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HOW WELL CAN DRIVERS SEE PEDESTRIANS TO AVOID COLLISIONS? THE RELATIONSHIP BETWEEN VEHICLE VISIBILITY AND PEDESTRIAN INJURY RISK AND THE SAFETY BENEFITS OF REVERSING TECHNOLOGIES FOR THE AUSTRALASIAN FLEET

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How well can drivers see pedestrians to avoid collisions? The relationship between vehicle visibility and pedestrian injury risk and the safety benefits of reversing technologies for the Australasian fleet.

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Abstract:

Crashes and incidents involving pedestrians are a significant part of the road toll in Australia and New Zealand. Visibility of pedestrians from vehicles is one possible risk factor that can lead to pedestrian road trauma. As a subset, back-over injuries to pedestrians are a significant road safety issue, but their prevalence is underestimated as the majority of such injuries are often outside the scope of official road injury recording systems, which just focus on public roads. Based on experimental evidence, reversing cameras have been found to be potentially effective in reducing the rate of collisions when reversing whilst the evidence for the effectiveness of reverse parking sensors has been mixed. This study aimed to assess the relationship between pedestrian crash risk and both forward and rearwards visibility as assessed by the indices of forward and rearward visibility derived and published by the Insurance Australia Group (IAG) Research Centre. In addition, the research aimed to assess the benefits of reversing sensors and cameras on vehicles in mitigating the risk of pedestrian back-over crashes. The wide availability of vehicle reversing technologies in recent model vehicles provided impetus for real-world evaluation using police reported crash data. Analysis was based on police reported crash and registration data from Australia and New Zealand over the years 2007-2013.

Analysis found an association between the IAG forward visibility index and pedestrian injury crash risk with vehicles rated 1 or 2 stars having a higher crash risk than those rated 3 stars. Some indication of an association between the IAG reversing visibility index and real world pedestrian back-over risk was identified, with vehicles rated less than 5 stars having a higher risk than those rated 5 stars. These results indicate the potential benefits of technologies that assist driver visibility and awareness of objects outside the vehicle. Compared to vehicles without reversing cameras or sensors, reduced odds of back-over injury were estimated for all three of these technology configurations: 0.59 (95% CI 0.39 to 0.88) for reversing cameras alone; 0.70 (95% CI 0.49 to 1.01) for both reversing cameras and sensors; 0.69 (95% CI 0.47 to 1.03) for reverse parking sensors alone. Analysis also showed that reversing cameras were also associated with a 30% reduction in fatal and serious injury crashes (95% CI 0.50-0.99). There was also good evidence that the safety benefit for these more serious crashes was greater for cars equipped with the cameras than for SUVs or light commercial vehicles. For cars, the fitment of cameras was associated with only half the rate of back-over crashes of other cars without cameras or with unknown fitment status (risk ratio 0.49 with 95% CI 0.3-0.8).

Key Words:

Rear cameras, Reverse cameras, Rear-view cameras, Pedestrian injury, Injury Crash, Back-over injury

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Preface

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Stuart Newstead: Project conception, data analysis, review and management and final version of report

Mike Keall: Data assembly, analysis design, preparation and statistical analysis of datasets, manuscript preparation

Laurie Budd: Data assembly, analysis design, preparation and statistical analysis of datasets, manuscript preparation

Ethics Statement

Ethics approval was not required for this project.

EXECUTIVE SUMMARY

Crashes involving pedestrians are a significant part of the road toll in Australia and New Zealand. In New Zealand during 2016 there were 25 pedestrian fatalities, representing around 8% of the road toll. In the same year 182 pedestrians died on Australian roads, around 14% of the total road toll. Vehicle safety is an important countermeasure in reducing pedestrian road trauma.

The National Highway Traffic Safety Administration describe a back-over crash as a "specifically-defined type of incident, in which a non-occupant of a vehicle (i.e., a pedestrian or cyclist) is struck by a vehicle moving in reverse" (NHTSA, 2010).Visibility of pedestrians from vehicles is one possible risk factor that can lead to pedestrian road trauma. As a subset, back-over injuries to pedestrians are a significant road safety issue, but their prevalence is underestimated as the majority of such injuries are often outside the scope of official road injury recording systems, which just focus on public roads. Based on experimental evidence, reversing cameras have been shown to have potential in reducing the rate of collisions when reversing; the evidence for the effectiveness of reverse parking sensors has been mixed.

The aim of this study was to assess the relationship between pedestrian crash risk and both forward and rearwards visibility as assessed by the indices of forward and rearward visibility derived and published by the Insurance Australia Group (IAG) Research Centre. In addition, the research aimed to assess the benefits of reversing sensors and cameras on vehicles in mitigating the risk of pedestrian back-over crashes. The wide availability of reversing technologies in recent model vehicles provides impetus for real-world evaluations using crash data.

In evaluating the relationship between pedestrian crash risk and both forward and rearwards visibility, data on vehicles involved in crashes with pedestrians in Australia and New Zealand over the year 2010-2013 were analysed. Analysis was limited to vehicles manufactured over the year 2007-2013 since visibility ratings were only available for vehicles over this age range, and reversing sensors and cameras have only been commonly available for vehicles manufactured from 2007. Vehicle registration records for the years 2010-2013 in Victoria, New South Wales and New Zealand were also assembled for measuring exposure in the analysis. Vehicle visibility indices were obtained from the IAG web site whilst reversing camera and sensor fitment information was obtained from RedBook. Both induced exposure and direct risk estimation measures were used to estimate the association between pedestrian crash risk and the visibility indices and camera or sensor fitment. Statistical models were fitted to data from crashes that occurred on public roads constituting 3,172 pedestrian injuries in New Zealand and four Australian States to estimate the odds of back-over injury (compared to other sorts of pedestrian injury crashes) for the different technology combinations fitted as standard equipment (both reversing cameras and sensors; just reversing cameras; just sensors; neither cameras nor sensors) controlling for vehicle type, jurisdiction, speed limit area and year of manufacture restricted to the range 2007-2013.

The classification of vehicles for the current analyses relied on motor vehicle industry classification of vehicles (Automated Data Services Pty Ltd, 2014) according to whether the safety technologies studied were fitted as standard equipment, optional equipment or not available for the given vehicle. There was also a proportion of the vehicles studied (around 12% of those manufactured between 2007 and 2013) that could not be classified, as the information on the vehicle was limited by either errors or omissions in recording details of the crash. Those makes and models of vehicles classified as having the relevant technologies fitted optionally, as well as vehicles fitted with safety technology after manufacture were classified, were grouped together with those vehicles without the relevant technologies or with unknown specification, to form the comparison group of vehicles. This approach will have led to underestimated safety effects in general, although it was considered that such underestimation would not have been large if only a small proportion of vehicles were fitted with these technologies as aftermarket installations.

An induced exposure analysis of the forward visibility ratings with respect to pedestrian injury crashes suffered from lack of data. However, primary safety estimates derived from matched registration and crash data did find an association between the IAG forward visibility index and pedestrian injury crash risk with vehicles rated 1 or 2 stars having a higher crash risk than those rated 3 stars. Some indication of an association between the IAG reversing visibility index and real world pedestrian back-over risk was identified, with vehicles rated less than 5 stars having a higher risk than those rated 5 stars. Overall, this research has identified some indication of an association between visibility from a vehicle as measured by the IAG indices and pedestrian crash risk, particularly for the forward visibility index, indicating potential benefits of technologies that assist driver visibility and awareness of objects outside the vehicle.

Compared to vehicles without any of these technologies, reduced odds of back-over injury were estimated for all three of these technology configurations: 0.59 (95% CI 0.39 to 0.88) for reversing cameras alone; 0.70 (95% CI 0.49 to 1.01) for both reversing cameras and sensors; 0.69 (95% CI 0.47 to 1.03) for reverse parking sensors alone. A model fitted to 2,340 crashes where pedestrians were killed or seriously injured showed that reversing cameras were also associated with a 30% reduction in fatal and serious injury crashes (with a 95% confidence interval 0.50-0.99). There was also good evidence that the safety benefit for these more serious crashes was greater for cars equipped with the cameras than for SUVs or light commercial vehicles. For cars, the fitment of cameras was associated with only half the rate of back-over crashes of other cars without cameras or with unknown fitment status (risk ratio 0.49 with 95% CI 0.3-0.8). These findings are important as they are the first to our knowledge to present an assessment of real-world safety effectiveness of these technologies.

