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Analysis of trends in the composition of Australasian vehicle fleets associated with pedestrian injury severity

Michael D. Keall[1], Angelo D'Elia[2], Stuart Newstead[2] and Linda Watson[2]

[1] *University of Otago, Wellington, PO Box 7343, Wellington South, New Zealand*
[2] *Monash University Accident Research Centre, Melbourne, Australia*

Corresponding author: Michael D. Keall, University of Otago, Wellington, PO Box 7343, Wellington South, New Zealand, Michael.Keall@otago.ac.nz, Tel +64 4 918 6794

Key Findings

- Pedestrians are very vulnerable to injury when impacted by a vehicle: policy and regulation around vehicles and fleet composition must therefore consider their safety
- Increases in sports utility vehicles (SUVs) and light commercial vehicles in Australasian fleets will have decreased pedestrian safety
- However, newer vehicles pose less risk than older vehicles for pedestrian severe and fatal injury
- Trends in the vehicle fleets show this last effect will have reduced injury severity levels much more than the effects of more SUVs and light commercial vehicles in the fleet

Abstract

Australasian fleets have changed substantially over the past decade, with SUVs and light commercial vehicles becoming more popular. These vehicles have been shown in other studies to impose higher fatality risk to pedestrians. For newer vehicles, pedestrian safety may also benefit from international New Car Assessment Program protocols and safety regulation. To quantify such vehicle fleet effects on pedestrian injury severity, this paper analyses pedestrian injury outcomes using Australian crash data. Younger drivers (aged 25 and under) and male drivers were associated with higher severity pedestrian injury. Collisions with commercial vehicles (vans and utility vehicles) and SUVs were associated with higher odds of fatal and serious pedestrian injury than collisions with cars, which is likely to be related to their frontal structure configuration. There was a trend towards better injury outcomes when the vehicle had a more recent year of manufacture, consistent with – but not necessarily attributable to – changes in vehicle design. Trends over the past 15 years were also assessed using crash data from New Zealand and five Australian States. All other factors being equal, increasing proportions of SUVs and commercial vehicles in these fleets will have increased pedestrian injury severity risks. Nevertheless, this was more than counterbalanced by a reduction in injury severity associated with newer vehicles entering the fleets. The strong effects of vehicle factors found in our analysis support assessment protocols and safety regulations that measure the impact of vehicle frontal structure design on pedestrian injury outcomes.

Keywords

Pedestrian; injury severity; vehicle safety standards

Introduction

Globally, more than one third of the 1.2 million annual road fatalities are pedestrians (WHO, 2009). Pedestrian injury is particularly important in countries with high levels of pedestrian activity, which are generally low-income countries with relatively low levels of motorisation. In low-income countries, around 54% of road fatalities are pedestrians and cyclists, compared to an average of about 23% in high-income countries (Naci, Chisholm, & Baker, 2009). In Australia, 182 pedestrians were killed in 2016, constituting 14% of the road toll (BITRE, 2017); the corresponding figure for New Zealand in 2016 was 25, 8% of that year's road toll (NZ Transport Agency, 2017).

There has been a growing recognition that the design of vehicles, particularly the frontal structures that impact on pedestrians and cyclists, plays an important role in injury outcomes for unprotected road users (Hu & Klinich, 2012). Injuries to the pedestrian can be caused by impacts with the vehicle, the road, or both. Analysis of pedestrian injury using US data has shown that in 80% of cases studied, the primary mechanism in producing pedestrian injuries was the impact with the vehicle (Zhang, Cao, Hu, & Yang, 2008). Despite this, there are currently no Australasian vehicle safety regulations specifically aimed to minimise the risk of injury to unprotected road users apart from some general requirements specified in Australian Design Rule 42/04 (Office of Parliamentary Counsel, 2005). However, the New Car Assessment Programs in Australia (from 2000), Europe (from 1997) and Japan (from 2003) all include pedestrian protection tests. From 2011 the ANCAP Roadmap (ANCAP, 2018) has required at least minimum pedestrian protection for vehicles to achieve five stars, and this required minimum level of protection has been increased periodically since then. Standards have been adopted in Japan and the European Union (United Nations Economic Commission for Europe, 2008) to promote the design of safer front-end structures for impacts with unprotected road users. As given makes and models are mass-produced for a variety of markets internationally, the establishment of these testing protocols and regulation standards will affect the safety characteristics of vehicles intended for the international market (Hu & Klinich, 2012), which include most popular car models. Analyses of pedestrian injuries have shown that the head and lower extremities are the most commonly injured body regions, which is the rationale for these regions to be the sole focus of the pedestrian impact-test procedures (Hu & Klinich, 2012). Favourable pedestrian impact-test scores arise from front-end structures able to effectively absorb the energy of an impact with a pedestrian, focusing on these key body regions.

