004599
CU	-0.00508	-0.00468	-0.00524	0.000668	0.001843
CV	-0.00652	-0.00620	-0.00679	0.000865	0.002141
L	-0.00469	-0.00412	-0.00464	0.000740	0.001715
LX	-0.00566	-0.00500	-0.00554	0.000955	0.001977
M	-0.00497	-0.00438	-0.00493	0.000782	0.001792
PM	-0.00754	-0.00664	-0.00731	0.001883	0.003223
S	-0.00484	-0.00422	-0.00476	0.000723	0.001723
SL	-0.00525	-0.00444	-0.00502	0.000696	0.001760
SP	-0.00649	-0.00609	-0.00635	0.001432	0.001879

Table B4: *Estimated injury severity odds ratios for market group within driver sex and 95% confidence intervals (for drivers aged 25 years or less only)*

Driver sex	Market group	Odds Ratio	95% Confidence interval	
Male	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	1.38	1.09	1.73
	Medium Four Wheel Drive	0.93	0.66	1.31
	Commercial - Ute	1.21	1.00	1.46
	Commercial - Van	1.03	0.82	1.31
	Large	1.24	1.04	1.48
	Luxury	1.19	0.97	1.47
	Medium	1.13	0.94	1.36
	People Mover	1.30	0.99	1.69
	Small	1.16	0.97	1.39
	Light	1.16	0.97	1.40
Sports	1.20	0.99	1.47	
Female	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	1.38	1.07	1.80
	Medium Four Wheel Drive	1.27	0.88	1.82
	Commercial - Ute	1.36	1.10	1.68
	Commercial - Van	1.22	0.93	1.62
	Large	1.22	1.02	1.47
	Luxury	1.22	0.98	1.52
	Medium	1.13	0.93	1.36
	People Mover	1.16	0.87	1.56
	Small	1.12	0.93	1.35
	Light	1.18	0.98	1.43
Sports	1.14	0.91	1.42	

Odds ratio estimates for market groups within each driver sex category that are significantly ($p < 0.05$) different to that for Compact Four Wheel Drive vehicles have been highlighted

Table B5: *Estimated injury severity odds ratios for market group within driver sex and 95% confidence intervals (for drivers aged 60 years or greater only)*

Driver sex	Market group	Odds Ratio	95% Confidence interval	
Male	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	0.70	0.46	1.06
	Medium Four Wheel Drive	0.66	0.40	1.09
	Commercial - Ute	0.92	0.64	1.32
	Commercial - Van	0.76	0.51	1.14
	Large	0.80	0.57	1.12
	Luxury	0.81	0.57	1.14
	Medium	0.93	0.66	1.30
	People Mover	0.91	0.58	1.42
	Small	1.01	0.72	1.41
	Light	1.16	0.82	1.63
	Sports	0.86	0.57	1.29
Female	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	0.71	0.45	1.10
	Medium Four Wheel Drive	0.90	0.53	1.53
	Commercial – Ute	1.04	0.71	1.52
	Commercial - Van	0.90	0.58	1.40
	Large	0.79	0.56	1.12
	Luxury	0.83	0.57	1.19
	Medium	0.92	0.65	1.31
	People Mover	0.82	0.51	1.31
	Small	0.98	0.69	1.39
	Light	1.17	0.82	1.67
	Sports	0.81	0.53	1.24

Odds ratio estimates for market groups within each driver sex category that are significantly ($p < 0.05$) different to that for Compact Four Wheel Drive vehicles have been highlighted

Table B6: *Estimated injury severity odds ratios for market group within driver sex and 95% confidence intervals (for all ages)*

