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RELATIVE VEHICLE SAFETY, ROAD ENVIRONMENT AND CRASH TYPE

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Abstract:

The Used Car Safety Ratings (UCSRs) measure relative vehicle safety performance averaged over a standard set of crash circumstances and occupant characteristics. As such they reflect the average serious injury risk to which vehicle occupants are exposed across the full range of crash circumstances and occupant characteristics. An important question is whether relative vehicle safety, as measured by crashworthiness, can identify combinations of road types and crash types where the ability of the vehicle to protect its occupants is inadequate. In such circumstances focus on improving vehicle safety will not yield road safety benefits indicating the need to focus on other areas of the road system, such as infrastructure, to reduce road trauma.

Analysis was conducted of data on injuries sustained by drivers of almost one million crashed vehicles from New Zealand and the Australian States of Victoria, Queensland, Western Australia, South Australia and New South Wales. To obtain separate vehicle market group estimates of crashworthiness (risk of fatal and serious injury per tow-away crash of the particular type studied) for each of the crash types and crash circumstances of interest, logistic regression models were constructed using relevant data for the crash type or road classification studied.

Analysis found that different market groups show quite different patterns of injury outcome for different crash types. The most marked differences are between head-on crashes and single vehicle into object crashes. For the former, the mass of the vehicle plays a very important role. Drivers of smaller vehicles generally suffer more severe injuries as (on average) they collide with larger vehicles, which impose higher levels of deceleration on the smaller vehicle. Conversely, drivers of larger vehicles generally fare better. Three crash types, head-ons, rollovers and single vehicle-fixed object, all impose at least three times the risk of fatal and serious injury as the other crash types, indicating clear limitations to the capacity of secondary safety systems in vehicles to modulate injury risks adequately. Circumstances that impose very higher risk of fatal and serious injuries are clearly worth addressing, particularly under a Vision Zero framework.

Key Words: Injury, Vehicle Occupant, Collision, Passenger Car Unit, Passive Safety System, Statistics, Road Safety

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PREFACE

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Contributor Statement

A/Prof Stuart Newstead:	Project conception, data analysis, review and management and final version of report
Dr Mike Keall:	Data assembly, analysis design, preparation and statistical analysis of datasets, manuscript preparation

Ethics Statement

Ethics approval was not required for this project.

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PART 1 BACKGROUND

PREVIOUS RESEARCH

The Used Car Safety Ratings (UCSRs) measure relative vehicle safety performance averaged over a standard set of crash circumstances and occupant characteristics. As such they reflect the average serious injury risk to which vehicle occupants are exposed across the full range of crash circumstances and occupant characteristics. Due to their ease of presentation, average safety ratings for vehicles remain the most useful source of consumer information on relative vehicle safety.

A project previously completed under the VSRG program has examined the relationship between relative vehicle safety performance and driver characteristics as measured by driver age and gender. It found that relative vehicle safety between vehicle market groups was generally consistent for each age and gender group apart from a few exceptions where particularly high risk combinations were identified including females in commercial vehicles, young people in 4WDs and males in compact 4WDs. These results confirmed the general applicability of the UCSRs to all age and gender groups.

Further work recently completed by MUARC has examined the relationship between relative vehicle aggressivity towards pedestrians and speed limit. Analysis found that vehicle safety performance only differed at travel speeds low enough to allow the pedestrian some chance at survivability. Results highlighted the system issues – vehicle and environment – that interact to determined safety outcomes for pedestrians and indeed highlighted the need to look at vehicle safety from a broader perspective in relationship to the other elements of the system in which the vehicle operates.

CRASHWORTHINESS

Crashworthiness ratings represent the relative safety of vehicles in protecting their own occupants in the event of a crash. It is a measure of the risk of death or serious injury to the driver in the event of a crash where a vehicle is towed away or someone is injured.

Reflecting properties of the available data, the crashworthiness measure estimated here is a product of two components:

1. Risk of injury for drivers involved in crashes where a vehicle is towed away or someone is injured (injury risk).
2. Risk of serious injury (death or hospital admission) for injured drivers (injury severity).

Multiplying these two risks together formed the crashworthiness rating. These components, representing risk and severity of injury respectively, and were first used to compile crashworthiness measures by Folksam Insurance, which publishes the Swedish ratings (Gustafsson et al, 1989).

OBJECTIVE

There remains a question however as to whether relative vehicle safety as measured by crashworthiness measures differs according to crash circumstances. The objective of the proposed study is to investigate whether relative vehicle secondary safety varies by crash circumstances including road environment and crash type. It is likely that there are thresholds for certain crash types and circumstances where the crashworthiness of the vehicle ceases to provide a reasonable level of safety. A safe system approach to road safety demands that other aspects of the safe system then need to play their part to reduce areas of unacceptable risk. This information will assist in setting priorities for road infrastructure improvements that will assist in allowing vehicle safety improvements to produce maximum benefits.