Vehicle aggressivity ratings measure the injury risk that a vehicle poses to road users other than its own occupants (including other vehicle drivers, pedestrians, motorcyclists and bicyclists) in a collision (Newstead, Keall, & Watson, 2011). The Australasian Used Car Safety Ratings vehicle safety rating system includes a measure of relative vehicle aggressivity defined as the risk of death or serious injury to the other road user given crash involvement. Initially, two discrete indices were developed in the Australasian system for vehicle drivers and unprotected road users (pedestrians, cyclists and motorcyclists) (Cameron, Newstead, & Le, 1999). This was later combined into a single index incorporating both other vehicle drivers and unprotected road users (Newstead, Watson, & Cameron, 2006). The current study focuses on an analogous pedestrian aggressivity measure, which is the relative rate of a fatal or serious (hospital admission) injury to a pedestrian given that the pedestrian has sustained some level of injury in a collision with the vehicle. A high value for this measure, all other things (including impact speed) being equal, indicates a poorly performing vehicle. Higher values should coincide with vehicle front-end structures that are relatively unforgiving, are geometrically unfavourable with respect to pedestrian impacts or promote unfavourable pedestrian dynamics in the collision.

As the forces imposed on an impacted pedestrian increase with vehicle speed, any attempt to assess vehicle-related factors contributing to pedestrian injury severity should take this into account. Accurate information on impact speeds is rarely available, so proxies must be used, such as the speed limit of the crash site and characteristics of the driver. Drivers' speed choice is clearly important in determining impact speeds, which is related to the age and gender of the driver. For example, crashes involving young drivers have been found to be more likely to have excessive speed as a factor, and more so for young males (McGwin & Brown, 1999). Characteristics of the pedestrian are also likely to have an effect on injury severity. It is well established that because of their greater fragility, older people are more likely to die (Evans, 2001) or to be injured (Keall & Frith,

Table 1. Variables used in models estimating associations between pedestrian injury severity and driver, pedestrian and vehicle characteristics

Variable	Values
Injury severity (outcome variable)	=1 if pedestrian fatally injured or admitted to hospital =0 otherwise
Pedestrian Age	0-9; 10-25; 26-59; 60 plus
Driver Age	up to 25; 26-59; 60 plus
Pedestrian Sex	Male; Female
Driver Sex	Male; Female
Speed limit	Up to 80km/h; 80km/h plus
Year of manufacture	1982-2012
Vehicle type	Car; SUV; light commercial vehicle
State	Victoria, Queensland, South Australia
Year of crash	2010, 2011, 2012
State*year of crash	(interaction between the above variables)

2004) when in car crashes. An analogous steep increase for older people in the probability of fatal pedestrian injury has also been found (Kim, Ulfarsson, Shankar, & Kim, 2008)

Given the importance of pedestrian injury and their vulnerability in crashes, there is a need to identify factors that lead to more severe pedestrian injury if suitable countermeasures are to be implemented. This study analysed crashes involving pedestrians to identify factors associated with reduced injury severity, and looked at how trends in Australasian vehicle fleets are likely to affect trends in pedestrian injury severity levels.