Driver sex	Market group	Odds Ratio	95% Confidence interval	
Male	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	1.12	0.96	1.30
	Medium Four Wheel Drive	0.88	0.73	1.07
	Commercial - Ute	1.10	0.96	1.25
	Commercial - Van	1.06	0.91	1.24
	Large	1.07	0.94	1.22
	Luxury	1.02	0.88	1.17
	Medium	1.07	0.94	1.23
	People Mover	1.19	1.02	1.40
	Small	1.11	0.98	1.27
	Light	1.17	1.02	1.34
	Sports	1.16	1.00	1.35
	Female	Compact Four Wheel Drive	1.00	
Large Four Wheel Drive		1.14	0.95	1.37
Medium Four Wheel Drive		1.21	0.99	1.49
Commercial - Ute		1.24	1.06	1.44
Commercial - Van		1.26	1.03	1.54
Large		1.05	0.92	1.19
Luxury		1.03	0.89	1.19
Medium		1.06	0.92	1.22
People Mover		1.07	0.85	1.35
Small		1.07	0.94	1.21
Light		1.18	1.03	1.34
Sports		1.12	0.95	1.31

Odds ratio estimates for market groups within each driver sex category that are significantly ($p < 0.05$) different to that for Compact Four Wheel Drive vehicles have been highlighted

Table B7: *Estimated injury severity odds ratios for market group within driver age and 95% confidence intervals (for males and females)*

Driver age	Market group	Odds Ratio	95% Confidence interval	
25 years or less	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	1.38	1.12	1.70
	Medium Four Wheel Drive	1.04	0.76	1.44
	Commercial - Ute	1.24	1.05	1.47
	Commercial - Van	1.07	0.86	1.33
	Large	1.23	1.06	1.44
	Luxury	1.20	1.00	1.45
	Medium	1.13	0.96	1.33
	People Mover	1.26	0.98	1.61
	Small	1.14	0.98	1.34
	Light	1.18	1.00	1.38
26-59 years	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	1.09	0.94	1.26
	Medium Four Wheel Drive	1.02	0.86	1.21
	Commercial - Ute	1.08	0.95	1.23
	Commercial - Van	1.14	0.99	1.33
	Large	1.03	0.91	1.16
	Luxury	0.99	0.87	1.13
	Medium	1.04	0.92	1.18
	People Mover	1.12	0.97	1.30
	Small	1.05	0.93	1.19
	Light	1.16	1.02	1.31
60 years or more	Compact Four Wheel Drive	1.00		
	Large Four Wheel Drive	0.70	0.47	1.05
	Medium Four Wheel Drive	0.71	0.44	1.16
	Commercial - Ute	0.94	0.66	1.33
	Commercial - Van	0.78	0.52	1.17
	Large	0.80	0.57	1.11
	Luxury	0.81	0.58	1.14
	Medium	0.92	0.66	1.29
	People Mover	0.89	0.57	1.38
	Small	0.99	0.71	1.38
	Light	1.17	0.84	1.63
Sports	0.83	0.56	1.25	

Odds ratio estimates for market groups within each driver age category that are significantly ($p < 0.05$) different to that for Compact Four Wheel Drive vehicles have been highlighted

**LOGISTIC REGRESSION MODELS
USED TO ESTIMATE
CRASHWORTHINESS**

Table C1: *Estimated crashworthiness odds ratios for market group within driver sex and 95% confidence intervals (for drivers aged 26-59 years)*