PART 2 ANALYSIS

DATA

The data analysed (see Table 1) consisted of crash data for almost one million crashed vehicles from New Zealand and the Australian States Victoria, Queensland, Western Australia, South Australia and New South Wales. Crashes were divided into the following types according to information provided in the crash data bases on crash impact points and vehicle movement at the time of impact:

- front impact, where the vehicle in question hit another vehicle's side or rear;
- head-on, where the vehicle collided head-on with another vehicle;
- rear, where the vehicle was impacted from the rear;
- rollover, where the vehicle rolled over;
- side, where the vehicle was impacted from the side (either driver's or passenger's side);
- single vehicle crash into a fixed object (a tree, wall, post or building);
- other, all other crash types, excluding collisions with heavy vehicles or unprotected road users (pedestrians, cyclists or motorcyclists).

For the current analysis, we excluded crashes with pedestrians, cyclists or motorcyclists as the focus was on the injury outcome for the driver of the vehicle. It is rare for crashes with unprotected road users to result in fatal or serious injuries to the driver unless other impacts (with vehicles or fixed objects) are involved. Heavy vehicle crashes were excluded as the light vehicle's crashworthiness can play little part in preventing injury when the other colliding vehicle has such a large mass in relation to the light passenger vehicle.

Crash circumstances were studied in relation to:

- speed limit (75km/h and under; higher speed limits);
- whether road was divided or not (with or without a median barrier or substantial median strip).

Jurisdiction	Crash data years	Crashed drivers	Fatal and serious injured drivers
New South Wales	2010-2015	307,471	18,018
Victoria	2010-2015	93,494	13,295
Queensland*	2010-2015	108,293	23,259
Western Australia	2012-2015	211,864	3,472
New Zealand	2010-2015	57,015	4,631
South Australia	2010-2015	211,789	2,437
TOTAL		989,926	65,112

*For Queensland, the crash data were poorly completed in 2014 and 2015, so data for crash types relying on the coding of an impact point or classification of road configuration could not be used.

Table 1: Data years, numbers of vehicles, numbers of fatal and serious driver injuries for the jurisdictions and crash types studied

This project will use a similar analytical approach as previously conducted to identify differences in relative vehicle secondary safety by occupant age and gender. It will examine relative vehicle safety by crash type and broad road environment to establish whether these factors interact with vehicle type to produce different relative secondary safety outcomes. Analysis will test for interactions between these factors and relative vehicle secondary safety, including identifying those combinations that are most likely to produce severe injury outcomes. It will also identify those road environment features that do not allow vehicle safety features to operate within the domain where they have the potential to reduce serious casualty risk. By doing so it will identify the safe system requirements involving vehicle and road environment safety factors to reduce or eliminate trauma.

Crash type	Total	Proportion
Frontal impact (excluding head-on)	322,719	33%
Head-on	31,629	3%
Rear impact	150,814	15%
Rollover	24,391	2%
Side impact	136,051	14%
Single into fixed object	117,639	12%
Other	206,683	21%
Total	989,926	100%

Table 2: Number of crashed vehicles according to crash type studied

MODELLING CRASHWORTHINESS FOR PARTICULAR CRASH CIRCUMSTANCES

The modelling approach used to estimate crashworthiness was analogous to that used to produce the Used Car Safety Ratings (Newstead et al, 2017). This method, well-suited to Australian and New Zealand crash data bases, was developed to maximise the reliability and sensitivity of the estimates using the available data whilst adjusting for the effects on injury outcome of non-vehicle factors that differ between vehicles. In addition to the speed zone and driver sex, the method of analysis adjusts for the effects of driver age and the number of vehicles involved.

Before adjusted total secondary safety ratings can be obtained it is necessary to consider logistic models of each of the total secondary safety components separately to identify possible factors, other than vehicle design, which might influence the crash outcomes in terms of driver or unprotected road user injury outcome. A stepwise procedure was used to identify which factors had an important influence. This was done without considering the model or market group of car in the model, as the aim was to determine which other factors were most likely to have had an influence across crashes. Furthermore, the car model variable had to be excluded from the logistic modelling process at this stage to avoid having relative vehicle total secondary safety estimates between models that were dependent on the crash circumstance and occupant characteristics. Only the average total secondary safety across a standardised set of crash circumstances and occupant characteristics was of interest.