Some important questions remained unanswered by the analysis, possibly arising from lack of statistical power associated with a relatively small sample of crashes. First, analysis presented here could not validly compare the safety benefits of the different technology configurations; second, a sub-analysis hinted at a differential safety effect for different vehicle types, which was supported by the secondary analysis of back-over risk showing a stronger safety effect in terms of fatal and serious crash reductions for the reversing cameras fitted to cars than for SUVs or light commercials. More data are required to investigate both these aspects further as they have important implications for this significant road safety issue.

Contents

1. Introduction

Crashes involving pedestrians are a significant part of the road toll in Australia and New Zealand. In New Zealand during 2016 there were 25 pedestrian fatalities, representing around 8% of the road toll. In the same year 182 pedestrians died on Australian roads, around 14% of the total road toll. Vehicle safety is an important countermeasure in reducing pedestrian road trauma. The National Highway Traffic Safety Administration describe a back-over crash as a “specifically-defined type of incident, in which a non-occupant of a vehicle (i.e., a pedestrian or cyclist) is struck by a vehicle moving in reverse” (NHTSA, 2010). In the United States, Austin (2008) reported an estimated 292 total annual back-over fatalities. This comprised 71 deaths on-road (from official statistics) and a further 221 deaths off-road from the newly created Not-in-Traffic Surveillance (NiTS) database. Austin further estimated that the annual back-over injuries in the United States totalled approximately 18,000 (4,000 on-road, and 14,000 off-road). Many road injury databases internationally record only crashes on public roads, excluding a significant proportion of back-over crashes that occur in driveways, parking lots and other off road locations. Fildes et al. (2014) reported 2,324 back-over injuries to pedestrians in the Australian State of Victoria, as recorded by the Traffic Accident Commission, the state-wide injury compensation database, which encompasses all settings, both on-road and off-road. Despite the limited coverage of off-road injuries, other countries have also identified back-over injuries as important. In Canada, Glazduri (2005) reported that there were approximately 900 pedestrians struck and injured by reversing vehicles each year. In the United States, Mortimer (2006) reported that a minimum of 93 children killed in 2003 were by backing vehicles. Most of these accidents involved children less than five years old in residential driveways impacted by an SUV, light truck or a van driven by a parent or relative.

In terms of causal factors identified in the crash, Fildes et al. (2014) noted that the most frequent cause of the collision involved either the driver or the pedestrian not looking properly during a reversing manoeuvre. A number of common pre-crash manoeuvers were further identified from in-depth crash data including manoeuvres such as backing out of a parking space, reversing into a lane or off-road, and circumstances where a driver is distracted while reversing.

In the case of the driver, obscured vision from the vehicle can also represent a risk factor for impacting a pedestrian. Vehicles can have varying degrees of visibility both forward and to the rear of the vehicle. Forward visibility, in particular, has been noted as being compromised by structural features such as A-pillars, which obscure vision to the front left and right of the vehicle (Beissmann, 2011). It has also been proposed that vehicles rated with better forward and rearward visibility are less likely to collide with a pedestrian. By using a laser rotated 180 degrees to mimic the range of a driver’s forward vision, IAG developed a forward visibility rating by deducting points for how significantly the forward structures of the vehicle including the A-pillars disrupted the laser’s path. In the case of rear visibility, the IAG developed a separate index that accounts for the visible area to the rear of a vehicle and whether a camera and sensors have been installed. Cars were rated on a scale of 0 to 5 stars, with a 5 indicating better reversing visibility. Test equipment consisted of a laser pointing device, a test cylinder to represent the shoulder height of an average two-year-old child, and a grid that extended 1.8m x 15m from the rear of the vehicle. A laser was pointed out the rear window of the vehicle and the position where the laser was visible on the test cylinder was recorded. An overall rating was compiled from these various measurements.

The National Highway Traffic Safety Administration (2009) and others have identified an obvious countermeasure for back-over injuries: reversing cameras and associated on-board equipment. If used appropriately, such technology can assist the driver to avoid pedestrians and cyclists to the rear of the vehicle. In an experiment where reversing drivers encountered an unexpected stationary or moving object, Kidd et al. (2015) found significant benefits in terms of collision avoidance for vehicles equipped with a reversing camera compared with vehicles without any relevant technology, but the benefit was greatly reduced when a stationary object was partially or completely in shade. Parking sensors are proximity sensors for road vehicles designed to alert the driver to obstacles while parking. These systems, which use either electromagnetic or ultrasonic sensors, provide an audible warning when an object is detected. Llaneras et al. (2011) studied reverse parking sensors that provided four types of audible warnings from a sensor system, but found them relatively ineffective in avoiding collisions with unexpected moving objects. Consistent with these results, Kidd et al. (2015) found no apparent benefit for vehicles equipped with reversing sensors. Both studies found the effectiveness of the technologies varied considerably for different collision configurations.

It might be expected that the reverse parking sensors would work synergistically with the reversing cameras if the audible warning from the sensors could alert the driver look for objects on the reversing camera screen. However, Mazzae et al. (2008) found that drivers of vehicles equipped with both the camera and the audible warning often did not even use the camera. When reversing, drivers of vehicles solely equipped with reverse parking sensors often ignored the audible warning; drivers of vehicles with just a reversing camera paid much greater heed to the image from a camera (Kidd et al, 2015). This may reflect a general limitation to the way that drivers are willing or able to attend to several stimuli at once. For example, Rudin-Brown et al. (2012) found that drivers in vehicles equipped with reversing cameras made little use of mirrors while reversing, instead focusing on the camera screen.

1.1 Study Aims

As both reversing cameras and reversing sensors are becoming more common in newer vehicles, it has become possible to analyse the safety effects of these technologies using real-world crash data. This study aimed firstly to assess the potential for vehicle reversing technologies to improve pedestrian safety by assessing the relationship between real world pedestrian crash risk and visibility from the vehicle as measured by separate forward and rearwards visibility indices for vehicles developed by the Insurance Australia Group (IAG) Research Centre. It also aimed to evaluate the real-world benefits of reversing sensors and cameras using police road injury data from some Australian States and from New Zealand.

The results of the primary analysis of the effectiveness of reversing camera and parking sensor technologies have already been published in Keall et al. (2017). As this analysis is novel internationally, some additional (secondary) analyses were conducted using a dataset with an expanded set of variables and inclusion criteria to examine the sensitivity of the findings to the methods used. The larger dataset was also expected to allow an analysis of interactions of vehicle, crash, and driver characteristics to describe how effectiveness of the technology may vary across real-world driving circumstances.

2. Methods and Materials

2.1. Data

2.1.1. Pedestrian injury data

Government authorities in New Zealand and each Australian State maintain databases of road crashes reported to the police that meet common guidelines for reporting and classification (Giles, 2001; Ministry of Transport, 2015). Although these datasets theoretically cover all traffic injuries on public roads, around one third of traffic injuries requiring hospital admission are not recorded, with reporting rates likely to be lower for pedestrian injury (Alsop and Langley, 2001; Lujic et al, 2008). The crash reports from the police are then normally checked and coded to ensure that the data are consistent. The way these data are coded nevertheless varies between jurisdictions. For example, back-over injuries needed to be defined according to the vehicle's direction of movement for some databases or according to the point of impact of the vehicle with the pedestrian for other databases. For the primary analysis of reversing technologies, data were collated for all police-reported crashes where a pedestrian was injured in New Zealand and the Australian States New South Wales, Victoria, Western Australia and South Australia for the years 2010-2013. Data from recent years provides more information for this sort of analysis as more recent vehicles have higher fitment rates of technologies such as reversing cameras, and feature more often in the visibility ratings available. Data for Queensland were only available for 2010-2012, so lacked critical recent crash data, and these were not used in the analysis. As older vehicles may have different exposure patterns with respect to pedestrians, it made sense to restrict the analysis to newer vehicles, with year of manufacture between 2007 and 2013.

For the secondary analysis of reversing technologies, data for the crash years 2007 to 2014 and a wider span of manufacture years 2005 to 2014 were used to increase the amount of data available.