Methods

Data

Pedestrian injury data matched to information on the driver and the vehicle involved were analysed from the Australian States Victoria, Queensland and South Australia, covering vehicles manufactured over the period 1982-2012 and crashing during the years 2010-2012. Only crashes involving cars, SUVs and light commercial vehicles were included. Injuries not occurring on public roads, such as pedestrians injured on driveways that are private property, were not analysed as they are not officially within the scope of the crash surveillance systems. Also excluded were crashes where more than one vehicle was involved, as the role of vehicle characteristics in resultant injury outcomes is more complex to infer. In aggregate, there were data for 4,416 pedestrians, 52% of whom were fatally or seriously injured.

Vehicles were classified either from VIN numbers (obtained by matching the crash data to registers of licensed vehicles) or from detailed make and model descriptions into three types: cars; SUVs; light commercial vehicles (vans and utility vehicles – sometimes referred to as pickup trucks in the US).

The second stage of analysis, which evaluated changes in the composition of Australasian crash fleets over time, was conducted on data from 2.6 million crash-involved vehicles from the Australian States New South Wales (NSW), Victoria (VIC), Queensland (QLD) and Western Australia (WA) together with New Zealand (NZ) for the years 2001 to 2015. Aspects considered were the average year of manufacture of crashed vehicles, the proportion of the fleet that consisted of SUVs and light commercial vehicles, and finally, the prevalence of young drivers and male drivers involved in crashes. As trends in the on-road fleet were being examined, all crashes (not just those involving pedestrians) were analysed.

Analysis

The main outcome measure used in this study is the risk of death or serious injury (hospitalisation) to the pedestrian given that some injury was sustained in a crash. In practice, pedestrians are almost always injured when hit by a vehicle in reported crashes, so including uninjured pedestrians in the analysis would have added little value to the analysis. To estimate the role of vehicle, pedestrian and driver factors in pedestrian injury severity, a logistic model was fitted with a response variable defined as 1 if the pedestrian was killed or hospitalised and 0 for injuries of lower severity.

Logistic regression was carried out using Proc Logistic from the SAS statistical package (SAS Institute Inc, 2012), employing maximum likelihood estimation. The explanatory variables available to be used to model pedestrian aggressivity are listed in Table 1. These were available for all jurisdictions and were expected from prior research to be associated with the injury outcome. The final three terms (State, year of crash, and the interaction between these) were designed to capture differences in the reporting of injury severity for different jurisdictions and changes in road safety levels across time.

Results

Estimates of pedestrian injury severity ratings

The logistic regression model for estimating changes in pedestrian injury severity by vehicle year of manufacture was of the following general form (with the levels of the main factors estimated shown in Table 2):

> Logit(Probability(Fatal or serious injury given some level of injury)) = year-of-manufacture age(driver) sex(driver) age(pedestrian) sex(pedestrian) speed-limit jurisdiction year-of-crash jurisdiction×year-of-crash (1)

Table 2 shows the estimated odds ratios derived from this model. Statistically significant terms in the model have 95% confidence intervals that do not overlap 1. The comparison level for each factor is also shown. For example, the odds of a pedestrian fatal or serious injury when hit by a SUV was estimated to be around 20% higher than for a car (odds ratio point estimate of 1.2), although this was not statistically significant. Although not shown in this table, the model was run again but with a single term representing either a SUVs or commercial vehicles, to measure an average for this group of vehicles, as studied by Desapriya et al. (2010). The estimated odds of pedestrian fatal or serious injury when hit by either a SUV or commercial vehicle compared to a car (with all other terms in the model remaining the same) was 1.3 (95% CI 1.1-1.5)

Figure 1 shows the aggressivity to pedestrians of individual vehicle market groups by year of manufacture, represented as grouped years of manufacture to smooth some of the variation in the estimates. Nevertheless, there are often quite large confidence intervals (not shown, to avoid clutter),

Table 2. Adjusted odds ratio estimates with 95% confidence intervals for model predicting a fatal or serious injury given that the pedestrian was injured