Logistic models were obtained separately for injury risk and injury severity because it was likely that the various factors would have different levels of influence on these two probabilities.

The factors considered during this stage of the analysis for both injury risk and injury severity were:

- **sex**: driver or unprotected road user sex (male, female);
- **age**: driver or unprotected road user age (≤25 years; 26-59 years; ≥60 years);
- **speed zone**: speed limit at the crash location (≤75 km/h; ≥80 km/h);
- **nveh**: the number of vehicles involved (one vehicle; >1 vehicle);
- **state**: jurisdiction of crash (Victoria, NSW, QLD, WA, SA, NZ);
- **year**: year of crash (1987, 1988, … ,2004).

These variables were chosen for consideration because they were part of the databases of Victoria, Queensland, New South Wales, Western Australia, South Australia and New Zealand. Using other variables available only from a subset of these jurisdictions would have drastically reduced the number of cases that could have been included in the analysis.

Jurisdiction of crash was a necessary inclusion in the logistic model because each jurisdiction has its own level of general road safety performance that affects injury outcome. Including the jurisdiction factor in the covariate model is necessary to adjust for rating bias towards those vehicle models that are sold and driven more in one jurisdiction than another. There are some likely differences between jurisdictions in the reporting rates of crashes at certain crash severity levels. Such differences are also controlled for by including the state variable in the regression models. Inclusion of a year of crash indicator in the model is necessary to adjust for the different trends in crash severity between each of the jurisdictions contributing data (Newstead et al, 2017).

To obtain separate vehicle market group estimates of crashworthiness (risk of fatal and serious injury per tow-away crash of the particular type studied) for each of the crash types and crash circumstances of interest, logistic regression models were constructed as described above using just the relevant data for the crash type or road classification studied.

PART 3 RESULTS

CRUDE MEASURES

A crude measure of relative crashworthiness between crash types can be obtained by using the unadjusted counts of crash-involved vehicles, injured drivers and fatally/seriously injured drivers.

	Injury severity	Injury risk	CWR
Overall	23%	19%	4.2%
Front	20%	15%	3.0%
Head-on	38%	40%	15.3%
Other	15%	11%	1.7%
Rear	10%	20%	2.1%
Rollover	33%	40%	13.3%
Side	22%	19%	4.2%
Single-object	37%	35%	13.1%

Table 3: Crude measures of injury risk, severe injury risk once an injury has occurred and crashworthiness by crash type