2.1.2. Classifying vehicles

RedBook (Automated Data Services Pty Ltd, 2014) provided a spreadsheet detailing vehicle make, model and variant data from 1990 to identify those vehicles with Rear Parking Sensor and Rear Cameras as standard equipment. All other vehicles (including those with reversing cameras or rear parking sensors as non-standard and those never equipped at manufacturing stage with these technologies) constituted the comparison set of vehicles. The primary and secondary reversing technology analyses were therefore conservative in the sense that some of the comparison set of vehicles would have had the relevant technology, either installed as after-market devices (in the case of reversing cameras and sensors), or installed at the time of manufacture but as non-standard equipment. Such misclassification will therefore tend to generate slight underestimates of the true effectiveness of reversing cameras. The secondary analysis can be expected to be even more conservative as the focus vehicles included vehicle models where all variants were fitted with a camera as well as models where only some variants were fitted with a camera. Furthermore, the comparison set of vehicles may have included vehicles with aftermarket fitment of the technology that was unknown.

2.1.3. Back-over data

Reversing cameras are sometimes packaged with rear parking sensors, which could potentially influence the effectiveness measured for the reversing cameras alone. The primary analysis looked at the effectiveness for preventing pedestrian injury by reversing vehicles of the technologies separately and together. The secondary analysis considered only the fitment of reversing cameras with reversing sensors being present in both the focus vehicle group as well as the comparison set.

As different types of vehicles (as defined by market group) may have different rates of back-over crashes with pedestrians arising from different uses made of the vehicles or from characteristics of the vehicles themselves, it was desirable to identify broad vehicle types in the analysis. Only light passenger vehicles were within the scope of this study, classified as cars, SUVs and light commercial vehicles (vans or utility vehicles / pickup trucks). The reversing cameras are relatively rare in older vehicles (in the data analysed, only 15% of pedestrian crash-involved vehicles identified with standard equipment reversing cameras were manufactured before 2007). A total of 3,172 pedestrian injury crashes were used in the primary analysis, of which 305 (just under 10%) were back-over crashes. For the secondary analysis, which just focused on reversing cameras, vehicles with years of manufacture 2005 and 2006 were included to expand the amount of data available. These included 2,340 crashes where pedestrians were killed or seriously injured.

2.1.4. Visibility ratings data

Visibility ratings were obtained from the IAG website and through media reports for the frontal visibility ratings by make, model and year of manufacture of the vehicle. These were then matched to the vehicle model groupings derived from the crash and registration data. There were some many-to-one matches for the reverse visibility ratings: in these cases, an average rating was allocated. These were averaged across the contributing descriptions. For example, if a sedan version for a given vehicle in the crash and registration data had 3 stars and the hatchback version 2 stars, the given VSRG vehicle was allocated 2.5 stars. For the reverse visibility rating analysis, a total of 1,201 pedestrian injury crashes were analysed, of which 127 (11%) were back-over crashes. Only a relatively small proportion of the pedestrian crash-involved vehicles had visibility ratings, hence there was a smaller amount of data available compared to the analysis considering the effectiveness of reversing technologies.

2.1.5. Back-overs: comparison sets of crashes

For the analyses of reversing vehicle technologies and the reverse visibility ratings, all non-reversing pedestrian crashes for vehicles with year of manufacture between 2007 and 2013 were used as the comparison set. For the analyses of the forward visibility ratings, a set of crashes likely to be unaffected by forward visibility of the vehicle needed to be used. These were from reported two-vehicle crashes in the years 2010-2013 in Western Australia, New South Wales, Victoria and New Zealand in which the vehicle in question was impacted from the rear. A total of 785 frontal impact pedestrian crash-involved vehicles were analysed that had a forward visibility rating allocated and complete data indicating speed limit area, driver age and driver sex ; a total of 1,787 vehicles impacted from the rear were analysed that had a forward visibility rating allocated and complete data indicating speed limit area, driver age and driver sex.

2.1.6. Other pedestrian injury

Further analyses were carried out to measure the relationship between the forward visibility ratings as produced by IAG and pedestrian injury crashes where the vehicle was moving forwards. There were two analyses conducted: an induced exposure analysis and a primary risk analysis.

Induced exposure analysis

Data for vehicles with year of manufacture between 2007 and 2013 were analysed for New Zealand and the Australian States New South Wales, Victoria and Western Australia from police-reported crash data for the period 2010-2013. Crashes were classified into two categories: pedestrian injury crashes where the vehicle was not reversing; crashes where the vehicle in question was impacted from the rear by another vehicle. The latter crashes acted as the comparison set of crashes, used to estimate exposure in the induced exposure analysis.

Primary risk analysis

This approach used estimation methods developed previously by Keall and Newstead (2015). Data on all licensed vehicles were assembled for Victoria, New South Wales and New Zealand for the period 2010-2013. These were matched by license plates to crashes recorded in these jurisdictions over the same time period.

2.2. Methods

The analysis procedure used was one that could be applied to the Australasian databases using consistent variables common to all databases. Sensitive crash types for the reversing analysis were pedestrians injured by a reversing vehicle while non-sensitive crashes were all pedestrian crashes involving a vehicle not reversing and a pedestrian. The secondary analysis also tested a second definition of non-sensitive crash, potentially more closely related to the sensitive crashes (and hence providing a better measure of exposure). These were crashes where a pedestrian was injured while the vehicle was manoeuvring, but not reversing. Induced exposure was the method used to control for extraneous influences as discussed in (Keall and Newstead, 2009). Available data were analysed using the New Zealand and Australian quasi-national (police-reported) crash database described above for crashes that occurred during 2010-2013 for the primary analysis and during 2007-2014 for the secondary analysis.

Using a logistic regression technique, statistical models were fitted to the data to ensure that the primary analysis estimates were adjusted for important factors that could confound estimates of the safety effects of reversing camera or reverse parking sensors. Quasi-induced exposure methods (Keall and Newstead, 2009) were used to estimate the risk of pedestrian back-over crashes for the primary and secondary analysis. This approach makes use of crash counts of a comparison crash type specially chosen to reflect the exposure of a given vehicle type to a particular driving situation where the crash type of interest could occur. Where a given vehicle safety feature is being evaluated, this safety feature should not affect the occurrence of the comparison crashes (Fildes et al, 2013). In this study, counts of non-reversing pedestrian injuries were used as the crash type in the primary analysis to represent exposure to risk. Logistic models were fitted to an outcome variable Y set as follows:

Y=0 (pedestrian injury excluding reversing)
Y=1 (pedestrian injury where vehicle reversing)

A logistic model was fitted to estimate the odds of back-over pedestrian injury (compared to other sorts of pedestrian injury crashes) for the different technology combinations fitted as standard equipment with explanatory variables for the primary analysis as listed in Table . Ages of both drivers and victims were classed into three groups within which both crash risk and fragility are relatively homogeneous (Keall and

Frith, 2004a; Keall and Frith, 2004b). The approach to fitting the model was to include all variables that could potentially confound the relationship between the safety features of the vehicle and the outcome (the ratio of back-over pedestrian injuries to other pedestrian injuries). An example of confounding due to driver age could arise if older drivers already at higher risk of being involved in back-over injury crashes tend to buy vehicles with reversing cameras to cope with difficulty turning their heads when reversing. To avoid biases when measuring the effects of a particular exposure on an outcome, potential confounders should generally be included in models even if they make no statistically significant contribution (McNamee, 2005).

For the primary analysis, vehicles were restricted to the year of manufacture range 2007-2013, which included 85% of all the crash-involved vehicles fitted with cameras. As noted above, fitment of reversing cameras as standard equipment was rare prior to 2007 in the fleets studied. Observations with data missing in any of the fields shown in Table 7 were excluded from the analysis. In addition to fitting logistic models in the secondary analysis, Poisson models were also fitted to estimate relative rates of back-over crashes as a proportion of all pedestrian crashes for vehicles fitted with reversing cameras compared to those without cameras or with unknown fitment status. To study safety effects for more serious injuries, a model was fitted to 2,340 crashes where pedestrians were killed or seriously injured.

Further models were fitted using the same outcome variable and general approach to estimate the potential effect of the front and rear visibility of the vehicle, as measured by the IAG ratings.