Effect	Point Estimate	95% Wald Confidence Limits	
Vehicle type SUV vs car	1.2	0.9	1.4
Vehicle type commercial vs car	1.5	1.2	1.9
Additional decade since manufacture	0.8	0.7	0.9
Speed limit 55+ vs <55	1.6	1.4	1.8
Driver age under 26 vs 60 plus	1.4	1.1	1.8
Driver age 26-59 vs 60 plus	1.0	0.9	1.2
Driver sex F vs M	0.8	0.7	0.9
Pedestrian sex F vs M	0.8	0.7	0.9
Pedestrian age 0 - 9 vs 26-59	1.2	0.8	1.6
Pedestrian age 10-25 vs 26-59	1.0	0.9	1.2
Pedestrian age 60 plus vs 26-59	1.8	1.5	2.1

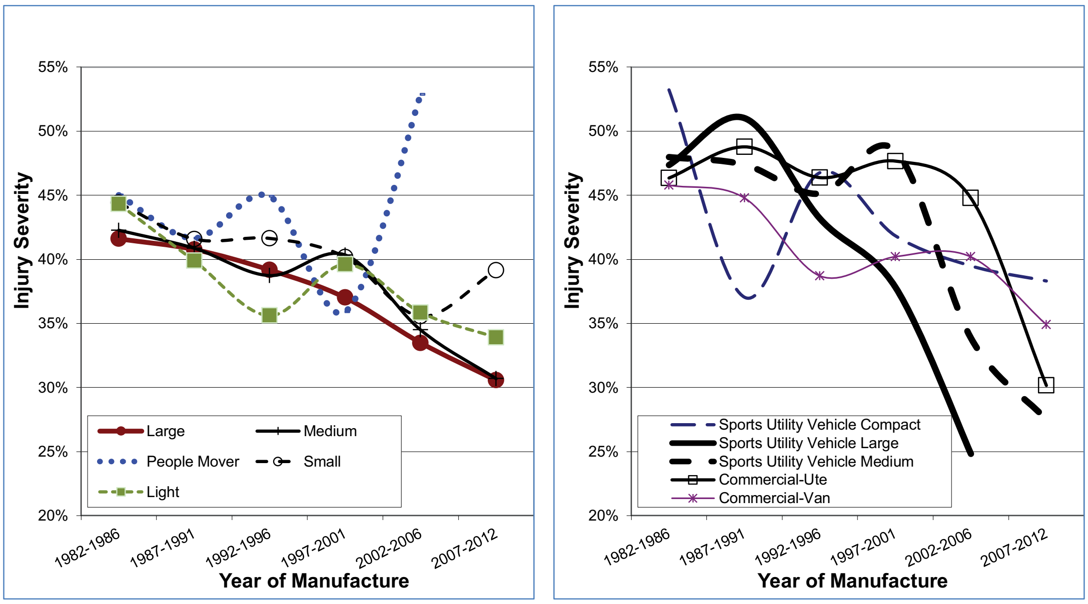

Figure 1. Estimated injury severity risks by vehicle market group for year of manufacture ranges, estimated from combined New Zealand and Australian data. Cars and people movers on LHS; SUVs and commercial vehicles on RHS

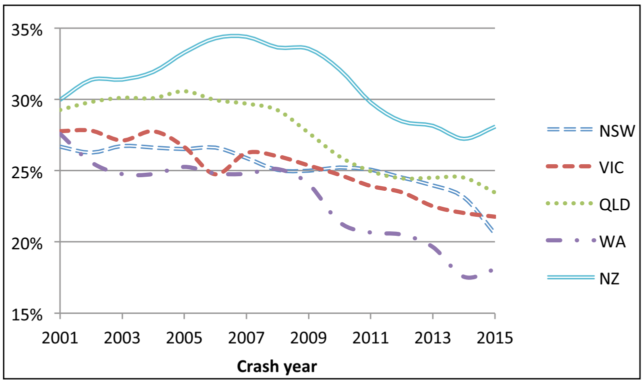

Figure 2. Percent of crashes that involved a driver age 25 or under, by crash year and jurisdiction