Market group		Injury Risk		Injury Severity		Crashworthiness		
		Odds Ratio	Variance	Odds Ratio	Variance	Odds Ratio	95% Confidence interval	
Male	Compact Four Wheel Drive	1.00		1.00		1.00		
	Large Four Wheel Drive	0.58	0.001998	1.09	0.008519	0.66	0.56	0.78
	Medium Four Wheel Drive	0.69	0.003457	0.88	0.013248	0.65	0.53	0.80
	Commercial - Ute	0.74	0.001529	1.06	0.006856	0.80	0.69	0.93
	Commercial - Van	0.88	0.001936	1.10	0.008686	0.97	0.82	1.14
	Large	0.76	0.001376	1.03	0.006225	0.81	0.70	0.93
	Luxury	0.73	0.001681	0.98	0.007482	0.75	0.64	0.87
	Medium	0.88	0.001482	1.04	0.006642	0.93	0.80	1.07
	People Mover	1.05	0.002098	1.17	0.009448	1.19	1.00	1.41
	Small	0.98	0.001436	1.07	0.006464	1.04	0.90	1.20
	Light	1.21	0.001529	1.15	0.007006	1.32	1.14	1.52
	Sports	0.87	0.002190	1.21	0.008761	1.03	0.88	1.22
Female	Compact Four Wheel Drive	1.00		1.00		1.00		
	Large Four Wheel Drive	0.69	0.002277	1.10	0.010330	0.78	0.65	0.93
	Medium Four Wheel Drive	0.76	0.003307	1.20	0.012815	0.91	0.75	1.12
	Commercial – Ute	0.99	0.001759	1.19	0.007784	1.15	0.98	1.34
	Commercial - Van	1.29	0.003043	1.30	0.012442	1.53	1.27	1.86
	Large	0.94	0.001169	1.02	0.005625	0.96	0.84	1.10
	Luxury	0.83	0.001462	1.00	0.006916	0.85	0.74	0.99
	Medium	1.08	0.001247	1.04	0.005937	1.10	0.96	1.26
	People Mover	1.05	0.002027	1.06	0.010068	1.09	0.92	1.30
	Small	1.20	0.001184	1.04	0.005677	1.20	1.05	1.37
	Light	1.41	0.001243	1.16	0.005954	1.50	1.32	1.72
	Sports	1.13	0.001935	1.14	0.008124	1.23	1.05	1.44

Odds ratio estimates for market groups within each driver sex category that are significantly ($p < 0.05$) different to that for Compact Four Wheel Drive vehicles have been highlighted

Table C2: *Estimated crashworthiness odds ratios for market group within driver sex and 95% confidence intervals (for drivers aged 25 years or less)*

Sex	Market group	Injury Risk		Injury Severity		Crashworthiness	
		Odds Ratio	Variance	Odds Ratio	Variance	Odds Ratio	95% Confidence interval
Male	Compact Four Wheel Drive	1.00		1.00		1.00	
	Large Four Wheel Drive	0.64	0.003343	1.38	0.013656	0.86	0.70 1.05
	Medium Four Wheel Drive	0.73	0.008103	0.93	0.030920	0.72	0.52 0.99
	Commercial - Ute	0.69	0.002049	1.21	0.009377	0.85	0.72 1.00
	Commercial - Van	0.84	0.003256	1.03	0.014809	0.88	0.71 1.10
	Large	0.68	0.001763	1.24	0.008146	0.85	0.73 0.99
	Luxury	0.63	0.002575	1.19	0.011008	0.77	0.64 0.93
	Medium	0.76	0.001917	1.13	0.008761	0.87	0.73 1.02
	People Mover	0.89	0.003984	1.30	0.018190	1.11	0.89 1.41
	Small	0.82	0.001782	1.16	0.008326	0.96	0.82 1.12
	Light	0.99	0.001898	1.16	0.008942	1.12	0.95 1.33
	Sports	0.76	0.002648	1.20	0.010505	0.92	0.77 1.10
Female	Compact Four Wheel Drive	1.00		1.00		1.00	
	Large Four Wheel Drive	0.76	0.004102	1.38	0.017563	1.02	0.81 1.28
	Medium Four Wheel Drive	0.81	0.008739	1.27	0.034182	1.01	0.73 1.39
	Commercial – Ute	0.94	0.002477	1.36	0.011641	1.21	1.01 1.45
	Commercial - Van	1.23	0.004610	1.22	0.020296	1.40	1.10 1.80
	Large	0.84	0.001793	1.22	0.009026	1.01	0.86 1.19
	Luxury	0.72	0.002662	1.22	0.012352	0.88	0.73 1.07
	Medium	0.92	0.001932	1.13	0.009620	1.03	0.87 1.22
	People Mover	0.90	0.004699	1.16	0.022576	1.03	0.79 1.34
	Small	1.01	0.001759	1.12	0.008985	1.11	0.94 1.31
	Light	1.15	0.001822	1.18	0.009282	1.29	1.09 1.53
	Sports	0.98	0.002929	1.14	0.012732	1.10	0.90 1.34

Odds ratio estimates for market groups within each driver sex category that are significantly ($p < 0.05$) different to that for Compact Four Wheel Drive vehicles have been highlighted