3. Results

3.1 Back-over injury and reverse visibility ratings

Data were analysed using the induced exposure techniques described in the methods restricted to those vehicles for which a reverse visibility rating had been calculated by IAG which included 1,201 records. To enable the analysis to be conducted on these relatively sparse data when disaggregated by the visibility ratings, these were combined into three groups, as shown in Table 1 (crude numbers of pedestrian crashes analysed, classified according to the visibility rating of the vehicle and the movement of the vehicle – reversing or otherwise), and Table 2 (results of a logistic model fitted to the data to predict the odds of a pedestrian back-over injury, controlling for jurisdiction, year of manufacture of the vehicle, speed limit (55km/h and over; under 55km/h), driver age, driver sex, pedestrian age, pedestrian sex). As shown in Table 2, the confidence intervals for the odds associated with the visibility ratings both overlapped 1, indicating that there was insufficient statistical evidence that there was a difference in the rate of back-overs between the vehicles grouped by reverse visibility rating (P=0.29). When fitting the same model but with the reverse visibility rating included as a continuous variable, the reverse visibility rating was associated with a reduction of 11% in the odds of pedestrian back-over injury for each unit increase, which approached statistical significance (P=0.07).

Table 1: Crude data - numbers of pedestrian injury crashes by reverse visibility rating of vehicle and movement of vehicle (reversing or forward)

Reverse visibility rating	Non-back-over	Back-over	Total	%back-over
0 – 2	115	20	135	15%
>2 - <5	196	26	222	12%
5	763	81	844	10%

Table 2: Adjusted odds of pedestrian back-over injury according to reverse visibility rating of vehicle

Reverse visibility rating	Odds pedestrian back-over injury (95% C.L.)
0 – 2	1.40 (0.77, 2.53)
>2 - <5	1.44 (0.83, 2.48)
5	Reference level

Forward pedestrian injury and forward visibility ratings – induced exposure analysis

Data were analysed using the same induced exposure techniques but restricted to those vehicles for which a forward visibility rating had been calculated by IAG with 823 and 2,357 records being available for pedestrian injury crashes and rear-impact crashes respectively for rated vehicles. The crude data shown in Table 3 appear to be consistent with reduced forward impact risk with improved forward visibility ratings, but such small differences are unlikely to be statistically significant. Also, as the data come from a range of different vehicles in different jurisdictions, these aspects need to be controlled for to make valid comparisons.

Table 4 shows that compared to the best visibility ratings able to be evaluated (those vehicles with a 3), the risk of a forward-moving vehicle injury crash with a pedestrian was slightly elevated for vehicles with a rating of 1 or 2, but not statistically significantly so. The probability of there being no association between the visibility ratings and the risk of pedestrian injury was estimated to be 0.73.

Table 3: Crude data - numbers of crashes by forward visibility rating of vehicle and type of crash (pedestrian injury forward moving vehicle; two-vehicle rear-impact)

Forward visibility rating	Rear impact 2-vehicle	Forward impact pedestrian	Total	%pedestrian
1	540	195	735	27%
2	948	334	1282	26%
3	869	294	1163	25%

Table 4: Adjusted risk of pedestrian injury (forward moving vehicle) according to forward visibility rating of vehicle

Forward visibility rating	Risk pedestrian injury (95% C.L.)
1	1.05 (0.81,1.37)
2	1.13 (0.84,1.51)
3	Reference level

Forward pedestrian injury and forward visibility ratings – primary risk analysis

Using crash data matched to registers of licensed vehicles in New Zealand, Victoria and New South Wales, all vehicles that could be allocated an IAG forward visibility rating were compared using a primary safety analysis. The outcome evaluated was the risk of non-reversing pedestrian injury, controlling for counts of an unrelated crash type (multi-vehicle side or rear impacts where the driver was over 25), the degree of urbanisation of the owner's address, the State or country of the vehicle, and statistically significant interactions between these. These statistical models were formulated and tested in previous research on primary vehicle safety (Keall and Newstead, 2015).

The primary safety rating with regard to pedestrian safety was calculated on all the available data excluding the one vehicle make/model available with a visibility rating of 4, the Volkswagen Golf (see Table 5). Ratings are unlikely to be valid when only one make/model represents a given level. Also, there were no such vehicles available in the New South Wales data, which made up an important part of the analysis dataset. This lack of coverage would have generated likely biases. There were few vehicle makes and model combinations representing the poorest rating of 1: only two were present in the data analysed. However, these vehicles (Holden Commodore VE sedan and utility vehicles) were well-represented in terms of numbers of vehicles. The statistical model identified strongly statistically significant elevated pedestrian injury crash risk for vehicles with a rating of 1 or 2 compared to 3, which was the reference value (see Table 6). Although vehicles rated with a 2 had a point estimate for their relative risk that exceeded that for vehicles rated with a 1, these were not statistically significantly different from one another.

Table 5: Data used in primary risk assessment of vehicles according to forward visibility ratings

Make and model	forward visibility rating	Non-reversing pedestrian injury	multi-vehicle side or rear impact, driver over25	n identified in fleets
Holden Commodore VE 06-11	1	226	1,949	845,456
Holden Commodore VE Ute 07-11	1	24	205	110,074
Ford Falcon FG 08-11	2	183	1,212	286,869
Holden Cruze JG / JH 09-11	2	26	414	215,456
Toyota Aurion 06-11	2	48	580	211,272
Toyota Camry 06-11	2	107	980	322,220
AudiA3 04-09	3	9	95	44,894
AUDI TT 8J	3	2	12	8,251
Mini Cooper 02-11	3	6	47	34,304
BMW1 Series E81 / E82 / E87 / E88 04-11	3	19	134	62,702
BMW3 Series E90 /E91 /E92 /E93 05-11	3	28	304	118,282
BMW Z4 E89	3	0	5	1,666
BMW 1 Series F20	3	0	2	4,162
CITROEN C5	3	0	3	3,677
FIAT 500	3	1	11	6,801
Mitsubishi / Peugeot Outlander / 4007 06-11	3	15	215	98,481
Mazda RX-8 03-11	3	5	30	19,215
MAZDA CX-9	3	5	76	36,335
Mazda 6 / Atenza 08-11	3	23	44	40,827
NISSAN 370Z	3	0	12	5,871
Peugeot 308 08-11	3	5	77	41,701
Subaru Forester 08-11	3	24	376	162,567
SUZUKI APV	3	3	14	5,370
Toyota Corolla 07-11	3	199	1,641	604,898
Toyota Kluger / Highlander 07-11	3	31	454	178,281
VOLVO C30	3	1	5	4,259
VOLKSWAGEN GOLF/JETTA 2004-10	4	33	109	94,210
TOTAL		1,023	9,006	3,568,101

Table 6: Adjusted estimates of risk of pedestrian injury from forward moving vehicle associated with IAG visibility ratings

Forward visibility rating	Relative risk of pedestrian injury
1	1.48 (1.10, 1.98)
2	1.73 (1.30, 2.31)
3	reference value

3.2 Back-over injury and vehicle reversing technology

3.2.1 Primary analysis

Table 7 summarises the data analysed and the results of the primary analysis of the crash effects of vehicle reversing technologies. It shows counts of pedestrian crashes disaggregated by the available variables and whether the vehicle was reversing (back-over) or not (other pedestrian crash). Unadjusted odds ratios are shown relative to the specified referent level along with 95% confidence intervals. The adjusted odds ratios were estimated by a logistic model fitted to all the data shown. Each of the latter was estimated while controlling for the effects of the other factors in the model (represented by the factor levels in column two). These represent the best estimates of the effects of each factor on the odds of a back-over crash as confounding variables, which are liable to affect the crude odds ratios, are controlled for statistically. The logistic models were fitted using the SAS procedure LOGISTIC (SAS Institute Inc, 2014). The Hosmer-Lemeshow goodness of fit criteria showed no evidence of a poor fit (Chi-Square of 5.12 with 8 degrees of freedom: P=0.74) for the full model that estimated the adjusted odds ratios shown in the last column.

Reversing cameras by themselves were associated with a statistically significant (P=0.01) estimated reduction in the odds of injury of 41% (the estimated odds ratio was 0.59, with 95% CI of 0.39 to 0.88). The other technology combinations: reversing cameras and rear parking sensors together, and the sensors by themselves, were associated with non-statistically significant estimated reductions in the odds of injury, although reversing cameras and rear parking sensors together had an estimated odds ratio that was almost statistically significantly different from 1 (P=0.055).