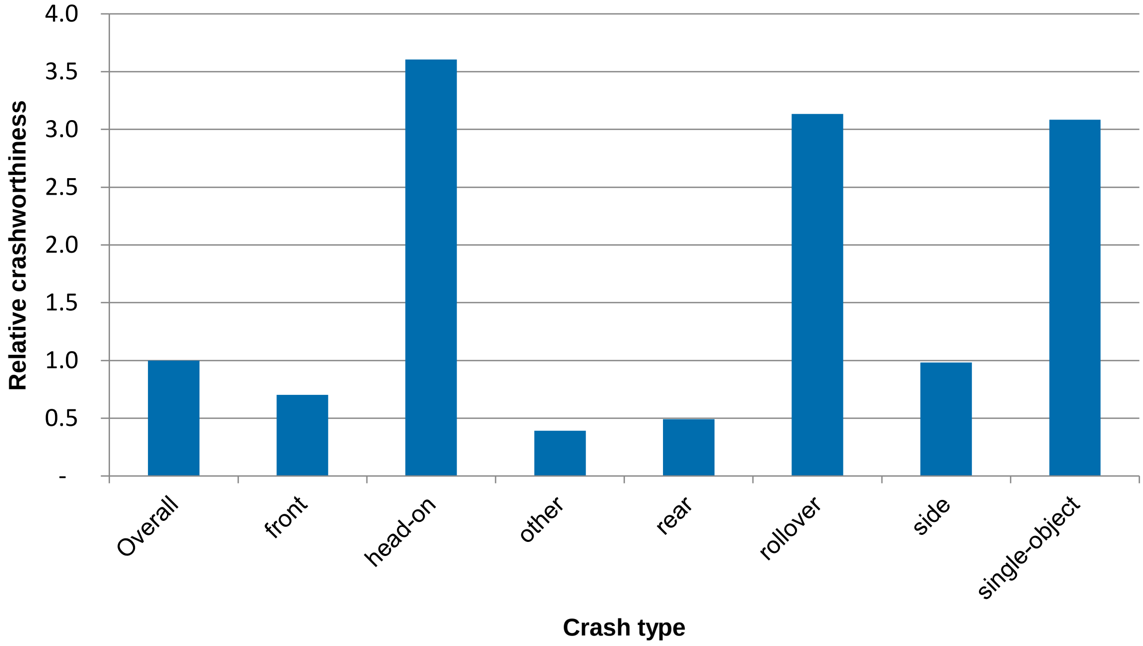

Figure 1: Crude relative measures of crashworthiness by crash type

Table 3 and Figure 1 show crude measures of injury severity outcomes arising from the different crash types studied, and overall. Table 3 presents these as unadjusted risks of fatal and serious injury to drivers given a tow-away crash; Figure 1: presents the consequent crashworthiness estimates relative to the overall measure (set to 1). For the latter, it is clear that head-ons, rollovers and single vehicle into fixed object crashes all have much more severe outcomes on average (more than three times the average risk of fatal and serious injury).

PREVALENCE OF DIFFERENT CRASH TYPES

Drivers undertake different manoeuvres when negotiating different road configurations and conditions and are more likely to engage in particular crash types arising from such manoeuvres. The following analysis looks at some differences in crash distributions for different road types.

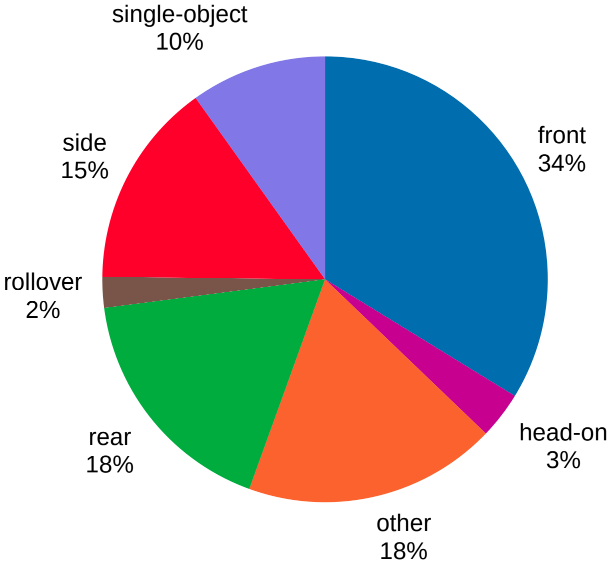

Figure 2: Proportion of crashed vehicles by crash types overall

Figure 2 shows the distribution of crashed vehicles overall according to the crash types studied. The most common crash type (just over a third of crash-involved vehicles) is where the front of the vehicle made impact with another vehicle ("front").

Differences between the prevalence of common crash types on different speed limit roads are clearly shown in Figure 3. This shows how crashes are distributed for roads with speed limits of 75km/h and under (on the left-hand side) and those with higher speed limits (on the right hand side). Lower speed limit areas have more multi-vehicle crashes; higher speed limit areas have more crashes involving loss of control (rollovers or single vehicle collisions with fixed objects) and manoeuvres such as overtaking (including head-on crashes). Some of poorer safety outcomes shown in Figure 1: (for rollovers, head-on and single vehicle into object crashes) will arise from generally higher speeds involved; some will be due to different forces imposed on the occupants by the given crash types that are not adequately moderated by current secondary safety features of vehicles.