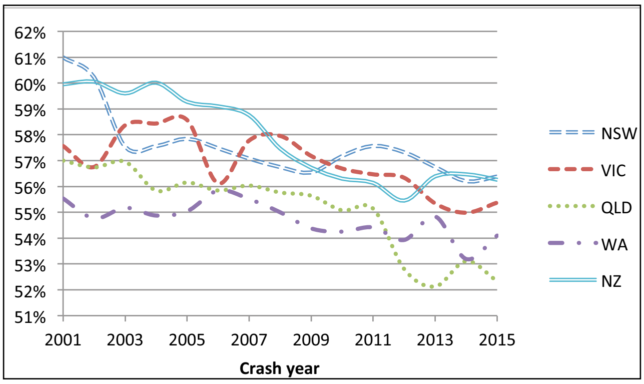

Figure 3. Percent of crashes that involved a male driver, by crash year and jurisdiction

consistent with substantial fluctuation of the point estimates derived from relatively small sample sizes for some market groups. The more numerous market groups, such as the regular passenger car market groups (large, medium, small and light) show distinct downwards trends, whereas some of the other market groups display considerable fluctuation without clear trends (such as compact SUVs and people movers). It is the average of these trends that is captured by the term in Table 2 for "Additional decade since manufacture".

Likely pedestrian fatal and serious injury effects from trends in driver and vehicle fleet composition

Figure 2 shows the proportion of reported crashes that involved a driver age 25 or under, by crash year and jurisdiction. In all the Australian States shown there has been a reduction in the proportion of young drivers who were crash involved from 2001 to 2015. In New Zealand, there has been an overall reduction as well, despite an initial increase from 2001 to 2007.

Figure 3 shows the proportion of crashes that involved a male driver, by crash year and jurisdiction. This shows a similarly stronger trend for all jurisdictions studied. Of course, a graph of female driver involvement would show correspondingly increasing trends.

Table 3 shows total numbers of crash-involved vehicles and drivers, the proportion of these drivers who were male or age 25 or under, the average year of manufacture of the vehicle and the proportion that were SUVs and light commercial vehicles (known as Light Trucks and Vans, or LTVs, in the US) using combined data from NSW, VIC,

Table 3. Combined data from NSW, VIC, QLD, WA and NZ for crash-involved vehicles and drivers by year of crash

Year of crash	n vehicles	Driver Under 26	Male driver	Mean year of manufacture	Proportion SUVs and light commercials
2001	188,075	28%	59%	1992.8	14%
2002	195,574	28%	58%	1993.4	14%
2003	193,186	28%	57%	1994.2	15%
2004	194,973	28%	57%	1995.1	19%
2005	188,894	28%	57%	1996.2	20%
2006	188,617	28%	57%	1997.1	21%
2007	192,004	27%	57%	1998.1	22%
2008	185,965	27%	56%	1999.1	23%
2009	179,863	26%	56%	2000.0	24%
2010	163,652	25%	56%	2000.9	25%
2011	163,107	25%	56%	2001.7	26%
2012	169,703	24%	56%	2002.7	28%
2013	163,986	23%	56%	2003.6	29%
2014	158,063	22%	55%	2004.6	30%
2015	122,035	21%	55%	2004.9	31%

Table 4. Estimated relative odds of pedestrian fatal and serious injury arising from changes in Australasian fleets and driver characteristics from 2001 to 2015: contribution of each aspect individually and overall effect

Period	Driver Under 26	Male driver	Mean year of manufacture	Proportion SUVs and light commercials	Overall
2001-2015	0.98	0.99	0.76	1.04	0.77

QLD, WA and NZ. These aspects are important predictors of pedestrian fatal or serious injury according to the odds ratios estimated in Table 2. By applying estimated odds ratios from Table 2 to the changes in fleet composition and driver characteristics shown in Table 3, it is possible to estimate how pedestrian injury severity may have changed over time in response to these changes in the fleet and drivers, as shown in Table 4. Even though the increased proportion of SUVs and light commercial vehicles in the fleet was estimated to have increased pedestrian injury severity slightly (a 4% increase in the odds of fatal or serious injury), this is counterbalanced by the other factors, most notably more recent year of manufacture, which reduced fatal and serious injury odds by an estimated 24% on average, controlling for the other factors in the model represented by equation (1).