As was expected, there were also differences in the odds of back-over crashes between levels of the other variables considered. In the higher speed limit areas, back-over crashes were relatively rare, as could be expected. SUVs and commercial vehicles, both of which present typically poorer visibility when reversing, had higher odds than cars of back-over crashes: almost 50% higher for SUVs and more than twice as high for commercial vehicles. Differences between jurisdictions may reflect different patterns of road usage and pedestrian activity; differences between years of manufacture are likely to reflect different ways the vehicles are used. Note that vehicles manufactured in 2013 would only have featured in the 2013 crash data but not in the data for 2010-2012. Similarly, 2011 and 2012 model vehicles would not have featured in earlier crash years.

The inclusion of driver age or sex in the model had little effect on the back-over odds estimates. These were included in the model in case drivers of particular ages or sexes favoured vehicles with the technologies studied. Such patterns could have confounded the results if there were independently a relation between driver age and sex and liability to injure a pedestrian when reversing. Pedestrian age and sex were clearly important factors, however. Compared to younger pedestrians, those aged 60 plus had odds that were approaching eight times as high, and those injured pedestrians aged 26-59 had trebled odds of being injured by a reversing vehicle. Female pedestrians also had statistically significantly increased odds relative to males.

In a sub-analysis, an interaction term was fitted between vehicle type and technology combinations (in addition to the first order terms already discussed above), but there was poor evidence that the interaction term coefficient was different from zero (P=0.13). In this model, the resultant estimated coefficients implied that in pedestrian back-over collisions, the odds of back-overs for SUVs were not reduced for those vehicles with the technologies. More data are required to investigate further any differential safety effects for different vehicle types. The current data hint at such a differential, but with weak statistical evidence. No other interaction terms approached significance in the models.

Table 7: Numbers of pedestrian crashes during the period 2010-2013 by classification variables and reversing (back-over) status and crude and adjusted relative odds of a back-over crash

Factor	Factor Level	Back-over pedestrian crash	Other pedestrian crash	Odds of back-over	Crude odds ratio (95% CI)	Adjusted odds ratio (95% CI)
Technology	both cameras and sensors	86	1019	0.08	0.65 (0.48,0.88)	0.70 (0.49,1.01)
	just camera	47	484	0.10	0.75 (0.51,1.08)	0.59 (0.39,0.88)
	just sensors	49	541	0.09	0.70 (0.48,1.00)	0.69 (0.47,1.03)
	neither	90	691	0.13	Reference value	Reference value
Jurisdiction	NSW	112	1127	0.10	1.22 (0.71,2.10)	0.95 (0.53,1.71)
	NZ	32	303	0.11	1.29 (0.69,2.42)	0.96 (0.49,1.88)
	SA	10	140	0.07	0.88 (0.39,1.99)	0.61 (0.25,1.44)
	VIC	102	969	0.11	1.29 (0.75,2.23)	1.17 (0.65,2.12)
	WA	16	196	0.08	Reference value	Reference value
Year of manufacture	2007	75	668	0.11	0.52 (0.23,1.16)	0.59 (0.25,1.42)
	2008	67	653	0.10	0.47 (0.21,1.06)	0.50 (0.21,1.20)
	2009	43	488	0.09	0.41 (0.18,0.93)	0.42 (0.18,1.03)
	2010	36	426	0.08	0.39 (0.17,0.90)	0.40 (0.16,0.98)
	2011	29	270	0.11	0.50 (0.21,1.17)	0.52 (0.21,1.30)
	2012	14	193	0.07	0.34 (0.13,0.86)	0.32 (0.12,0.88)
	2013	8	37	0.22	Reference value	Reference value
Vehicle type	SUV	49	440	0.11	1.32 (0.94,1.84)	1.45 (1.00,2.10)
	commercial vehicle	58	342	0.17	2.01 (1.46,2.77)	2.07 (1.40,3.06)
	car	165	1953	0.08	Reference value	Reference value
Speed limit	55km/h +	50	1087	0.05	0.34 (0.25,0.47)	0.32 (0.23,0.44)
	<55km/h	222	1648	0.13	Reference value	Reference value
Driver age	Unknown	15	91	0.16	2.20 (1.13,4.29)	2.43 (1.02,5.77)
	up to 25	28	374	0.07	Reference value	Reference value
	26-59	187	1843	0.10	1.36 (0.90,2.05)	1.35 (0.87,2.09)
	60 plus	42	427	0.10	1.31 (0.80,2.16)	0.96 (0.56,1.63)
Driver sex	Unknown	6	36	0.17	1.74 (0.72,4.24)	0.76 (0.23,2.53)
	Female	97	1014	0.10	Reference value	Reference value
	Male	169	1685	0.10	1.05 (0.81,1.36)	1.02 (0.76,1.37)
Pedestrian age	Unknown	8	96	0.08	2.71 (1.22,6.02)	2.71 (1.13,6.49)
	up to 25	33	1071	0.03	Reference value	Reference value
	26-59	96	1009	0.10	3.09 (2.06,4.63)	2.99 (1.98,4.52)
	60 plus	135	559	0.24	7.84 (5.29,11.62)	7.76 (5.17,11.65)
Pedestrian sex	Unknown	3	34	0.09	1.22 (0.37,4.04)	1.16 (0.30,4.54)
	Female	164	1248	0.13	1.82 (1.41,2.35)	1.56 (1.19,2.04)
	Male	105	1453	0.07	Reference value	Reference value
Overall		272	2735	0.10	N/A	N/A

3.2.2 Secondary analysis

The aim of the secondary analysis was to test a second definition of non-sensitive crash, potentially more closely related to the sensitive crashes (and hence providing a better measure of exposure). These were crashes where a pedestrian was injured while the vehicle was manoeuvring, but not reversing. It was also hoped that enough data might be available to test some interactions between the safety effect of the reversing cameras and certain aspects of real-world driving circumstances, including vehicle type, lighting (day/night/dawn/dusk), and driver age to describe how the effectiveness of the technology may vary across these factors. Finally, there are potential benefits in terms of injury severity reductions provided by the cameras, in addition to preventing crashes. These were studied by examining the proportion of collisions with pedestrians that resulted in fatal or serious injuries, and counts of fatal and serious injury crashes.

Table shows the total of almost 9,000 crashes used for the analysis classified by jurisdiction and values of variables used. Queensland data did not have reversing vehicle crashes with pedestrians coded, so these data were not used. Injuries occurring in twilight (dawn and dusk) are potentially of interest in an analysis of camera effectiveness as the cameras may provide poorer images in reduced light. There was no information provided within the South Australian and New Zealand data on such light conditions.

Table 8 shows the number of crashes for the same factors, but according to the reversing camera fitment status of the vehicles involved. This shows that only 2.7% of the pedestrian crashes studied involved a vehicle for which all variants for the given model year were fitted with reversing cameras. These were too few to provide a viable set of crashes for analysing real-world safety effects. As a result, it made sense in the analysis to pool this group with vehicles for which at least some variants for the given model year were fitted with reversing cameras. This can be expected to generate conservative estimates of the safety benefits of reversing cameras as some of the vehicles involved in crashes used to attribute an injury rate would not have had cameras fitted. It is unknown what proportion of vehicles in the fleet were in this category, however.

Table provides some crude odds ratios for the key outcomes analysed: back-over injuries (as opposed to other sorts of pedestrian injuries), and fatal/serious injuries (compared to all injuries, including minor injuries). The key odds ratios are for the first factor shown in the table, the fitment of reversing cameras on the vehicle. In terms of the odds of back-over injury, the crude odds indicate a 14% reduction in reversing crashes; in terms of injury severity, the crude odds indicate an 8% increase in the odds of a fatal/serious injury. Subsequent logistic models examined these odds controlling for relevant factors, with results in Table 9. As the reversing cameras could be expected to provide a benefit in terms of injury severity reduction in back-over crashes, but not other pedestrian crashes, the key term assessed in the logistic model was an interaction between injury severity level and whether the vehicle was reversing or not.

