Contribution of structural incompatibility to asymmetrical injury risks in crashes between two passenger vehicles

by RWG Anderson and G Ponte
Centre for Automotive Safety Research, The University of Adelaide

Abstract

It is well known that mass ratio affects the probability of injury and death in both vehicles in two-vehicle crashes. Likewise, other evidence suggests that typical four-wheel drive (4WD) vehicles exhibit poorer than average aggressivity such that occupants of regular vehicles are more likely to be injured in a crash when it involves a 4WD. In this study, the ratio of the incidence of injury and death to drivers in two-vehicle crashes was calculated for crashes with different vehicle mass ratios. Injury ratios were calculated for crashes involving strictly two cars and again for those crashes where the heavier vehicle was a 4WD vehicle or a light truck (LT) and the lighter vehicle was a car. There is a common dependence of the injury risk ratio on vehicle mass ratio in both classes of crash, but there is an additional relative risk to the lighter vehicle driver when the heavier vehicle is a 4WD/LT. The effect is stronger for fatality ratios. Around twice as many drivers are killed per crash in car-to-4WD/LT crashes, indicating that the increased risk to the driver of the car is not completely offset by reduced risks to the driver of the 4WD/LT.

Keywords

Aggressivity, Compatibility, Four-wheel drive, Injury risk, Light Trucks, Mass ratio

Introduction

Newer passenger vehicles in Australia are much safer for their occupants than vehicles produced even several years before [2, 16]. Additionally, (and controversially) there is an indication that vehicle mass provides no significant intrinsic protection to occupants over and above the effect of the ratio of masses in a two-car collision [12]. Yet, incompatibility remains an issue for the occupants of cars when their collision partner exhibits traits that make it more aggressive; namely larger mass, and differences in geometry and stiffness.

It is well known that mass ratio affects the ratio of the probability of injury and death in each vehicle in two-vehicle crashes. Also, evidence suggests that typical four-wheel drive (4WD) vehicles exhibit higher than average aggressivity such that occupants of regular vehicles are more likely to be injured in a crash when it involves a collision with a 4WD. (For an example of early descriptive research on several kinds of geometrical incompatibility in an Australian context, see [18].)

Evans and Frick (1993) [5] showed empirically that the driver fatality ratio R in a two-car crash is a power function of the mass ratio of the heavier vehicle to the lighter vehicle μ. The relationship is shown by Equation 1. The factor A accounts for differences in the colliding vehicles other than mass (i.e. difference in vehicle years, driver differences such as frailty and seat belt wearing, and important geometrical and structural differences etc.)

$$R = A\mu^{u} \qquad (1)$$

Evans and Frick (1993) [5] identified the parameters of Equation 1 in several categories of crash, based on data from the Fatality Analysis Reporting System (FARS) for crash years 1975–1989. The power u derived for all fatal car-to-car crashes (including all model years, all crash configurations, all seat belt configurations etc.) was 3.53. Considering vehicle years >1980, the power u was 2.75. Considering crash type, the variable A ranged from 1.09 (for example in a crash for a rear vs. front impact) to as high as 10 for a left vs. front impact.

Joksch et al. (1998) [13] suggested that u is about 4 for fatal crashes and 2-3 for injury crashes. However, in their empirical fatal data (26-55 year old, non-airbag fatalities) the relationship seemed more consistent with a power of 3.

Many studies have identified the value of R in specific combinations of vehicles and crash types without separately estimating the values of the parameters on the right of Equation 1. These studies have consistently found that Sports Utility Vehicles (SUVs) or 4WDs have an increased aggressivity compared to cars. Fatality ratios in head-on collisions have been estimated at around 5:1 and 30:1 for side impacts [9, 13, 19].

Attewell et al. (1999) [3] noted a growing heterogeneity in the sizes of cars being sold in Australia and found that, for frontal crashes, smaller car driver relative fatal injury risks were 3.6, 6.3 and 17.0 for crashes with medium, large and 4WD vehicles respectively.

Les et al. (1999) [14] focussed on non-fatal, injury crashes based on vehicle mass incompatibilities and found that the relative injury risks for a smaller car driver were 1.12, 1.18 and 1.29 times that of the other driver, when the other driver was associated with a medium, large and 4WD vehicle respectively. For side impacts (into a smaller car) the relative injury risks were 2.25, 2.35 and 2.44 for crashes with medium, large and 4WD vehicles respectively.