Discussion

This paper has looked at the way that different contributing factors to the severity level of pedestrian injury associated with changes in the vehicle fleets and characteristics of drivers in New Zealand and Australia. Pedestrian injury severity ratings were estimated as the probability of fatal or serious injury to the pedestrian given that a pedestrian injury occurred. Younger drivers (aged 25 and under) and male drivers were associated with higher severity pedestrian injury. Collisions with commercial vehicles (vans and utility vehicles) and SUVs were associated with higher odds of fatal and serious pedestrian injury than collisions with cars, which is likely to be related to their frontal structure geometry and stiffness. There was a trend towards better injury outcomes when the vehicle had a more recent year of manufacture, consistent with – but not necessarily attributable to – changes in vehicle design and manufacture. Trends over the past 15 years were also assessed using crash data from New Zealand and five Australian States. Applying the results of the regression conducted, these trends are likely to have yielded an approximate reduction of 23% in the odds of a pedestrian fatal or serious injury. All other factors being equal, increasing proportions of SUVs and commercial vehicles in these fleets will have increased pedestrian injury severity risks, but only by a small proportion. Estimates from this study suggest the main effect on pedestrian injury severity over the past 15 years has been a reduction in injury severity associated with gradually improving pedestrian outcomes with more recent year of manufacture of the colliding vehicle.

Desapriya et al. (2010) in a meta-analysis of studies comparing pedestrian injury outcomes in collisions with LTVs (light trucks and vans - equivalent to SUVs and commercial vehicles in our study) found an odds ratio for fatal injury of 1.54 (95% CI 1.15–1.93). If the risk of hospitalised pedestrian injury is also increased in collisions with these vehicles, as is indicated by this study, then our finding of odds of 1.3 (95% CI 1.1-1.5) for fatal *or* serious injury is generally consistent with their estimate. There was insufficient power in our study to produce an estimate for fatal injury only. In the United States, 44% of pedestrians injured in crashes with vehicles are struck by LTVs (National Highway Traffic Safety Administration, 2018). From 2010 to 2012, the equivalent percentage in New South Wales, Queensland, South Australia and Victoria was 23%, only a little more than half the US figure. Although SUVs and light commercial vehicles are a concern in pedestrian injury in Australasia, there is clearly more cause for concern in the US. The current study indicates that increases in the proportions of these vehicles in Australasian fleets in recent years has had only a minor influence on pedestrian injury severity.

Based on the modelling of injury severity as a function of vehicle, driver and pedestrian characteristics, along with speed limit and jurisdiction, a reduction in pedestrian injury severity of around 23% was inferred over the past 15 years, all other factors being equal. It would have been useful to have looked at actual injury severity for pedestrians in crashes over this period to see whether this estimate derived from modelling is borne out. It is a limitation of the crash data available for the current study that injury severity is not consistently recorded over time, which hampers any attempts at consistent time series comparing severity levels. It is further a limitation of the current study that impact speeds could not be accommodated in the analysis. As with any cross-sectional study, there is the potential for some confounding. For example, if more recently manufactured vehicles were consistently driven at higher or lower speeds, this could confound the association between year or manufacture and pedestrian injury severity examined here.

The statistically significantly increased odds of pedestrian fatal or serious injury when the driver was young or male may be a consequence of higher speeds. As noted in the Introduction, crashes involving young drivers have been found to be more likely to have excessive speed as a factor, and more so for young males (McGwin & Brown, 1999). A recent Australian study found that surveyed male drivers were more commonly speeding than females according to self-report (Stephens, Nieuwesteeg, Page-Smith, & Fitzharris, 2017). Young drivers also lack the ability to recognise potential crash circumstances, limiting their options when averting a collision (Konstantopoulos, Chapman, & Crundall, 2010).