The considerable variation in the odds ratios between jurisdictions in Table 9 indicates the importance of including this factor in the logistic models. It represents differences in coding the crashes between jurisdictions as well as differences in the actual crash rates. The very low odds of back-over injuries when light conditions are dark is likely to be an artefact of exposure: pedestrians are much less exposed to reversing vehicles at night. Pedestrian age in the crash was coded in a prioritised fashion to cope with circumstances where there were two or more pedestrians of different ages injured in the crash. Pedestrian age was coded as: child under 10 if there was at least one child; age 60+ if there were no children aged under 10 but at least one injured pedestrian 60-years-old or older; age 10-59 for all other cases where the age was known.

Table 8: Number of crashes used for analysis by jurisdiction and values of variables used

Factor	Factor level	NSW	VIC	WA	NZ	SA	Total
Rear-view camera	No cameras or unknown	2680	2429	703	826	513	7151
	At least some variants with cameras	716	676	145	153	134	1824
Vehicle age when crashing	Less than 3 years	1375	1297	349	355	242	3618
	3 to 5 years	1411	1241	322	361	269	3604
	6 to 10 years	610	567	177	263	136	1753
Driver age group	60+ years	500	445	82	240	99	1366
	25-59 years	2344	2220	536	611	409	6120
	0-24 years	380	371	128	96	104	1079
	Age unknown or missing	172	69	102	32	35	410
Light Conditions	Dark	923	838	235	217	175	2388
	Light	2244	2036	581	762	472	6095
	Dusk/Dawn**	229	231	32	0	0	492
Vehicle type	Sedan/Convertible/Coupe	2568	2233	578	736	461	6576
	SUV	403	449	136	62	89	1139
	Van/ute	425	423	134	181	97	1260
Pedestrian age*	Child under 10	245	176	58	123	36	638
	Age 10-59	2238	2061	534	580	374	5787
	Age 60+	777	806	126	183	198	2090
	Unknown or missing	136	62	130	93	39	460
Speed zone	Below 55km/hr speed zone	2290	1685	514	898	348	5735
	At or above 55 km/hr zone	1106	1420	334	81	299	3240
Crash type	Reversing Vehicle	325	294	81	114	116	930
	Manoeuvring but not reversing vehicle	237	254	34	25	66	616
	Other non-reversing	2834	2557	733	840	465	7429
Total		3396	3105	848	979	647	8975

*If more than one pedestrian was injured, crash was coded as: child under 10 if there was at least one child; age 60+ if there were no children aged under 10 but at least one injured pedestrian 60-years-old or older; age 10-59 for all other cases where the age was known.
**As dusk/dawn crashes were not identified within the data for two jurisdictions, crashes with these values were excluded from the analysis of the safety benefits.

Table 9: Number of crashes used for analysis by rear-view camera fitment status and values of variables used

Factor	Factor level	Fitted to all	Fitted to some	No camera or unknown	Total
Vehicle age when crashing	Less than 3 years	166	847	2605	3618
	3 to 5 years	59	624	2921	3604
	6 to 10 years	16	112	1625	1753
Jurisdiction	NSW	88	628	2680	3396
	VIC	109	567	2429	3105
	WA	12	133	703	848
	NZ	22	131	826	979
	SA	10	124	513	647
Driver age group	60+ years	27	214	1125	1366
	25-59 years	190	1148	4782	6120
	0-24 years	14	130	935	1079
	Unknown or missing	10	91	309	410
Light Conditions	Dark	46	484	1858	2388
	Light	179	1023	4893	6095
	Dusk/dawn**	16	76	400	492
Vehicle type	Sedan/Convertible/Coupe	37	1126	5413	6576
	SUV	184	383	572	1139
	Van/ute	20	74	1166	1260
Pedestrian age*	Age 10-59	151	1049	4587	5787
	Child under 10	18	111	509	638
	Age 60+	61	355	1674	2090
	Unknown or missing	11	68	381	460
Speed zone	Below 55km/hr speed zone	153	1050	4532	5735
	At or above 55 km/hr zone	88	533	2619	3240
Crash type	Reversing Vehicle	28	152	750	930
	Manoeuvring but not reversing vehicle	19	113	484	616
	Other non-reversing	194	1318	5917	7429
	Total	241	1583	7151	8975

*If more than one pedestrian was injured, crash was coded as: child under 10 if there was at least one child; age 60+ if there were no children aged under 10 but at least one injured pedestrian 60-years-old or older; age 10-59 for all other cases where the age was known.
**As dusk/dawn crashes were not identified within the data for two jurisdictions, crashes with these values were excluded from the table.

Table 10: Number of crashes by driver, crash and vehicle characteristics by crash configuration and injury severity, along with odds ratios

Factor	Factor level	Manoeuvring but not reversing	Other non-reversing	Reversing	Fatal or Serious	Minor Injury	Odds ratio reversing	Odds ratio fatal/serious
Rear-view cameras	Some/all variants	91	913	144	426	722	0.86	1.08
	None/unknown	335	3352	613	1522	2778	1	1
Vehicle age when crashing	Less than 3 years	167	1660	320	757	1390	1.06	0.96
	3 to 5 years	173	1775	285	805	1428	0.88	1.00
	6 to 10 years	86	830	152	386	682	1	1
Jurisdiction	NSW	165	1705	273	882	1261	0.40	3.05
	VIC	178	1174	210	601	961	0.43	2.72
	WA	21	408	68	196	301	0.43	2.84
	NZ	25	760	113	204	694	0.39	1.28
	SA	37	218	93	65	283	1	1
Driver age group	60+ years	59	711	130	327	573	0.61	2.14
	25-59 years	291	2854	499	1342	2302	0.57	2.19
	0-24 years	41	512	66	219	400	0.43	2.05
	Unknown or missing	35	188	62	60	225	1	1
Light Conditions	Dark	89	1232	76	592	805	0.28	1.46
	Light	337	3033	681	1356	2695	1	1
Vehicle type	Sedan/Convertible/Coupe	299	3197	507	1435	2568	0.67	0.98
	SUV	69	509	116	240	454	0.92	0.93
	LCV	58	559	134	273	478	1	1
Pedestrian age*	Age 10-59	230	2815	305	1088	2262	0.55	3.52
	Child under 10	22	422	38	187	295	0.47	4.64
	Age 60+	153	803	369	638	687	2.11	6.79
	Unknown or missing	21	225	45	35	256	1	1
TOTAL		426	4265	757	1948	3500		

*If more than one pedestrian was injured, crash was coded as: child under 10 if there was at least one child; age 60+ if there were no children aged under 10 but at least one injured pedestrian 60-years-old or older; age 10-59 for all other cases where the age was known.

Table 11: Adjusted odds ratios of reversing pedestrian injury crash, speed zones below 55km/h

Effect	Point Estimate	95% Wald Confidence Limits	
Cameras installed in at least some variants: yes vs no	0.823	0.661	1.025
Vehicle age at crash: 3 to 5 years vs Less than 3 years	0.851	0.71	1.021
Vehicle age at crash: 6 to 10 years vs Less than 3 years	0.879	0.702	1.099
Jurisdiction: NSW vs WA	0.944	0.695	1.281
Jurisdiction: NZ vs WA	0.944	0.67	1.33
Jurisdiction: SA vs WA	2.322	1.599	3.372
Jurisdiction: VIC vs WA	0.927	0.674	1.274
Driver age group: 0-24 years vs 25-59 years	0.78	0.586	1.038
Driver age group: 60+ years vs 25-59 years	0.883	0.707	1.101
Driver age group: Unknown or missing vs 25-59 years	1.88	1.233	2.867
Light conditions: Dark vs Light	0.331	0.256	0.428
Vehicle type: Van/Ute vs Sedan/Convertible/Coupe	1.269	1.007	1.598
Vehicle type: SUV vs Sedan/ Convertible /Coupe	1.275	0.999	1.627
Pedestrian age*: Age 10-59 vs unknown	0.628	0.442	0.893
Pedestrian age*: Child under 10 vs unknown	0.45	0.281	0.72
Pedestrian age*: Age 60+ vs unknown	2.136	1.496	3.049
Driver sex: Female vs unknown/missing	0.879	0.487	1.586
Driver sex: Male vs unknown/missing	0.991	0.555	1.769

*If more than one pedestrian was injured, crash was coded as: child under 10 if there was at least one child; age 60+ if there were no children aged under 10 but at least one injured pedestrian 60-years-old or older; age 10-59 for all other cases where the age was known.

