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Real-world evaluation of the effectiveness of reversing camera and parking sensor technologies in preventing backover pedestrian injuries

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ABSTRACT

Backover 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 effective in reducing the rate of collisions when reversing; the evidence for the effectiveness of reverse parking sensors has been mixed. The wide availability of these technologies in recent model vehicles provides impetus for real-world evaluations using crash data. A logistic model was fitted to data from crashes that occurred on public roads constituting 3172 pedestrian injuries in New Zealand and four Australian States to estimate the odds of backover 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. Compared to vehicles without any of these technologies, reduced odds of backover injury were estimated for all three of these technology configurations: 0.59 (95% CI 0.39–0.88) for reversing cameras by themselves; 0.70 (95% CI 0.49–1.01) for both reversing cameras and sensors; 0.69 (95% CI 0.47–1.03) for reverse parking sensors by themselves. These findings are important as they are the first to our knowledge to present an assessment of real-world safety effectiveness of these technologies.

1. Introduction

The National Highway Traffic Safety Administration describe a backover 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 US, Austin (2008) reported an estimated 292 total annual backover 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 backover injuries in the US totalled approximately 18,000 (4000 on-road, and 14,000 off-road). Many road injury databases internationally record only crashes on public roads, excluding a significant proportion of backover crashes that occur in driveways and parking lots. Fildes et al. (2014) reported 2324 backover 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 backover injuries as important. In Canada, Glazduri (2005) reported that there were approximately 900 pedestrians struck and injured by reversing vehicles each year. In the US, Mortimer (2006) reported that a minimum of 93 children killed in the US 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

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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.

The US National Highway Traffic Safety Administration (2009) and others have identified an obvious countermeasure for backover 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 for preventing, 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.

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. The current study aimed to evaluate the real-world benefits of these technologies using police road injury data from some Australian States and from New Zealand.

2. Methods and materials

2.1. 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, backover 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. Data were collated for all police-reported crashes where a pedestrian was injured in New Zealand and the Australian States NSW, 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. Data for Queensland were only available for 2010–2012, so lacked critical recent crash data, and these were not used in the analysis.

RedBook (Automated Data Services Pty Ltd, 2014) provided a spreadsheet detailing make, model, basic 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 analysis was 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), 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. Reversing cameras are sometimes packaged with rear parking sensors, which could potentially influence the effectiveness measured for the reversing cameras. The analysis looked at the effectiveness for preventing pedestrian injury by reversing vehicles of the technologies separately and together.

As different types of vehicles (as defined by market group) may have different rates of backover 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 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). As older vehicles may have different exposure patterns with respect to pedestrians, it also made sense to restrict the analysis to newer vehicles, with year of manufacture between 2007 and 2013. A total of 3172 pedestrian injury crashes were analysed, of which 305 (just under 10%) were backover crashes.

2.2. Methods

The analysis procedure was one that could be achieved within the Australasian databases. Sensitive crash types were pedestrians injured by a reversing vehicle while non-sensitive crashes were all pedestrian crashes involving a vehicle not reversing and a pedestrian. 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 quasi Australian national (police-reported) crash database described above for crashes that occurred 2010–2013.

Using a logistic regression technique, statistical models were fitted to the data to ensure that the 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 backover crashes. 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 the current study, counts of non-reversing pedestrian injuries were used to represent exposure to risk. Logistic models were fitted to an outcome variable Y set as follows:

$$Y = 0(\text{pedestrianinjuryexcludingreversing})$$

$$Y = 1(\text{pedestrianinjurywherevehiclereversing})$$

A logistic model was fitted to estimate the odds of backover pedestrian injury (compared to other sorts of pedestrian injury crashes) for the different technology combinations fitted as standard equipment with explanatory variables as listed in Table 1. 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,b). Our 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 backover 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 backover 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). 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 1 were excluded from the analysis.

3. Results

Table 1 summarises the data analysed and the results of the analysis. It shows counts of pedestrian crashes disaggregated by the available variables and whether the vehicle was reversing (backover) 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 our best estimates of the effects of each factor on the odds of a backover 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 of 41% (the estimated odds ratio was 0.59, with 95% CI of 0.39–0.88). The other technology combinations: reversing cameras and rear parking sensors together, and the sensors by themselves, were associated with non-statistically significant estimated reductions, 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 backover crashes between levels of the other variables considered. In the higher speed limit areas, backover 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 backover 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 neither driver age nor sex had much effect on the backover 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 backover collisions, the odds of backovers 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.

4. Discussion

This research has evaluated three different vehicle technology configurations in terms of their safety benefits for pedestrians. These were: reversing cameras; rear parking sensors; both cameras and sensors; neither technology. Data were collated for 3172 pedestrian injury crashes where a pedestrian was injured in New Zealand and the Australian States NSW, 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 backover 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 backover injuries. A strength of this analysis 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 limitation of the analysis was the scope of the data analysed compared to the safety issue addressed (pedestrian backover injury). 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 backover injuries to pedestrians according to some US analysis (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 backovers 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.

Table 1
Numbers of pedestrian crashes 2010–2013 disaggregated by the available variables and whether the vehicle was reversing (backover) or not (other pedestrian crash). Also shown are the odds of a backover crash, unadjusted odds ratios relative to a specified reference level and adjusted odds ratios as estimated by a logistic model fitted to all the data shown.

Factor	Factor Level	Backover pedestrian crash	Other pedestrian crash	Odds of backover	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	55 km/h +	50	1087	0.05	0.34 (0.25,0.47)	0.32 (0.23,0.44)
	<55 km/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

The classification of vehicles for the current analysis 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. The comparison crashes used in the current analysis 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.

Since drivers generally only reverse vehicles when parking or leaving parking, it can be expected that it is on these occasions that backover 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 backover 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.

These results 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 backover 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-recorded 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 our analysis, 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 could only hint at a differential safety effect for different vehicle types. More data are required to investigate both these aspects further as they have important implications for this significant road safety issue.

5. Conclusions

Backover 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 we could only study officially recorded pedestrian injuries, we analysed the rate of backover injuries compared to other pedestrian injuries for vehicles with three technology configurations: 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. The estimated odds ratios were respectively 0.59 (95% CI 0.39–0.88), 0.70 (95% CI 0.49–1.01) and 0.69 (95% CI 0.47–1.03). These findings are important as this study is the first to our knowledge to look at the real-world safety effectiveness of these technologies.

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