Grzebieta et al. (2000) [10] (see also[11]) conducted crash tests to demonstrate one mechanism of increased injury risk to nearside occupants of cars subjected to a side-impact with a 4WD: in each of the crash tests the car driver dummy was subjected to direct contact with the colliding 4WD.

Mayrose and Jehle (2002) [15] examined the effect of vehicle weight and the relative likelihood of fatalities in SUVs and cars in head-on collisions. They found that fatality risk ratios for car occupants compared to SUV occupants were in the order of 3.2 overall, 1.7, when masses were the same (mass ratio 1), and 1.6 even when the car weighed more (on average 234 lb more, mass ratio approximately 1.1) than the SUV.

Some studies have used multiple logistic regression to distil effects of vehicle type in the outcome of two-vehicle crashes. Toy and Hammitt (2003) [21] found that, in the U.S., vans and pick-ups seemed more crashworthy than cars, but there was no clear picture for the crashworthiness of SUVs. They also found that SUVs, light trucks and vans appeared to be more aggressive to all other vehicle drivers, and only pick-up trucks showed increased 'self protection'. Fredette at al.(2008) [6]also found that pick-ups, vans and SUVs showed increased aggressiveness toward cars (particularly for masses equal to or 20% greater than cars) and increased self-protection.

Newstead et al. (2011) [16], using a very comprehensive Australian (and New Zealand) crash data set have, for many years, published used car vehicle safety ratings. These ratings are based on vehicle crashworthiness (relative safety of a vehicle based on driver injuries in the crashed vehicle) and vehicle aggressivity (a vehicle's associated risk of injury to other drivers or vulnerable road users in a crash). They have showed that over the last 30 years, vehicle crashworthiness has improved considerably. When they considered vehicle market groups, they found that, for 4WD vehicles, crashworthiness improves and aggressivity increases with vehicle size (or more specifically, between the market categories compact, medium and large). Similar relationships can be seen for cars. Nearly all 4WD market groups are more crashworthy and more aggressive than all passenger car market groups.

Newstead et al.(2011) [16] did not specifically consider vehicle mass in their analysis, and found there was an "absence of a strong relationship between the measures of aggressivity and crashworthiness". They also suggest that "vehicle mass is only playing a small part in aggressivity rating relative to vehicle total safety design".

Recently, Teoh and Nolan (2011) [20] examined death rates for 1-4 year old passenger vehicles, SUVs and light trucks in the U.S. for the crash periods 2000-2001 and 2008-2009 to determine whether a 2003 voluntary agreement by vehicle manufacturers to improve compatibility (especially in front-to-front and front-to-side crashes) was effective. Their study suggested that the voluntary changes (particularly through increased fitment of head-protecting side airbags and frontal vehicle design changes) have been effective in the U.S. across all of these vehicle categories. Death rates for car-to-car crashes and SUV-to-car crashes were nearly identical in 2008-09 (controlling for vehicle mass).

In summary, there have been several studies examining vehicle aggressivity and incompatibility in 4WDs and light trucks (LTs), and the asymmetry in crash outcomes when these vehicles hit regular cars. Some studies have examined crash data to understand the effect of incompatibilities on injury risk ratios. However, few have tried to disentangle the components of Equation 1. Less work has been done to examine the net outcomes of such crashes, and the extent to which aggressivity is balanced by crashworthiness in such vehicles is not clear.

The purpose of this paper is to present an alternative method of examining and presenting crash injury risk in two-vehicle crashes, in a contemporary Australian context. This is done primarily by examining injury and fatality ratios and rates by mass ratio and by vehicle combinations in two-vehicle crashes, to identify effects on relative injury risk beyond the effect of vehicle mass ratio. The method is also extended to sparse fatality data, and the effect of incompatibilities on the overall fatality rate is also calculated.

Data

The present analysis is of 87,147 two-vehicle casualty crashes (fatal or injury) that occurred in NSW between 1999 and 2009. The crash records were obtained from Transport for NSW. The crash records were those available through the CrashLink system and these were supplemented with vehicle mass data (tare mass) through the Roads and Maritime Services (previously RTA) Vehicle Registration and Driver Licensing System (DRIVES). Within the sample of 87,147 injury crashes, 1,187 (1.4%) were fatal (the highest degree of injury outcome for an individual crash); the remaining 85,960 (98.6%) were injury crashes.

Of interest was the determination of vehicle types, the vehicle mass ratio, the incidence of specific types of crashes, and the driver injury and fatality rates in these crashes. Focusing on driver injury severity removes any confounding due to the level of occupancy in each vehicle in each crash.