Table C3: *Estimated crashworthiness odds ratios for market group within driver sex and 95% confidence intervals (for drivers aged 60 years or more)*

Sex	Market group	Injury Risk		Injury Severity		Crashworthiness		
		Odds Ratio	Variance	Odds Ratio	Variance	Odds Ratio	95% Confidence interval	
Male	Compact Four Wheel Drive	1.00		1.00		1.00		
	Large Four Wheel Drive	0.61	0.013789	0.70	0.044710	0.48	0.32	0.72
	Medium Four Wheel Drive	0.72	0.021263	0.66	0.064744	0.53	0.32	0.88
	Commercial - Ute	0.74	0.010794	0.92	0.033741	0.72	0.51	1.02
	Commercial - Van	1.06	0.013457	0.76	0.042892	0.84	0.56	1.25
	Large	0.79	0.009437	0.80	0.029273	0.68	0.49	0.94
	Luxury	0.70	0.010230	0.81	0.031897	0.61	0.43	0.86
	Medium	0.97	0.009606	0.93	0.029761	0.91	0.66	1.26
	People Mover	1.03	0.016004	0.91	0.051139	0.95	0.62	1.46
	Small	1.12	0.009518	1.01	0.029416	1.11	0.81	1.53
	Light	1.42	0.009796	1.16	0.030345	1.50	1.10	2.07
	Sports	0.83	0.016461	0.86	0.044285	0.74	0.50	1.12
Female	Compact Four Wheel Drive	1.00		1.00		1.00		
	Large Four Wheel Drive	0.72	0.015680	0.71	0.051875	0.56	0.36	0.88
	Medium Four Wheel Drive	0.80	0.023973	0.90	0.073509	0.75	0.45	1.27
	Commercial – Ute	1.00	0.012054	1.04	0.038355	1.03	0.72	1.49
	Commercial - Van	1.56	0.015692	0.90	0.050930	1.32	0.87	2.02
	Large	0.97	0.010183	0.79	0.032103	0.80	0.57	1.13
	Luxury	0.80	0.011146	0.83	0.035285	0.70	0.49	1.00
	Medium	1.18	0.010377	0.92	0.032640	1.07	0.77	1.51
	People Mover	1.04	0.017745	0.82	0.058205	0.87	0.55	1.38
	Small	1.38	0.010227	0.98	0.032075	1.28	0.92	1.79
	Light	1.64	0.010488	1.17	0.032813	1.72	1.24	2.39
	Sports	1.06	0.017154	0.81	0.047406	0.88	0.58	1.35

Odds ratio estimates for market groups within each driver sex category that are significantly ($p < 0.05$) different to that for Compact Four Wheel Drive vehicles have been highlighted

Table C4: *Estimated crashworthiness odds ratios for market group within driver sex and 95% confidence intervals (for drivers of all ages)*

Sex	Market group	Injury Risk		Injury Severity		Crashworthiness		
		Odds Ratio	Variance	Odds Ratio	Variance	Odds Ratio	95% Confidence interval	
Male	Compact Four Wheel Drive	1.00		1.00		1.00		
	Large Four Wheel Drive	0.58	0.001429	1.12	0.005898	0.68	0.59	0.78
	Medium Four Wheel Drive	0.68	0.002652	0.88	0.009920	0.64	0.54	0.77
	Commercial - Ute	0.72	0.001069	1.10	0.004651	0.81	0.71	0.91
	Commercial - Van	0.87	0.001369	1.06	0.006006	0.93	0.81	1.07
	Large	0.73	0.000973	1.07	0.004251	0.80	0.71	0.90
	Luxury	0.68	0.001197	1.02	0.005112	0.73	0.64	0.83
	Medium	0.84	0.001043	1.07	0.004502	0.91	0.81	1.03
	People Mover	0.99	0.001537	1.19	0.006740	1.15	0.99	1.32
	Small	0.93	0.001011	1.11	0.004396	1.02	0.91	1.15
	Light	1.14	0.001089	1.17	0.004802	1.27	1.13	1.44
	Sports	0.83	0.001505	1.16	0.005715	0.96	0.84	1.10
Female	Compact Four Wheel Drive	1.00		1.00		1.00		
	Large Four Wheel Drive	0.68	0.001930	1.14	0.008735	0.80	0.68	0.94
	Medium Four Wheel Drive	0.74	0.002858	1.21	0.011058	0.90	0.75	1.09
	Commercial – Ute	0.97	0.001419	1.24	0.006313	1.16	1.01	1.33
	Commercial - Van	1.27	0.002611	1.26	0.010647	1.47	1.23	1.76
	Large	0.90	0.000900	1.05	0.004401	0.95	0.84	1.06
	Luxury	0.78	0.001169	1.03	0.005481	0.83	0.73	0.94
	Medium	1.02	0.000961	1.06	0.005384	1.07	0.94	1.21
	People Mover	1.00	0.001726	1.07	0.013921	1.06	0.87	1.30
	Small	1.14	0.000901	1.07	0.004377	1.18	1.05	1.32
	Light	1.32	0.000936	1.18	0.004515	1.44	1.28	1.62
	Sports	1.07	0.001487	1.12	0.006415	1.16	1.01	1.33