Table 11 provides an estimate of another facet of the safety benefits of reversing cameras: an 18% reduction in the rate of back-over injuries to pedestrians compared to all pedestrian injuries. The data were restricted to speed zones below 55km/h but this restriction made little difference compared to a model fitted to data from all speed zones. The rationale for the restriction was to focus on areas where vehicle-pedestrian conflicts are common and the safety benefits of the reversing cameras are most relevant.

Table 12 shows the results of fitting a logistic model to an outcome defined to be a fatal or serious injury using the same factors as Table 11 but with two additional terms: whether the vehicle was reversing and an interaction between likely camera fitment and the vehicle reversing into a pedestrian. This latter term was designed to capture the potential effects of camera fitment on the severity of a back-over injury. The estimated coefficient for the term ("Vehicle reversing and Cameras installed in at least some variants") had a large P value (0.4202), indicating poor evidence of any effect distinguishable from the random variation in the data as fitted by the model. These results do show the greater vulnerability of older pedestrians and children to any impact. The rather strange results for unknown age are artefacts of the crash recording systems rather than signalling any important road safety patterns: these records were included in the analysis to maximise the data available.

Table 12: Coefficient estimates for model fitting the log of the odds of a given pedestrian injury being fatal or serious

Parameter	Level	Estimate	Standard error	Wald Chi-Square	Pr > ChiSq
Intercept		-0.6617	0.8208	0.6498	0.4202
Cameras installed in at least some variants	Yes	-0.3773	0.291	1.6818	0.1947
Vehicle reversing	Yes	-0.0278	0.1605	0.0299	0.8626
Vehicle reversing *and* **Cameras installed in at least some variants**	Yes	0.2993	0.3594	0.6933	0.405
Vehicle age at crash	3 to 5 years	0.0801	0.1529	0.2745	0.6004
Vehicle age at crash	6 to 10 years	0.0767	0.1886	0.1653	0.6843
Jurisdiction	NSW	0.00287	0.2736	0.0001	0.9916
Jurisdiction	NZ	-0.9062	0.3383	7.1739	0.0074
Jurisdiction	SA	-1.22	0.3604	11.4581	0.0007
Jurisdiction	VIC	-0.1704	0.2782	0.3755	0.54
Driver age group	0-24 years	-0.0967	0.2375	0.1658	0.6839
Driver age group:	60+ years	-0.2297	0.1893	1.4717	0.2251
Driver age group	Unknown	-1.7543	0.6264	7.844	0.0051
Light conditions	Dark	0.5728	0.2099	7.4473	0.0064
Vehicle type	LCV	0.2309	0.2046	1.274	0.259
Vehicle type	SUV	0.1774	0.2656	0.4462	0.5041
Pedestrian age*	Child under 10	0.5845	0.3202	3.3318	0.068
Pedestrian age*	Age 60+	1.2314	0.1554	62.786	<.0001
Pedestrian age*	Unknown	-0.9869	0.488	4.0898	0.0431
Driver sex	Female	-0.6894	0.7433	0.8601	0.3537
Driver sex	Male	-0.6414	0.7388	0.7536	0.3853

*If more than one pedestrian was injured, crash was coded as: child under 10 if there was at least one child; age 60+ if there were no children aged under 10 but at least one injured pedestrian 60-years-old or older; age 10-59 for all other cases where the age was known.

Table shows the results of fitting a Poisson model to counts of pedestrian crashes. The risk ratios shown are rates of back-over crashes compared to other pedestrian crashes for vehicles with reversing cameras as either standard or optional equipment compared to other vehicles. Although the safety benefits estimated overall for all casualties can only be regarded as indicative (with a P value of 0.157), fatal and serious injury crashes overall were associated with a 30% reduction that was statistically significantly greater than zero (with a 95% confidence interval 0.50-0.99). There was also good evidence that the safety benefit was greater for cars equipped with the cameras than for SUVs or light commercial vehicles. For cars, the fitment of cameras was associated with only half the rate of back-over crashes of other cars without cameras or with unknown fitment status (risk ratio 0.49 with 95% CI 0.3-0.8).

Table 13: Risk ratios for vehicle models with cameras (installed in at least some variants) compared to all others for a reversing pedestrian injury crash compared to other pedestrian crashes

Subgroup	All casualties		Fatal and serious	
	Risk ratio (95% CI)	P	Risk ratio (95% CI)	P
Overall	0.88 (0.73, 1.05)	.157	0.70 (0.50, 0.99)	.041
Age 60+ Drivers	0.76 (0.46, 1.24)	.272	0.53 (0.20, 1.43)	.210
Age <60 Drivers	0.90 (0.74, 1.09)	.284	0.73 (0.51, 1.05)	.090
LCV	1.25 (0.69, 2.24)	.462	1.31 (0.51, 3.36)	.575
SUV	0.97 (0.68, 1.39)	.867	1.05 (0.56, 1.93)	.887
Car	0.80 (0.63, 1.01)	.059	0.49 (0.30, 0.80)	.005

4. Discussion

This research has evaluated three different vehicle technology configurations in terms of their safety benefits for pedestrians as well as performing a form of validation of visibility ratings as estimated by IAG for some make/model combinations. The technology combinations evaluated were: reversing cameras; rear parking sensors; both cameras and sensors; neither technology. Data were collated for 3,172 pedestrian injury crashes where a pedestrian was injured in New Zealand and the Australian States New South Wales, Victoria, Western Australia and South Australia for the years 2010-2013, restricted to vehicles with year of manufacture between 2007 and 2013. For vehicles with different safety technology configurations, the odds of a pedestrian injury in a back-over crash were evaluated compared to other sorts of pedestrian injuries using a logistic model controlling for potential confounders, including the speed limit, the type of vehicle, driver age and sex, pedestrian age and sex, vehicle year of manufacture and the jurisdiction of the crash. Compared to vehicles not identified to have the relevant technologies, the analysis showed that all three technology configurations were associated with reduced rates of back-over injuries. Reversing cameras by themselves were associated with reduced the odds of a back-over injury of 41%. There was also indicative evidence that cameras combined with reverse parking sensors, and reverse parking sensors by themselves might be effective in preventing a proportion of back-over injuries to pedestrians ($P<0.1$).

Using a subset of the same data and an identical analytical approach, the IAG reverse visibility ratings were analysed, but there was only weak evidence of an association between the odds of back-over and the visibility ratings. Although an induced exposure analysis of the forward visibility ratings with respect to pedestrian injury crashes suffered from lack of data, primary safety estimates derived from matched registration and crash data did find elevated pedestrian injury risk for vehicles with a rating of 1 or 2 compared to a rating of 3. This provides some evidence that visibility is associated with pedestrian crash risk even though vehicles rated with a 1 were not found to be associated with higher risk than those rated with a 2. This last finding may be related to few make/model combinations represented at the lowest rating.

A strength of these analyses was that it spanned a number of different crash datasets, each with different coding protocols. This limits the effect that systematic issues with crash coding might have on the resultant safety estimates. A secondary analysis using a different set of comparison vehicles suggested that the safety benefits of reversing cameras might be a little lower than estimated in the primary analysis, but there was insufficient power to establish this with statistical certainty. There were also insufficient data to show whether the safety benefits might vary across light conditions, driver characteristics or vehicle type.

A limitation of the analysis of back-over injury risk was the scope of the data analysed compared to the safety issue addressed. The crash data analysed were official road injury data, which do not include injuries that occur in non-public road settings (private roads, drives and parking areas). These non-public areas were considered to be the setting for around three-quarters of all back-over injuries to pedestrians according to some analysis in the United States (Austin, 2008). If these omitted crashes differed in important respects from the sorts of crashes analysed then extrapolating the safety effects we found to all back-overs would not be valid. Such respects might include the speed of the reversing vehicle and the complexity of manoeuvres undertaken, both of which might affect the operation of the technology or the way that the driver uses it. The induced exposure analyses of the visibility ratings were poorly powered to detect differences between the rated vehicles.

The classification of vehicles for the current analyses relied on motor vehicle industry classification of vehicles (Automated Data Services Pty Ltd, 2014) according to whether the safety technologies studied were fitted as standard equipment, optional equipment or not available for the given vehicle. There was also a proportion of the vehicles studied (around 12% of those manufactured between 2007 and 2013) that could not be classified, as the information on the vehicle was limited by either errors or omissions in recording details of the crash. Those makes and models of vehicles classified as having the relevant technologies fitted optionally, as well as vehicles fitted with safety technology after manufacture were classified, were grouped together with those vehicles without the relevant technologies or with unknown specification, to form the comparison group of vehicles. This approach will have led to underestimated safety effects in general, although it was considered that such underestimation would not have been large if only a small proportion of vehicles were fitted with these technologies as aftermarket installations.