Amongst the 87,147 crashes, there were 174,294 drivers and vehicles. A total of 85,269 drivers were injured (48.9%), 961 (0.55%) drivers were killed and the remaining 88,064 (50.5%) driver injury severities were blank or zero. Around 86% of the crashes in the recorded in the entire NSW sample of two-vehicle crashes involved three vehicle types: cars (sedans/hatches), LTs and 4WDs. These three vehicle types in combination also account for around 71% of the crashes that were two-vehicle crashes.

It should be noted that 4WDs and LTs are generally grouped as a single vehicle type in the analyses (although they were often analysed separately) as they are similar in their frontal geometry and combined, provide greater numbers to work with. Station wagons and utilities were excluded from the analysis. Although a station wagon has similar characteristics to a sedan, it is probable that some 4WD vehicles are coded as station wagons. To prevent dilution of the effect of vehicle type that we wished to detect, station wagons were thus excluded. Utility vehicles were likewise excluded from the analysis.

For the main analysis, two variables were considered; the driver injury ratio and the crashed vehicle mass ratio. The crashed vehicle mass ratio is defined as the mass of the heavier vehicle divided by the mass of the lighter vehicle in any crash. The mass ratios were grouped so that any vehicle mass ratio between 1.0 and 1.099 was grouped as a mass ratio of 1.05, between 1.1 and 1.199 was grouped as 1.15 and so on.

The driver injury ratio is defined as the total number of drivers injured or killed in lighter vehicles divided by the total number of drivers injured or killed in heavier vehicles. The driver injury ratio was calculated for each vehicle mass ratio. Fatalities in lighter and heavier vehicles were also counted, but ratios were not calculated due to the sparseness of the data. A separate analysis was conducted with the crashes that caused a driver fatality.

Within the entire sample, 86,230 drivers were injured or killed. Collisions involving 4WDs, LTs and cars with other cars accounted for 58,165 (67.5%) of the total drivers injured or killed. Not all vehicles had masses recorded (13,919 vehicles of any type – of which 8,797 were cars, 4WD or LTs – either had zero or 9999 recorded against their mass). Also, to reduce the incidence of invalid vehicle types or invalid vehicle masses in the proceeding analysis a filter was applied to the crash sample. Any vehicles with a coded mass of less than 500 kg, cars with a coded mass greater that 2,000 kg, and 4WDs and LTs with a coded mass greater than 3,000 kg were excluded from the analysis. Vehicles were also excluded when the year of manufacture was unknown.

In total, 52,142 collisions were between a heavier 4WD, LT or car and a lighter car (60.4% of injuries/fatals). Filtering out invalid masses (as discussed above) reduced the sample to 51,309 (59.5% of injuries/fatals), and further filtering for unknown vehicle year, the final sample used in this analysis totalled 50,370 driver injuries/fatalities; 58.4% of the total driver injuries/fatalities within the NSW Crash Database sample.

Analysis and results

Effect of vehicle type on injury ratios

The driver injury ratio is plotted against the crashed vehicles' mass ratio in Figure 1. Figure 1 shows the expected increase in the injury ratio with mass ratio. However, the figure also shows that there are separate relationships for car-to-car crashes and car-to-4WD/LT crashes. A weighted linear regression was applied to the data to account for the variation in numbers of crashes at each mass ratio. The slopes (u in Equation 1) of the weighted regression lines for car-to-car crashes and car-to-4WD/LTs crashes are very similar: 1.50 and 1.53 respectively. This shows the common dependence of the injury ratio on the mass ratio in the crash in both crash types.

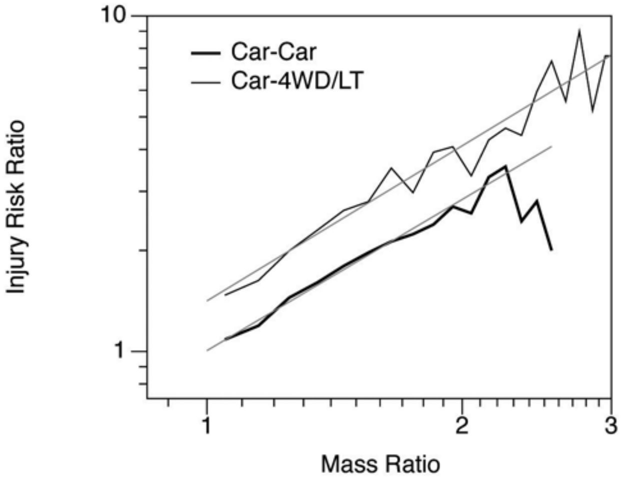

Figure 1.The ratio of driver injuries according to mass ratio for car-to-car crashes and car-to-4WD/LT crashes (New South Wales CrashLink data, 1999-2009)

Intercepts of the regression lines (*A* in Equation 1) are 1.01 and 1.42. The average mass ratio of car-to-4WD/LT crashes is 1.3. The ratio of the two lines at this mass ratio is 1.41, which can be considered the average increase in the injury ratio in 4WD/LT crashes with lighter cars.