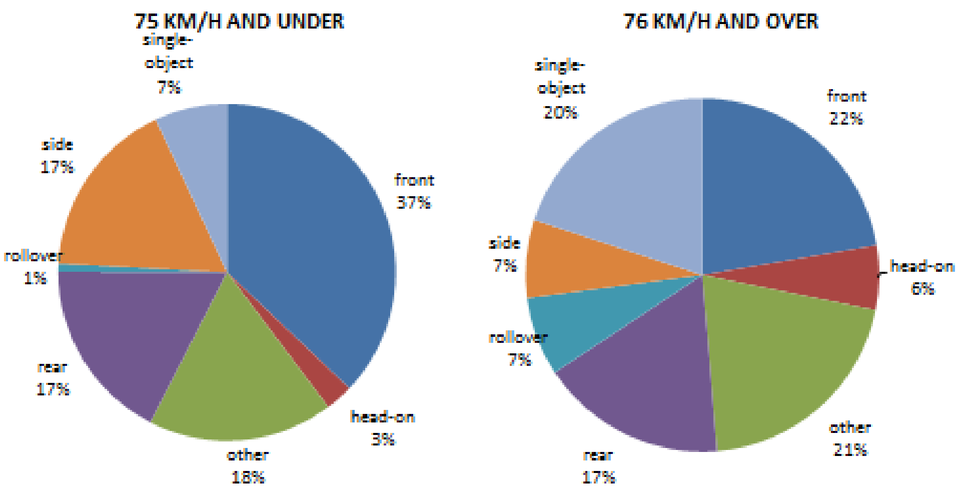

Figure 3: Proportion of crashed vehicles by crash types within speed limit areas

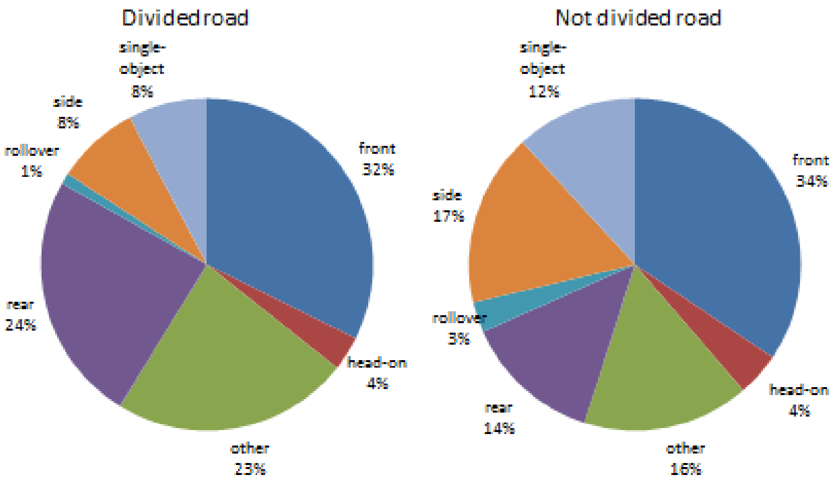

Figure 4: Proportion of crashed vehicles by crash types on roads classified as divided and those not classified as divided

Figure 4 shows proportions of all crashed vehicles that occurred on roads classified as being divided (LHS) or those not so classified (RHS). Some of the more injurious crash types, including rollovers and single vehicle collisions with fixed objects, are clearly averted to a large extent by features of divided roads, replaced to some extent by less injurious crash types, such as rear impacts. It is also well-established that divided roads reduce crash rates generally, so the risk per kilometre driven of crashes of any type tend to be reduced when the road is divided (Keall and Frith, 2004).

CRASHWORTHINESS ACCORDING TO MARKET GROUP

Figure 5 shows estimates from Newstead et al. (2017), showing how crashworthiness varies between market groups, controlling for relevant factors and their important interactions, including driver characteristics, speed limit, year of crash and jurisdiction. The least safe market group, on average, with significantly higher risks than other market groups of fatal and serious injury to drivers given tow-away crash occurrence, is light cars. The safest market group is large SUVs. If the perspective of Total Safety is considered (Newstead et al, 2011), where consideration is taken of injury levels to all road users involved in the crash, the ratings for these two market groups are not as extreme as shown in Figure 5 because the large SUVs impose a much higher risk on road users with whom they collide than do light cars. This penalises the Total Safety rating for large SUVs relative to less aggressive vehicles.

The best performing market group in higher speed limit areas (Figure 6) is SUV-Medium and the worst three are SUV-Small, Vans and Light cars. When crashworthiness is estimated overall, as shown in Figure 5, safety performance in lower speed limit areas is much more influential as 78% of crashes are in these areas. Light cars remain the worst performers in all speed limit areas, but are not so poor compared to the average in higher speed limit areas (only 16% greater than average compared to 41% greater in lower speed limit areas). This is likely to be strongly driven by mass – light vehicles perform badly in collisions with larger vehicles, and collisions between vehicles are much more common in lower speed limit areas.