A final aspect of the method used that deserves some discussion is the set of comparison crashes identified. Quasi-induced exposure methods (Keall and Newstead, 2009) estimate relative risk or odds by analysing counts of crashes for two sets of vehicles (here, those with relevant technology and those without) for two sets of crashes, one for which the technology is expected to be effective and the other comparison set of crashes unaffected by the technology (neither increasing nor decreasing this form of crash risk). This comparison set of crashes represents exposure to risk of the crash types expected to benefit from the technology. In the case of the primary analysis of back-over risk, the comparison crashes were non-reversing pedestrian injuries. It is probably reasonable to assume that these crashes represent vehicles' exposure to pedestrians; it is also probably reasonable to expect that the reversing cameras and reversing parking sensors would neither decrease nor increase the rate of pedestrian crashes for forward-moving vehicles. Both these assumptions need to hold in general if this estimation approach is valid. Similarly, the comparison set of crashes used for the evaluation of the forward visibility ratings were crashes where the vehicle was impacted from the rear. It would be reasonable to expect that such crashes would be unaffected by the forward visibility of the vehicle.

The secondary analysis of back-over risk considered a comparison set of crashes that involved a vehicle manoeuvring but not reversing, but lacked sufficient crashes to conduct an analysis with reasonable power to detect a safety effect. Although such crashes may represent exposure of vehicles to pedestrians in the same circumstances as back-over crashes, the failure of a driver to see a pedestrian in front of the manoeuvring vehicle suggests that there were aspects of driver distraction or pedestrian unpredictability that make these crashes unusual. It may be that non-reversing collisions with pedestrians remain the best comparison crash choice for induced exposure analysis.

Since drivers generally only reverse vehicles when parking or leaving parking, it can be expected that it is on these occasions that back-over crashes mainly occur. Analysis of data from New South Wales used in the current analysis, for which manoeuvre codes are generally complete, showed that around 70% of back-over crashes were identified as occurring during parking manoeuvres or reversing from drives. In contrast, 72% of pedestrian crashes involving a forward-moving vehicle occurred when no particular manoeuvre (such as pulling out into traffic, turning etc.) was being undertaken. So the circumstances of these two types of pedestrian crashes are clearly different. Nevertheless, the occurrence of pedestrian crashes – whatever the direction of movement of the vehicle – indicates that there are conflicts between vehicles and pedestrians, which is the underlying exposure measure relevant to assessing the technologies studied.

The results for the reversing technologies based on real-world crashes are generally consistent with those from experimental settings (Kidd et al, 2015; Llaneras et al, 2011): reversing cameras were found to be effective in reducing the odds of back-over injuries; reverse parking sensors either by themselves or in combination with reversing cameras had no statistically significant safety effect. As outlined in the Introduction, drivers often did not take the warnings provided by the reverse parking sensors seriously. When the vehicle was equipped with both features, drivers neither paid sufficient heed to the audible warnings, nor monitored the reversing cameras sufficiently.

It is an inherent limitation of analysis using statistical models that the findings depend to some extent on the construction of the model. Although our approach that included as covariates all available potential confounders is appropriate (McNamee, 2005), different models based on the same data would have generated slightly different estimates and levels of statistical significance. We also fitted a negative binomial model instead of a logistic model, but the results changed only slightly in terms of the point estimates and confidence intervals associated with the safety technologies.

Aspects of the crash configuration, which were found to be important in these experimental studies, could not be studied adequately in the current study using police-reported data from various jurisdictions that did not use a standard method to code pedestrian movement, for example. Nevertheless, the effectiveness measured can be considered an average across the range of crash situations encountered in real world driving in Australia and New Zealand, including some configurations where the technology would have little safety benefit.

Some important questions remained unanswered by the analysis in this study, possibly arising from lack of statistical power associated with a relatively small sample of crashes. First, our analysis could not validly compare the safety benefits of the different technology configurations; second, a sub-analysis hinted at a differential safety effect for different vehicle types, which was supported by the secondary analysis of back-over risk showing a stronger safety effect in terms of fatal and serious crash reductions for the reversing cameras fitted to cars than for SUVs or light commercials. More data are required to investigate both these aspects further as they have important implications for this significant road safety issue.

The secondary analysis of fatal and serious injury crashes showed that the reversing cameras were associated with a 30% reduction in these crashes (with a 95% confidence interval 0.50-0.99). There was also good evidence that the safety benefit for these more serious crashes was greater for cars equipped with the cameras than for SUVs or light commercial vehicles. For cars, the fitment of cameras was associated with only half the rate of back-over crashes of other cars without cameras or with unknown fitment status (risk ratio 0.49 with 95% CI 0.3-0.8). The secondary analysis of casualties of all severities was inconclusive. It is possible that the large number of crashes added to the analysis data set involving vehicles with unknown fitment status may have attenuated the safety effect estimated, possibly because the comparison set of vehicles had a reasonable proportion with reversing cameras fitted. Nevertheless, it is also possible that the true safety effect of reversing cameras is smaller than estimated in the primary analysis. Further research would be required to establish whether these possibilities are true or not.

The significant finding regarding elevated risk for vehicles rated with poor forward visibility is potentially very important. It would be unacceptable if structural features of the vehicle, such as A-pillars, designed to protect the vehicle occupants in the event of a crash, were to increase the risk posed to pedestrians and other unprotected road users. It also points to the potential value of pedestrian detection system in modern vehicle designs, particularly those with autonomous braking included.

5. Conclusions

Back-over injuries to pedestrians are a significant but underestimated road safety issue as the majority of such injuries are probably not within the scope of most official road injury recording systems, which just focus on public roads. With the limitation that only officially recorded pedestrian injuries could be identified, this study analysed the association between measures of vehicle visibility, both forward and rearward and the risk of a pedestrian impact along with the rate of back-over injuries compared to other pedestrian injuries for vehicles with three configurations of technology aimed at mitigating crashes involving reversing into pedestrians: just reversing cameras; both reversing cameras and reverse parking sensors; reverse parking sensors by themselves. These technology configurations were compared to vehicles not fitted with these technologies as standard equipment.

Analysis found an association between the IAG forward visibility index and pedestrian injury crash risk with vehicles rated 1 or 2 stars having a higher crash risk than those rated 3 stars. Some indication of an association between the IAG reversing visibility index and real world pedestrian back-over risk was identified, with vehicles rated less than 5 stars having a higher risk than those rated 5 stars. These results indicate the potential benefits of technologies that assist driver visibility and awareness of objects outside the vehicle. Compared to vehicles without reversing cameras or sensors, reduced odds of back-over injury were estimated for all three of these technology configurations: an odds of 0.59 (95% CI 0.39 to 0.88) for reversing cameras alone; 0.70 (95% CI 0.49 to 1.01) for both reversing cameras and sensors; 0.69 (95% CI 0.47 to 1.03) for reverse parking sensors alone. Analysis also showed that reversing cameras were also associated with a 30% reduction in fatal and serious injury crashes (95% CI 0.50-0.99). There was also good evidence that the safety benefit for these more serious crashes was greater for cars equipped with the cameras than for SUVs or light commercial vehicles. For cars, the fitment of cameras was associated with only half the rate of back-over crashes of other cars without cameras or with unknown fitment status (risk ratio 0.49 with 95% CI 0.3-0.8).

Findings from this study highlight the value of including reversing sensors and particularly reversing cameras in vehicles for improving pedestrian safety. An increasing number of new vehicles in Australia and New Zealand have one or both of these technologies as standard but it is also possible to retro-fit both these technologies to older vehicles which wold further increase the benefits. The significant finding regarding elevated risk for vehicles rated with poor forward visibility is potentially very important. It would be counter-productive for safety if structural features of the vehicle, such as A-pillars, designed to protect the vehicle occupants in the event of a crash, were to increase the risk posed to pedestrians and other unprotected road users. It also points to the potential value of pedestrian detection system in modern vehicle designs, particularly those with autonomous braking included

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