Injury ratios were calculated separately for car-to-4WD crashes and for car-to-LT crashes. The results are plotted in Figure 2. *A* and *u* for car-to-4WD crashes are 1.14 and 1.7; for car-to-LT crashes, they are 1.61 and 1.52. The increase in the driver injury ratio (relative to car-to-car crashes) at mass ratio = 1.3 is 19% in car-to-4WD crashes and 61% in car-to-LT crashes. Note that, in the case of car-to-4WD crashes there appears to be a discontinuity at about $\mu = 1.3$, such that at mass ratios below 1.3, there is less difference between car-to-4WD crashes and car-to-car crashes.

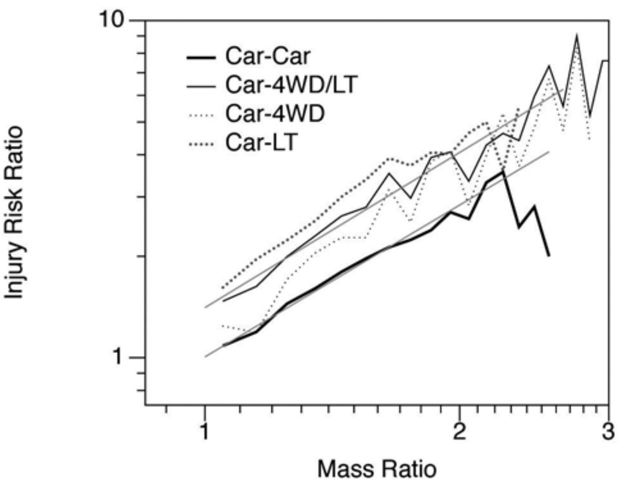

Figure 2.The ratio of driver injuries according to mass ratio for car-to-car crashes, car-to-4WD crashes and car-to-LT crashes (New South Wales CrashLink data, 1999-2009)

Effect of crash type on injury ratio relationships

The foregoing describes an aggregate effect of vehicle combination on driver injury ratio. To see if this effect is consistent across different crash types, the analysis was repeated at several levels of disaggregation; the analysis was repeated while restricting cases to common crash types and in specific speed limits. Due to the comparatively low numbers of 4WDs and LTs in the sample, the analysis in this section considers 4WDs and LTs as a group (4WD/LT) rather than separate vehicle types.

In NSW, crashes can be categorised using Definition for Coding Accidents codes (DCA codes). Ninety six per cent (70,774) of all crashes in the mass/year filtered NSW sample (of 73,709 crashes) were represented by twenty DCA codes. The four dominant crash types represented by six DCA codes in Table 1 account for 74.8% (55,147) of all crashes in the filtered sample. There were 38,832 (52.7%) crashes between cars and other cars and 15,051 (20.4%) crashes between cars and 4WDs/LTs – these crashes accounted for 73.1% of all the filtered crashes. Table 1 summarises the proportion of crashes (of the total filtered sample of 73,709 crashes) for the vehicles of interest for particular crash types.

Weighted regression was performed on the crash data, and the parameters *A* and *u* were found for each crash type and vehicle combination. The relative injury risk ratio (i.e. the injury risk ratio in 4WD-to-car crashes relative to car-to-car crashes) was calculated at $\mu = 1.3$, and the results are given in Table 2.

There is a consistent pattern of increased injury risk ratios for each crash type associated with 4WD/LT-to-car crashes. The difference is greatest for rear end collision types (DCA 301-303) for which the injury risk ratio is 73% higher.

It should be noted that while DCA codes provide a means to describe crash type, they do not always indicate important details about the impact configuration (i.e. which vehicle is being struck and where).

Effect of speed limit on crash severity

The speed limit in which crashes occur can often indicate the average degree of energy involved in those crashes. Hence, the analysis was repeated to examine the effect of crash combination on driver injury ratio within categories of crashes defined by the prevailing speed limit.