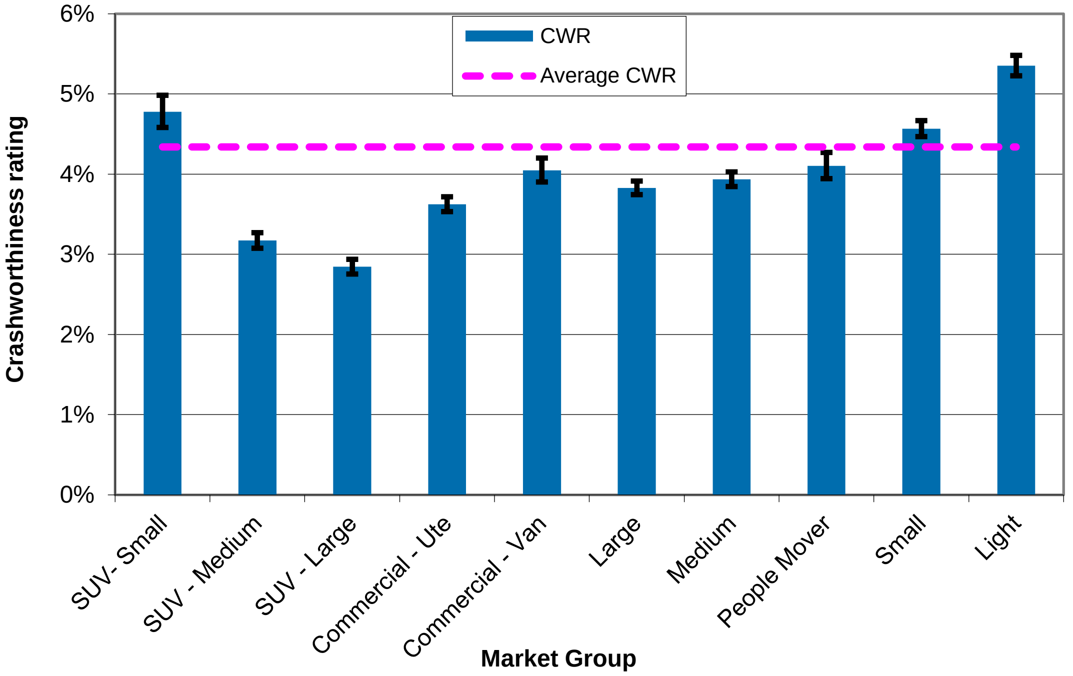

Figure 5: Crashworthiness overall according to market group of vehicle, with overall average and 95% confidence intervals

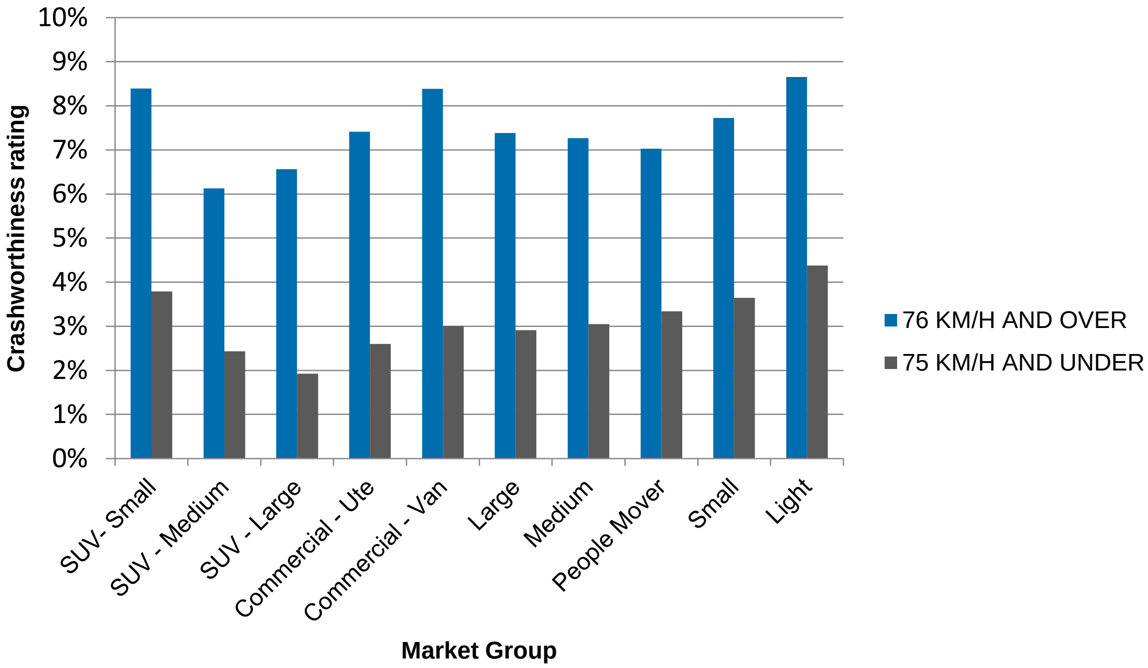

Figure 6: Crashworthiness by market group of vehicle and by speed limit of road where crash occurred