Odds ratio estimates for market groups within each driver sex category that are significantly ($p < 0.05$) different to that for Compact Four Wheel Drive vehicles have been highlighted

Table C5: *Estimated crashworthiness odds ratios for market group within driver age and 95% confidence intervals (for males and females)*

Age	Market group	Injury Risk		Injury Severity		Crashworthiness		
		Odds Ratio	Variance	Odds Ratio	Variance	Odds Ratio	95% Confidence interval	
25 years or less	Compact Four Wheel Drive	1.00		1.00		1.00		
	Large Four Wheel Drive	0.70	0.002778	1.38	0.011509	0.94	0.78	1.13
	Medium Four Wheel Drive	0.78	0.007015	1.04	0.027183	0.83	0.62	1.12
	Commercial - Ute	0.78	0.001595	1.24	0.007492	0.96	0.83	1.12
	Commercial - Van	0.96	0.002728	1.07	0.012680	1.02	0.84	1.24
	Large	0.76	0.001323	1.23	0.006381	0.93	0.81	1.07
	Luxury	0.68	0.002034	1.20	0.008958	0.83	0.70	0.97
	Medium	0.84	0.001439	1.13	0.006865	0.94	0.82	1.09
	People Mover	0.94	0.003437	1.26	0.015963	1.13	0.91	1.41
	Small	0.92	0.001295	1.14	0.006413	1.03	0.90	1.19
	Light	1.06	0.001349	1.18	0.006691	1.20	1.04	1.39
	Sports	0.86	0.002851	1.18	0.008376	1.01	0.85	1.19
	26-59 years	Compact Four Wheel Drive	1.00		1.00		1.00	
Large Four Wheel Drive		0.64	0.001246	1.09	0.005491	0.73	0.64	0.83
Medium Four Wheel Drive		0.73	0.001989	1.02	0.007709	0.77	0.66	0.91
Commercial – Ute		0.84	0.000955	1.08	0.004316	0.92	0.82	1.03
Commercial - Van		1.02	0.001289	1.14	0.005791	1.13	0.99	1.29
Large		0.85	0.000807	1.03	0.003721	0.89	0.80	0.99
Luxury		0.79	0.000980	0.99	0.004502	0.81	0.72	0.91
Medium		0.99	0.000864	1.04	0.003969	1.02	0.91	1.14
People Mover		1.07	0.001232	1.12	0.005776	1.17	1.02	1.33
Small		1.10	0.000829	1.05	0.003832	1.13	1.01	1.26
Light		1.31	0.000870	1.16	0.004058	1.42	1.27	1.58
Sports		1.01	0.001296	1.17	0.005344	1.14	1.00	1.30

Odds ratio estimates for market groups within each driver age category that are significantly ($p < 0.05$) different to that for Compact Four Wheel Drive vehicles have been highlighted

Table C5 (continued): *Estimated crashworthiness odds ratios for market group within driver age and 95% confidence intervals (for males and females)*