The relative injury risk ratios (at $\mu = 1.3$) were relatively uniform with respect to speed zone. For crashes occurring on roads with speed limits of 50 and 60km/h, the relative injury risk ratio was 1.42. For crashes occurring in70-90km/h and in 100-110 km/h speed zones, the relative injury risk ratios were1.41and 1.47.

Subgroups of crashes

Some of the analyses above may have been confounded by the effects of other differences between the vehicles and drivers in the crashes (for example, by driver age and vehicle age, which are both important factors). The analysis of the effect of vehicle type on injury ratios was repeated to remove some of the effects of some potentially confounding factors (at the expense of crash numbers). These were:

- Crashes between vehicles with a similar age (up to 5 year difference).
- Crashes involving 26-55 year old males.
- Crashes between newer vehicles (>1990).

Table 1.Percentage of the filtered sample falling into categories of DCA code and vehicle combinations

Crash Type	DCA Codes	Per cent	Car vs. Car (%)	Car vs. 4WD/LT (%)
All Crashes	All Codes	100	52.7	20.4
Rear End	301-303	34.6	18.4	7.4
Thru-Right	202	17.2	10.3	3.1
Thru-Thru	101	15.3	8.3	3.1
Head-On	201	7.7	3.1	1.8

Table 2. Relative injury risk ratios [(lighter car : heavier 4WD/LT) / (lighter car : heavier car)] at mass ratio = 1.3 by crash type

Crash Type	DCA Codes	Relative injury risk ratio
All Crashes	All Codes	1.41
Rear End	301-303	1.73
Thru-Right	202	1.32
Thru-Thru	101	1.15
Head-On	201	1.26

Table 3. Number of driver fatalities in the heavier and lighter cars, in car-to-car crashes, and expected numbers given from Equation 1 with u set to 2.7

Mass ratio	Actual Driver fatalities			Expected fatalities given u = 2.7	
group	Heavier	Lighter	Total	Heavier	Lighter
1.05	19	22	41	19.1	21.9
1.15	21	22	43	17.5	25.5
1.25	4	17	21	7.4	13.6
1.35	5	13	18	5.5	12.5
1.45	7	6	13	3.5	9.5
1.55	3	9	12	2.8	9.2
1.65	1	7	8	1.6	6.4
1.75	0	8	8	1.4	6.6
1.85	0	4	4	0.6	3.4
1.95	0	2	2	0.3	1.7
2.05	0	0	0	0.0	0.0
2.15	0	1	1	0.1	0.9
Total	60	111	171	60	111

Regardless of the driver and vehicle characteristics, the relative injury risk ratios were consistently greater than one for crashes between heavier 4WD/LT vehicles and lighter cars.

The effect of vehicle type on fatality ratios

One of the limitations of the forgoing results is the severity of the injury in each crash. There is no indication whether driver injury was minor or life threatening. In this respect, fatal crashes have a clearer definition, and are likely to be more uniform in relation to injury severity. However, the numbers of crashes leading to a fatality are much smaller, and figures similar to Figure 1, where specific vehicle combinations and mass ratios are considered, could not be successfully drawn using the fatal crash data. Nevertheless, it was possible to estimate the effect of vehicle type, independent of vehicle mass, by using Equation 1.

In the entire sample of data, 961 drivers were fatally injured; 397 (41.3%) of these fatalities occurred in collisions involving 4WDs, LTs and cars with other cars.

For collisions between heavier 4WDs, LTs and cars with lighter cars, driver fatalities totalled 314 (32.7% of total driver fatalities). Filtering out cases that had invalid vehicle masses (as discussed previously) reduced the sample to 286 (29.8% of total driver fatalities), and further filtering of cases with an invalid vehicle year produced a final sample of 279 driver fatalities, 29% of the total. In the final sample, 171 deaths were in car-to-car crashes and 108 in 4WD/LT-to-lighter car crashes.

To improve the categorisation of vehicle type, the VINs of the vehicles of interest were decoded using data from RL Polk Australia Ltd and matched against the vehicle type as recorded in the NSW crash database. Vehicle types were amended for consistency with market segment data from Polk. Note that this was a partial correction because, where no VIN was available, no correction was possible.

There were 171 car-to-car crashes in which at least one driver died; 60 drivers in heavier cars died and 111 drivers in lighter cars died. The numbers dying in heavier and lighter cars (and the total) were found for several categories of mass ratio. These are given in Table 3.