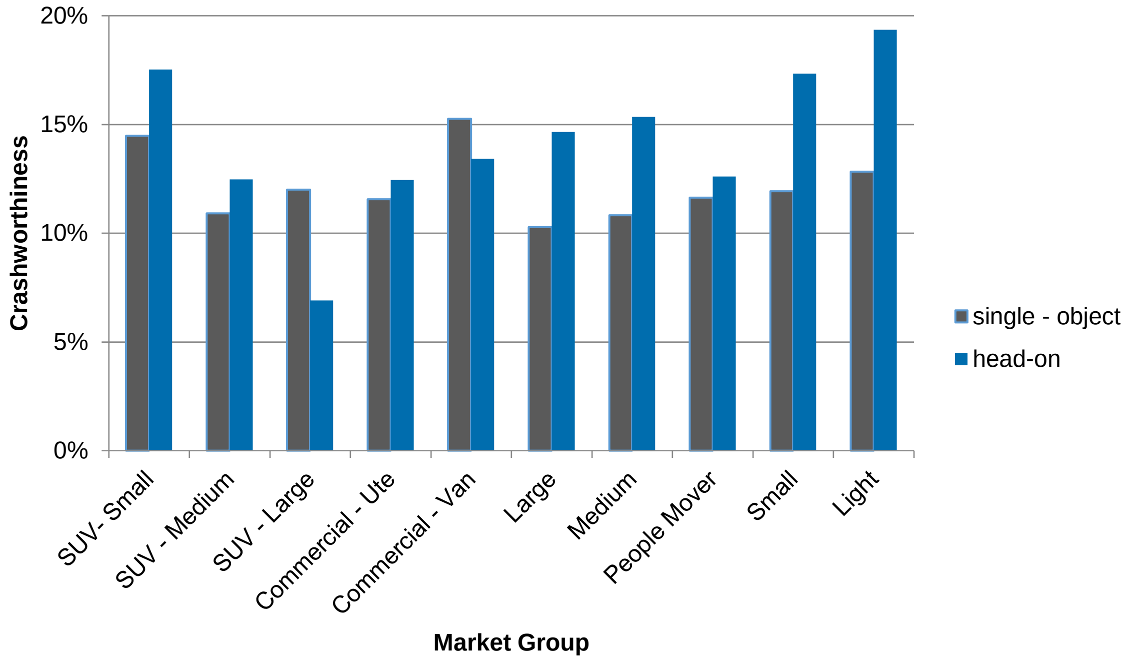

Figure 7: Crashworthiness for specific crash types by market group: single vehicle collisions with fixed objects; head-on crashes

Figure 7 contrasts the crashworthiness estimates for the market groups of passenger vehicles for two crash types, single vehicle into fixed object crashes and head-ons. These show likely strong effects of mass on the injury outcomes for head-ons. Occupants of larger vehicles, such as large and medium SUVs, people movers and commercial vehicles generally fare better in these crash types as they benefit from a larger mass compared to the average vehicle with which they crash. In contrast, occupants of smaller mass vehicles suffer from larger forces in head-on impacts with generally larger vehicles. When vehicles collide with a fixed object, mass plays a much smaller role.

AVERAGE REDUCTION IN FATAL AND SERIOUS INJURY RISK FOR DIVIDED ROADS

As described above, crashworthiness was modelled for all the crash types studied for all jurisdictions with complete data. This excluded Queensland data for the years 2013-2015 and all Western Australian data, as divided roads were not consistently coded these crash data. The following models were constructed, as described above, to estimate injury severity (equation 1) and injury risk (equation 2).

Injury severity= divided road +market group + driver age + driver sex+ speed limit zone + single/multi-vehicle crash + jurisdiction + year of crash + single/multi-vehicle crash * jurisdiction+ single/multi-vehicle crash * speed limit zone + jurisdiction* year of crash+ single/multi-vehicle crash *driver age + speed limit zone * jurisdiction (1)

Injury risk = divided road +market group + driver age + driver sex+ speed limit zone + single/multi-vehicle crash + jurisdiction + year of crash + driver age *driver sex + driver age *speed limit zone + single/multi-vehicle crash * speed limit zone + single/multi-vehicle crash * driver sex + single/multi-vehicle crash * jurisdiction + driver age * year of crash + driver sex * speed limit zone + driver sex * jurisdiction (2)

The influence on vehicle crashworthiness of driving on divided roads compared to undivided roads was estimated by adding the estimated coefficients for divided road in the above equations and then exponentiating to obtain a relative risk. Similar to the interpretation of the crashworthiness measure, this relative risk measure can be interpreted as the probability of fatal or serious injury to the driver in the event of a tow-away crash that occurs on a divided road compared to the same (or similar) crash occurring on an undivided road. The reduction was associated with divided roads was 35% (95% CI 33%-38%), averaged across the various crash circumstances studied and controlling for the other factors listed in equations (1) and (2). As a sensitivity analysis, the model was fitted again but with the make/model/year of manufacture group specified instead of the market group. Very similar estimates were obtained to those from (1) and (2) using market group.

Once risk overall was estimated for divided roads compared to other roads, the next step was to fit a model to see whether particular crash types might benefit from this road configuration. Similar models to those specified in equations (1) and (2) were fitted, but including a crash type factor and an interaction between crash type and divided road to show how driver fatal and serious injury risk given tow-away crash involvement may be reduced differentially across different crash types on divided roads.