The estimated improvement in pedestrian injury outcomes when impacted by vehicles of more recent year of manufacture found in the current study could be attributed to several factors. As noted in Background section, there are currently no Australian vehicle safety regulations specifically aimed to minimise the risk of injury to unprotected road users, despite the inclusion of pedestrian protection criteria in the New Car Assessment Programs of Australia, Europe and Japan. ANCAP results have shown important improvements in pedestrian protection ratings since 2003 (Paine et al., 2016), and these ratings have been shown to be correlated with real-world pedestrian injury outcomes, although only in lower speed limit areas (Strandroth, Rizzi, Sternlund, Lie, & Tingvall, 2011). It is also likely that pedestrian protection performance standards implemented in Europe and Japan have impacted on the Australian fleet via large numbers of vehicles from these markets sold in Australia.

Consultation with vehicle manufacturers was outside the scope of the current study, so it is unknown whether improved pedestrian outcomes have arisen from deliberate design choices aimed at pedestrian protection (perhaps in response to the new car assessment protocols or Japanese and European standards) or incidental changes related to materials and manufacturing methods along with the styling of the vehicles – or a combination of these mechanisms. The fitment of bullbars, more commonly to SUVs and light commercial vehicles, is not consistently recorded in the crash data so any potentially detrimental safety effects of this feature could not be examined. Some confounding of results is possible because of this. For example, if bullbars were fitted less frequently to more recent model vehicles, it is likely that some consequent safety benefit for newer vehicles would be found as a result.

Some emerging vehicle technologies are aimed specifically at – or include functionality for – preventing or reducing the severity of pedestrian injury, but considerable safety benefit may arise from technologies designed to reduce collision risk more generally, particularly those that are effective in lower speed limit areas where pedestrian crashes are more common. For example, Intelligent Speed Adaptation (ISA) assists compliance with speed limits either by warning the driver or actively slowing the vehicle control systems. It has the potential to reduce the risk of a wide range of crashes, including vehicle-pedestrian crashes, but its uptake may be limited by lack of acceptability to drivers who may resent its capacity to restrict speeds (Cairney, Imberger, Walsh, & Styles, 2010). Enhanced Night Vision similarly has some potential for reducing crashes with pedestrians at night. Collision Warning Systems and active pedestrian detection systems also have considerable potential, but the safety benefits for pedestrians and other unprotected road users are yet to be established with real-world crash data.

An example of a general crash-reducing technology that is most effective at higher speeds is Electronic Stability Control (ESC), for which benefits do not appear to accrue for pedestrians according to a meta-analysis (Høye, 2011). This may be because vehicle loss of control/traction (the situation where ESC becomes active in maintaining control) plays a relatively minor role in pedestrian injuries, or occurs predominantly in areas where pedestrian exposure is not high. Autonomous Emergency Braking (AEB) has demonstrated promising results for preventing vehicles colliding with other vehicles (Fildes et al., 2015) and cyclists (Ohlin, Strandroth, & Tingvall, 2017), but data for pedestrians impacted by AEB-equipped vehicles are still too scarce to support reliable estimation of safety benefits (Ohlin et al., 2017).

One technology applicable to a range of crash types that *has* been evaluated in terms of pedestrian safety is the Brake Assist System (BAS). This technology has been evaluated by Breuer et al. (2007) based on a study comparing crash involvement of vehicles fitted with BAS with a control group not fitted with BAC. They concluded that severe pedestrian accidents were reduced by 13% associated with the BAS technology, which is slightly higher than an estimate of 10% made by Page et al. (2005). Brake assistance systems are now standard on a wide range of recent model vehicles and since 2013, ANCAP has only awarded five-star ratings for vehicles that performed sufficiently well in the crash tests *and* were equipped with BAS (ANCAP, 2018).

Conclusions

In this analysis of pedestrian injury outcomes in Australia and New Zealand, an improvement in pedestrian injury severity when impacted by vehicles with more recent year of manufacture was found. Other influences on pedestrian injury severity modelled, including an increasing prevalence of SUVs and commercial vehicles in the fleets, were estimated to have a relatively modest effect in recent years compared to this year of manufacture effect. It is probable that a combination of the pedestrian protection performance standards implemented in Europe and Japan, and vulnerable road user protection testing by New Car Assessment Programmes in Australia and internationally have benefitted the safety of the Australasian fleet.

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