Given any value of u in Equation 1, there is an expected ratio of the number of deaths in the heavier and lighter vehicles at each mass ratio. Furthermore, a value of u can be fitted to the data to produce the same average expectation of the number of driver fatalities in the heavier and lighter vehicles over all car-to-car crashes. That is, there is some value of u, for which Equation 1 will produce 60 fatalities in heavier cars and 111 drivers in lighter cars, when applied to the numbers of crashes at each mass ratio in Table 3.

A solution for u can be found by iteration. In this case, u was found using the goal-seek function in Microsoft Excel, where the objective was to match the total number of fatalities in the lighter cars. This procedure produced a value of $u = 2.7$ (See Table 3). When this value of u was applied to the total number of crashes at each mass ratio, the result is the expected numbers of fatalities shown in the two right hand columns of Table 3.

In the case of car-to-4WD/LT crashes, there were two parameters to find: u and A. However, we have seen, in the case of injury crashes, a common dependence of the injury ratio on mass ratio (for example, the slopes in Figure 1 are very similar at 1.50and1.53). Hence, an initial estimate of u for car-to-4WD/LT crashes is 2.7, given that u 2.7 for car-to-car crashes.

Table 4. Number of driver fatalities in heavier 4WD/LTs compared to lighter cars in car-to-4WD/LT vehicle crashes, and expected numbers from Equation 1

Mass ratio	Actual Driver fatalities			Expected numbers given $u = 2.7$ and $A = 3.5$ in Equation 1	
Group	Heavier	Lighter	Total	Heavier	Lighter
1.05	0	2	2	0.4	1.6
1.15	2	9	11	1.8	9.2
1.25	2	8	10	1.4	8.6
1.35	0	7	7	0.8	6.2
1.45	0	10	10	1.0	9.0
1.55	1	12	13	1.1	11.9
1.65	1	9	10	0.7	9.3
1.75	2	10	12	0.7	11.3
1.85	0	8	8	0.4	7.6
1.95	1	5	6	0.3	5.7
2.05	0	2	2	0.1	1.9
2.15	0	3	3	0.1	2.9
2.25	0	4	4	0.1	3.9
2.35	0	2	2	0.1	1.9
2.45	0	2	2	0.0	2.0
2.55	0	1	1	0.0	1.0
2.65	0	2	2	0.0	2.0
2.75	0	2	2	0.0	2.0
2.85	0	1	1	0.0	1.0
Total	9	99	108	9	99

Table 4 shows the number of driver fatalities in the case of car-to-4WD/LT crashes in which at least one driver died. Also shown is the expected distribution of fatalities between the two vehicles, given $u = 2.7$ and $A = 3.5$. (As above, A was found using iteration, where the objective was to match the total number of car driver fatalities in the lighter and heavier vehicles in Table 4.) These values for u and A result in expected numbers of driver deaths that match the data overall, and closely at almost every mass ratio. This is indicating that the effect of the larger vehicle being a 4WD/LT is to inflate the fatality ratio by 3.5 times (noting that this is dependent on $u = 2.7$). Notable too is that the fatality ratio in the first two categories of mass ratio (where the vehicle masses are similar) is about 5.

As a check, the procedure described above was repeated, but only for crashes in which the VINs of both vehicles were known, and in which Polk decoding provided an independent categorisation of vehicle type. This resulted in estimates of $u = 2.4$ and $A = 3.9$.

Ideally, the estimates of u and A would be made using more sophisticated statistical methods. In the above analysis, error in the estimate of A will be compounded by error in the estimate of u. For example, logistic regression of driver injury severity on vehicle types and mass ratios might allow u and A to be estimated simultaneously using all crashes at once. Importantly, it would allow the calculation of confidence intervals on estimates of u and A. It is notable that the estimate of u in this study is at the lower end of estimates made by Evans et al. (1993) [5]. A higher value of u would have the effect of reducing the magnitude of A.

It is also important to note that u and A are unadjusted for effects such as differences in the build year of the vehicles or occupant characteristics. A difference in the build year of vehicles can have a marked effect on determining in which vehicle a driver is killed [2]. In the case of the car-to-4WD/LT crashes in this sample, the average year of manufacture of the cars was 1991 and the average for the 4WD/LT was 1996, and this could be substantially affecting the results. These average ages also emphasise the fact that the results here refer to a historical fleet, and are not necessarily a guide to the outcome of the crashes within and between future cohorts of vehicles.