Crash type	Relative risk
Head-on	0.57*
Other	0.90*
Rear impact	0.69
Rollover	0.58*
Side impact	0.88*
Single vehicle into object	0.79
Front impact (excl. head-on)	0.76

Table 4: Relative driver fatal/serious injury risk for vehicles involved in crashes on divided roads compared to undivided roads, by crash type. Asterisked crash types had a significantly different relative risk from the other crash types listed

Error! Reference source not found. shows relative driver fatal/serious injury risk for vehicles involved in crashes on divided roads compared to undivided roads, by crash type. Asterisked crash types had a significantly different relative risk from the other crash types listed. These crash types were: head-on and rollover (both with significantly lower relative risk than the other crash types); side impact and other crash types (both with significantly higher relative risk than the other crash types). It is likely that the head-ons on divided roads do not involve overtaking to the same extent as undivided roads, in which circumstances impact speeds are liable to be higher, leading to poorer outcomes.

PART 4 DISCUSSION

OBJECTIVE

Crashworthiness ratings published for different makes and models of used vehicles are a measure of the risk of fatal or serious injuries to drivers of these vehicles when they crash, averaged over the range of crash circumstances and road conditions encountered in Australia and New Zealand. The current research focuses on particular crash circumstances and road types to see how these contribute to road trauma. In particular, we were interested in considering the road safety environment as a system, in which vehicle safety plays an important role that nevertheless interacts with environmental factors. A further objective was to see how different market groups were prone to involvement in certain crash types and how these different vehicles performed in protecting drivers in different crashes.

SUMMARY OF FINDINGS

Three of the crash types considered stood out as having a particularly higher risk of fatal or serious injury. These were head-on crashes, rollovers and single vehicle crashes where the vehicle collides with a fixed object, such as a post, tree or a wall. Head-on crashes merit attention as they involve more than one vehicle and the road trauma consequences are at least doubled, on average. Rollovers and single vehicle into object crashes are much more common in higher speed limit areas, which will be partly due to the higher speeds involved, where control of the vehicle is often lost, and partly due to the different sorts of roads common in higher speed limit areas, such as rural roads with corners.

Different market groups show quite different patterns of injury outcome for different crash types. The most marked differences are between head-on crashes and single vehicle into object crashes. For the former, the mass of the vehicle plays a very important role. Drivers of smaller vehicles generally suffer more severe injuries as (on average) they collide with larger vehicles, which impose higher levels of deceleration on the smaller vehicle. Conversely, drivers of larger vehicles generally fare better.

In contrast, injury outcomes from single vehicle crashes into fixed objects appear to have little influence from the mass of the vehicle, although additional space available for vehicle occupants may prevent some injury from impacts with the vehicle interior, consistent with the gradually decreasing risk of serious or fatal injury with increasing size for cars.

Divided roads have been shown in this study to have an important benefit in terms of reduced injury severity. Quite apart from the reduced rate of crashes on divided roads compared to undivided roads (Keall and Frith, 2004), they also produce a different mix of crashes, generally reducing the rate of more injurious crashes. We estimated that they reduce the risk of fatal or serious injuries for drivers by around 35% (95% CI 33%-38%), averaged across the various crash circumstances studied and controlling for the other influential factors. This is a similar safety benefit that could be obtained by upgrading from a three-star UCSR vehicle (30% worse than benchmark) to a five-star vehicle (equivalent to benchmark). Some of this safety benefit also arises from better outcomes from all the crash types studied, although particularly for two of the more injurious crash types, rollovers and head-on crashes.

Circumstances that impose very higher risk of fatal and serious injuries are clearly worth addressing, particularly under a Vision Zero framework. Three crash types, head-ons, rollovers and single vehicle-fixed object, all impose at least three times the risk of fatal and serious injury as the other crash types, indicating clear limitations to the capacity of secondary safety systems in vehicles to modulate injury risks adequately. The current research has shown that divided roads successfully reduce these risks by approaching a half for rollovers and head-ons, and by around 30% for single vehicle into fixed object crashes. Divided roads have the additional benefit of reducing the rate of all injury crashes.

Results of this research show clearly that a focus on vehicle safety alone will not fully address the road safety problems seen across Australia and New Zealand. Road planning and design with respect to safety and consideration on how this links with the limits of safety available through vehicle design is important to address the full spectrum of road trauma under a safe systems approach. To achieve this, road designers must be conscious of the safety limitations of vehicle designs to produce road designs and their associated assigned speed limits that keep vehicle operation within the tolerances where the vehicle design can effectively mitigate injury in the event of a crash.

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