Age	Market group	Injury Risk		Injury Severity		Crashworthiness		
		Odds Ratio	Variance	Odds Ratio	Variance	Odds Ratio	95% Confidence interval	
60 years or more	Compact Four Wheel Drive	1.00		1.00		1.00		
	Large Four Wheel Drive	0.64	0.013655	0.70	0.043593	0.50	0.34	0.76
	Medium Four Wheel Drive	0.75	0.020961	0.71	0.062640	0.59	0.36	0.96
	Commercial - Ute	0.80	0.010676	0.94	0.032694	0.78	0.55	1.10
	Commercial - Van	1.16	0.013253	0.78	0.041692	0.92	0.63	1.37
	Large	0.84	0.009307	0.80	0.028286	0.71	0.52	0.99
	Luxury	0.73	0.010045	0.81	0.030621	0.64	0.46	0.90
	Medium	1.03	0.009467	0.92	0.028701	0.96	0.70	1.32
	People Mover	1.06	0.015855	0.89	0.049838	0.96	0.63	1.46
	Small	1.20	0.009350	0.99	0.028320	1.16	0.85	1.59
	Light	1.46	0.009596	1.17	0.028989	1.56	1.15	2.13
	Sports	0.90	0.015982	0.83	0.042537	0.79	0.53	1.18

Odds ratio estimates for market groups within each driver age category that are significantly ($p < 0.05$) different to that for Compact Four Wheel Drive vehicles have been highlighted

**DISTRIBUTION OF DRIVER INJURY CRASHES
BY VEHICLE MARKET GROUP,
DRIVER AGE AND SEX**

This appendix presents the distribution of injured drivers by the market group of the vehicle they were driving and their age and sex. These distributions enable the estimation of what proportion of injured drivers was made up by drivers of a particular market group who belonged to a particular demographic. This information was used in the discussion section of this report to provide context for the observed differences in the rankings of different market groups in terms of the different level of secondary safety they provide to different groups of road users. For example, from Table D1 it was established that that about 25% of injured drivers were driving small or light cars when they crashed. Other proportions presented in Table D1 that are relevant to the content of the discussion section of the report have been highlighted.

Table D1: *Distribution of injured drivers of vehicles manufactured from 1982-2006 by market group, driver age and driver sex, Australia and New Zealand, 2001-2005*

Driver sex Driver age Market Group	Male			All Males	Female			All Females	Males and Females			All Drivers
	≤25	26-59	60+		≤25	26-59	60+		≤25	26-59	60+	
Unknown	6.8%	11.5%	2.4%	20.7%	5.3%	9.1%	1.6%	16.1%	12.1%	20.6%	4.0%	36.8%
4WD - Compact	0.1%	0.3%	0.1%	0.5%	0.2%	0.7%	0.0%	0.9%	0.3%	1.0%	0.1%	1.4%
4WD - Large	0.1%	0.5%	0.1%	0.7%	0.1%	0.3%	0.0%	0.4%	0.2%	0.8%	0.1%	1.1%
4WD - Medium	0.0%	0.2%	0.0%	0.3%	0.0%	0.3%	0.0%	0.3%	0.1%	0.5%	0.1%	0.7%
Commercial - Ute	0.8%	1.8%	0.2%	2.9%	0.2%	0.5%	0.0%	0.7%	1.1%	2.3%	0.2%	3.6%
Commercial - Van	0.1%	0.5%	0.1%	0.7%	0.0%	0.1%	0.0%	0.2%	0.1%	0.6%	0.1%	0.8%
Large	3.2%	6.7%	1.4%	11.3%	1.9%	7.1%	0.7%	9.6%	5.1%	13.8%	2.1%	20.9%
Medium	1.0%	2.0%	0.6%	3.7%	1.1%	3.3%	0.5%	4.9%	2.1%	5.3%	1.2%	8.6%
People Mover	0.1%	0.3%	0.0%	0.4%	0.0%	0.3%	0.0%	0.4%	0.1%	0.6%	0.0%	0.8%
Small	2.3%	2.9%	0.8%	6.0%	4.8%	7.3%	1.3%	13.4%	7.1%	10.2%	2.1%	19.4%
Light	0.6%	0.8%	0.2%	1.6%	1.8%	2.1%	0.4%	4.4%	2.4%	2.9%	0.6%	6.0%
All market groups	15.2%	27.6%	6.0%	48.7%	15.5%	31.2%	4.6%	51.3%	30.7%	58.8%	10.6%	100.0%