Fatality rates of drivers between vehicles of different mass

The finding of a higher fatality and injury ratio when the heavier vehicle is a 4WD/LT is likely to arise both from aggressivity of the 4WD/LT as well as a degree of self-protection. The foregoing results do not inform us whether the overall fatality risk in a crash is increased by the effect of a vehicle mismatch.

For this reason, fatality rates are considered in the next analysis. Table 5 shows driver fatality rates per 100 crashes in the sample, for the different vehicle combinations where the first vehicle is the heavier vehicle and the second the lighter vehicle.

Table 5. The number of fatally injured drivers per 100 crashes for particular crash combinations

Heavy vs. Light	Fatals[1]	Fatally injured drivers per 100 crashes[1]	Crashes[1]
Car vs. Car	171	0.44	38533
4WD vs. Car	60	1.04	5779
4WD/LT vs. Car	117	0.92	12686
LT vs. Car	57	0.83	6907

[1] Injury or worse

Table 5 tells an interesting story. When the heavier and lighter vehicles were both cars, one driver was killed every 225 crashes. When the heavier vehicle was a 4WD/LT vehicle and the lighter vehicles was a car, one driver was killed every 108 crashes. Though not shown in the table, when the two vehicles were light trucks, one driver was killed every 80 crashes (based on 643 crashes), when the two vehicles were both 4WDs only a single driver was killed in the relevant 390 crashes.

Considering crash severity (that is, the maximum injury severity of any occupant in the crash) and not the driver fatality rate, 0.59 per 100 crashes involving two cars were fatal. When the other vehicle was a 4WD/LT, the rate was 1.25 per 100 crashes.

Driver Fatality Rates by speed zone and location

There may be several potential confounding factors that may be affecting the results presented above. Differences in vehicle year have already been mentioned. When considering rates, probably the most significant is the speed of the crash. If 4WD/LT crashes with cars occur in higher speed zones, then a higher overall fatality rate might be expected. Such factors could be taken into account with more sophisticated statistical methods, such as logistic regression. In the interim, the fatality rates were examined in sub-groups of crashes that are likely to have crash speeds most in common. Two specific crash categories were considered, crashes in urban 50 and 60km/h speed zones, and crashes in rural 100 and 110km/h speed zones. Table 6 shows the results.

Table 6. Number of driver fatalities and the driver fatality crash rate based on area and speed zone

	Urban 50 and 60 km/h			Rural 100 and 110 km/h		
Crash Combination	Driver fatalities	Fatally injured drivers per 100 crashes	Crashes	Driver fatalities	Fatally injured drivers per 100 crashes	Crashes
Car vs. Car	26	0.11	24683	61	6.22	981
4WD vs. Car	16	0.47	3369	16	5.97	268
4WD/LT vs. Car	21	0.30	7027	42	6.13	685
LT vs. Car	5	0.14	3658	26	6.24	417

Note that in Table 6, there were no driver fatalities in the heavier 4WD or LT vehicles in urban 50 and 60 km/h crashes. In the rural 100 and 110 km/h crashes, only three of the 42 driver fatalities occurred in the 4WD and LT vehicles.

In urban 50 and 60 km/h crashes, driver fatality rates were more than double (2.7 times) when a heavier 4WD/LT crashed with a lighter car, compared with the rate when a heavier car crashing with a lighter car. Driver fatality rates in 100 and 110 km/h rural areas were higher than the rates in 50 and 60 km/h urban areas, in all categories of vehicle crash combination, but there was very little difference in driver fatality rates across categories. It is possible that the issue of structural incompatibility at higher speeds may not be the primary cause of increased risk of death in cars in these crashes and it is more likely the result of the high delta-v in these crashes. However these increased risks appear to be effectively offset by reductions in risk to 4WD/LT drivers in such crashes.

There was some evidence within the fatal crash data that suggested that there were more head-on crashes and fewer side-impact type crashes in rural 100 and 110 km/h areas, compared to crashes in urban 50 and 60 km/h areas. It is therefore possible that the higher driver fatality rate in 4WD/LT vs. car crashes in urban 50 and 60 km/h areas may be due to the higher incidence of side impact crashes in these areas, although the crash data did not contain enough information for us to be able to confirm this.

Concluding remarks

This paper describes some exploratory analyses on the present situation based on the most recent and complete crash data available for one Australian state, with regard to 4WD/LT incompatibilities in Australian crashes. It is clear from the analysis that, consistent with previous findings, crashes involving a car and a 4WD/LT are resulting in increased injury and asymmetry in injury, than crashes involving two cars. The effect is in addition to and apparently independent from the effect of vehicle mass ratio. The effect in injury crashes was to increase injury ratios by about 1.4 times relative to car-to-car crashes. The effect seems greater when the heavier vehicle is a LT, rather than a 4WD.

The effect on fatalities was greater – approximately 3.5 times. Fatality rates in 4WD/LT-to-car crashes are consistently around twice as high as they are in car-to-car crashes, overall and in sub-groups of crashes, but no different in higher speed zones. Some caution is required as differences in 4WD/LT vehicles and the cars that they hit may relate to factors beyond geometry and may include differences in crashworthiness (the 4WD/LTs tend to be newer than the cars they hit), although results tend to be stable when these differences were narrowed.

It is therefore reasonable to assume that well-known factors related to the stiffness of the vehicle structures that interact in the crash are manifesting themselves in the result. These factors might include the over-riding of the car crash structures by the 4WD/LT, direct contact between the driver of the car with the 4WD/LT in side impact crashes and the high prevalence of bull bars on 4WD/LTs [4].

An agreement to reduce vehicle incompatibility made by Enhanced Vehicle Compatibility (EVC) group in the U.S. has been tentatively associated with a decrease in fatal crash rates between newer SUV/LT-to-car crashes in the U.S. [20]. Part of the EVC commitment was the fitting of head-protecting side airbags on all passenger vehicles by September 2009. A similar agreement was made by member companies of the Australian Federal Chamber of Automotive Industries (FCAI) for all vehicles built from January 2016 [7]. As of mid-2010, the standard fitment rates of curtain airbags on new passenger vehicles in Australia was about 45% [22] and recent data on vehicle sales in South Australia indicates that new vehicle fitment rates of side curtain airbags was around 70% in the third quarter of 2011 [8].

The results in this paper are based on historical crash data, and (as mentioned) there is some tentative evidence to suggest that incompatibility between newer 4WD/SUV/LT crashes and newer cars may be diminishing. However, there are several factors that need to be kept in mind:

- The average age of the registered vehicle fleet in Australia is about 10 years.
- Crash involved vehicles are older still [1].
- The prevalence of bullbars fitted on 4WD/LT vehicles in Australia is around 50% [4].
- While 4WD/LT-to-car crashes are not as common as car-to car crashes, the trends (not published here) suggest that the incidence of 4WD/LT-to-car crashes in absolute terms, as well as in relative terms, is increasing.

It is therefore likely that the current incompatibility issues raised in this paper will persist for some time. Both asymmetry in injury risk and overall risk should be monitored in 4WD/LT-to-car crashes, to ensure that risks arising from incompatibility are reduced as far as is practicably possible.

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Victorian family day care scheme providers' knowledge of child restraint best practice

by S Nikolin[1], H Lindner[2], LE Bilston[1] and J Brown[1]

[1]Neuroscience Research Australia
[2]Road Safety and Access, VicRoads

Abstract

In Victoria nearly half of the population under 12 years of age uses family day care services. Providers of family day care services are in a position to provide important information on the best practice of child transportation to family day care educators, and families accessing family day care. Our study, conducted in November 2011, aimed to investigate family day care service providers' level of knowledge of best practice for transporting children in cars. A sample of Family Day Care Victoria service providers (n=48) completed a survey on child restraint knowledge, practices and attitudes. Of the providers surveyed, 98% stated that they knew the law regarding child restraint usage. A high proportion offered professional and practical support (92%) as well as educational resources (94%) to family day care educators with regards to safe transportation. However, when asked to provide the minimum age at which children are able to use a specific restraint type only 81% correctly identified the minimum age for booster seats, 75% for forward-facing restraints, 40% for the front seat, and 58% for adult seat belts. These results indicate that more effort is required to support family day care services, which are required to ensure that transport is suitable and safe for all children. Family day care services act as information conduits to families with young children, and additionally educate and train family day care educators travelling daily with young children in their charge.This would ensure all children are provided optimal levels of protection whenever they travel in cars.

Keywords

Child care, Child restraints, Education

Introduction

In Australia, car crashes have consistently been identified as a leading cause of preventable injury and fatality in children [1, 2]. In Victoria, approximately half of all child fatalities due to unintentional injury are transport related, with 103 children fatally injured in transport related incidents between 2003 and 2005 [3]. Australia wide, approximately 70 children die each year as motor vehicle occupants, and many more are seriously injured [4].

Injury among restrained child passengers is largely due to suboptimal restraint practices. Suboptimal restraint occurs when a child inappropriately uses a restraint