The sample of injured drivers used to derive the distribution presented in Table D1 was restricted to drivers injured in the period 2001-2005 who were driving vehicles manufactured more-recently than 1981. Crash records were taken from the dataset that Newstead et al. (2006) used for their Used Car Safety Ratings. Records of vehicles manufactured prior to 1982 were not included in the distributions presented in this appendix because it was not possible to identify the market group a larger proportion of this group of vehicles than for more-recently manufactured vehicles. However, as only vehicles crashed in the period 2001-2005 were included in the sample, vehicles manufactured prior to 1982 would only represent a small proportion

of the total number of vehicles in the fleet. However, the reader should be aware that even when these steps were taken to minimise the effect of records of unknown market group on the distribution, 37% of the sample was still of unknown market group. Therefore many of the values presented in Table D1 probably underestimate the actual proportions.

The same sample of injured drivers was used to derive the distribution presented in Table D2. However, in Table D2 separate distributions are presented for each market group, with the proportion of injured drivers belonging to each demographic being presented separately for each market group. This table was also used in the discussion section of this report. For example, from Table D2 it was noted that only 20% of injured drivers of Commercial Vans were female. The fact that females represented only a small fraction of the drivers of Commercial Vans was suggested as a possible reason why this type of vehicle ranked poorly in terms of the secondary safety for female drivers when compared to the estimated level of protection they offered to male drivers. Other percentages specifically mentioned in the discussion have been highlighted in Table D2 for the reader's convenience.

Table D2: *Distribution of vehicles of different market groups, manufactured from 1982-2006, in which the driver was injured by driver age and driver sex, Australia and New Zealand, 2001-2005*

Driver sex Driver age Market Group	Male			All Males	Female			All Females	Males and Females		
	≤25	26-59	60+		≤25	26-59	60+		≤25	26-59	60+
Unknown	18.5%	31.3%	6.6%	56.4%	14.5%	24.8%	4.3%	43.6%	33.0%	56.1%	10.9%
4WD - Compact	7.0%	22.7%	3.8%	33.5%	15.2%	48.6%	2.7%	66.5%	22.2%	71.3%	6.6%
4WD - Large	11.5%	46.2%	6.5%	64.2%	6.0%	28.1%	1.7%	35.8%	17.5%	74.3%	8.2%
4WD - Medium	6.6%	36.3%	5.3%	48.2%	6.1%	43.6%	2.1%	51.8%	12.7%	79.9%	7.4%
Commercial - Ute	23.2%	50.5%	5.8%	79.5%	6.0%	13.5%	1.1%	20.5%	29.2%	63.9%	6.9%
Commercial - Van	13.7%	58.9%	7.4%	80.0%	4.4%	14.2%	1.4%	20.0%	18.1%	73.1%	8.8%
Large	15.4%	31.9%	6.6%	53.9%	8.9%	33.9%	3.2%	46.1%	24.3%	65.9%	9.9%
Medium	11.8%	23.4%	7.5%	42.7%	12.4%	38.8%	6.1%	57.3%	24.1%	62.2%	13.6%
People Mover	8.3%	39.6%	4.9%	52.8%	4.8%	41.1%	1.2%	47.2%	13.2%	80.7%	6.1%
Small	11.9%	15.0%	4.2%	31.0%	24.8%	37.6%	6.6%	69.0%	36.7%	52.6%	10.8%
Light	9.3%	13.5%	3.7%	26.6%	30.5%	35.8%	7.1%	73.4%	39.9%	49.3%	10.9%
All Market Groups	15.2%	27.6%	6.0%	48.7%	15.5%	31.2%	4.6%	51.3%	30.7%	58.8%	10.6%