Backing collisions: a study of drivers' eye and backing behaviour using combined rear-view camera and sensor systems

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ABSTRACT

Context Backing crash injures can be severe; approximately 200 of the 2,500 reported injuries of this type per year to children under the age of 15 years result in death. Technology for assisting drivers when backing has limited success in preventing backing crashes.

Objectives Two questions are addressed: Why is the reduction in backing crashes moderate when rear-view cameras are deployed? Could rear-view cameras augment sensor systems?

Design 46 drivers (36 experimental, 10 control) completed 16 parking trials over 2 days (eight trials per day). Experimental participants were provided with a sensor camera system, controls were not. Three crash scenarios were introduced.

Setting Parking facility at UMass Amherst, USA.

Subjects 46 drivers (33 men, 13 women) average age 29 years, who were Massachusetts residents licensed within the USA for an average of 9.3 years.

Interventions Vehicles equipped with a rear-view camera and sensor system-based parking aid.

Main Outcome Measures Subject's eye fixations while driving and researcher's observation of collision with objects during backing.

Results Only 20% of drivers looked at the rear-view camera before backing, and 88% of those did not crash. Of those who did not look at the rear-view camera before backing, 46% looked after the sensor warned the driver.

Conclusions This study indicates that drivers not only attend to an audible warning, but will look at a rear-view camera if available. Evidence suggests that when used appropriately, rear-view cameras can mitigate the occurrence of backing crashes, particularly when paired with an appropriate sensor system.

Young children are overrepresented in backing crashes.[1] Part of the recent problem is the increase in high-profile vehicles such as sports utility vehicles and minivans that provide little rearward view.[1] As a means of addressing backing safety, drivers' responses and eye movements were recorded in a field experiment. The purpose of the experiments is to gain information for the development of a collision warning system when backing.

The Centers for Disease Control and Prevention reported that in the years 2001–3, 40% of the injuries to children occurred in a driveway or parking lot,[2] while Patrick *et al*[3] conducted a 6-year review of paediatric pedestrian injuries and found that 80% of pedestrians struck in a driveway were aged under 5 years. Murphy *et al*[4] reported the average age of children in reversing crashes in driveways to be 23 months. Agran *et al*[5] found that the average age of children struck in a driveway was 2 years compared with 4 years for those struck in a parking lot. The Utah Department of Health reported that half of driveway deaths involved children aged 1–2 years and that 19 of 20 driveway deaths between 1997 and 2003 involved high-profile vehicles.[1]

Technologies designed to assist drivers in parking (herein called parking aid systems) have the potential for mitigating these crashes. Three types of parking aid systems are currently utilised: sensor exclusive (sensor system); camera exclusive (camera system) and combined sensor–camera systems (sensor–camera system). Sensor systems use ultrasonic sensors mounted on the rear bumper to detect the presence of, and distance to, an obstacle to be identified via an audible warning.[6] Camera systems utilise a rear-mounted camera to provide an image of the area behind the vehicle displayed on the consol.[6] The sensor–camera system utilises a combination of the sensor and camera system.

In a recent study by the US National Highway Traffic Safety Administration (NHSTA), sensor and camera parking aid systems were studied to determine their potential in reducing backing crashes.[6] The performance of parking aid systems was tested on myriad vehicles in a laboratory setting to determine their efficacy for detecting a 28-inch traffic cone. The NHTSA concluded that sensor systems were limited because the technology as currently configured would not provide an adequate warning for collision avoidance. By contrast, rear-view camera systems were identified as showing the potential to mitigate backing crashes because they allow drivers to detect the presence of obstacles further away from the vehicle; however, camera systems require diligence by the drivers as they are only effective if the driver glances at the display. The NHSTA concluded that 'the true efficacy of rearview camera systems cannot be known without assessing drivers' use of the systems and how they incorporate the information into their visual scanning patterns (ie., looking behind over the shoulder and glancing at mirrors).'

McLaughlin *et al*[7] studied the parking performance of drivers in vehicles equipped with sensor, camera, and sensor–camera parking aid systems when compared with a control condition (vehicle without a parking aid). While parking during the study, drivers encountered the potential for an unexpected rear collision. Of the 29 viable rear collision trials, only five participants avoided a collision: two camera subjects and one sensor—camera subject who looked at the rear-view camera and two who did not use the system but saw the object in the mirror or out of the back window.

Llaneras *et al*[8] studied the influence of the audible warning patterns for sensor systems on backing crash avoidance in the field. While the sensor system performed dismally, preventing only 25% of crashes with the best pattern, audible warnings do appear to affect drivers' awareness of an impending collision. Sensor systems are generally ineffective now because they do not provide drivers enough time for crash avoidance.

In summary, studies suggest only modest benefits from camera systems for mitigating backing crashes, yet the reasons for a lack of efficacy remain unclear. The current study hypothesised that the limited efficacy was due to an underutilisation of rear-view cameras and that efficacy could be improved through the integration of an audible warning. Therefore, the objectives of the current study were to quantify the use of rear-view cameras when driving in reverse and to measure the change in rear-view camera use with audible warnings.

METHODS

The study design was a non-randomised controlled field experiment. Experimental drivers were provided a vehicle equipped with a parking aid system that included both a rear-view camera and an audible alert, while control drivers were provided a vehicle with no parking aid system. Both experimental and control drivers participated in 16 trials, in which each trial included a sequence of parking manoeuvres. At the beginning of trial 7 on day 1, an object was surreptitiously placed in the blind spot behind the vehicle. Measured outcomes included eye movements (to determine driver utilisation of the rear-view camera), qualitative assessments, and whether the driver struck the hidden object in the three potential collision trials. The experiment described herein was conducted in a parking facility on the UMass campus under the supervision of multiple researchers.

Selection and description of participants

Participants were solicited from across Massachusetts. The experimental sample had 28 men and eight women with an average age of 27.6 years and 9.3 years of driving experience, and the control sample had five men and five women with an average age of 27.5 years and 9.2 years of driving experience. Participants were required to be licensed in the USA for over a year, could not wear glasses, and be between the ages of 21 and 35 years.

Table 1 Organisation of trials into days and groups

Day	1		2	
Group	1	2	1	2
Trial	1		1	
	2		2	
	3		3*	
		4		4
		5		5
		6		6
		7*		7*
		8		8

*Potential backing collision scenario.

Definitions

Unexpected crash scenario

A scenario in which either the sensor system on the rear bumper of the vehicle was remotely activated by the researcher without the presence of an obstacle or an object was surreptitiously placed behind the vehicle, which was visible in the rear-view camera display and would activate the sensor system.

Glance

A sequence of fixations on the same target location (eg., camera display).

Short-backing

The vehicle is parked in the middle of a standard 90 degree angle parking space and the driver is required to back out of the space to the left.

Long-backing

The vehicle is parked in the middle of a parking lane separating two rows of perpendicular parking spaces and the driver is

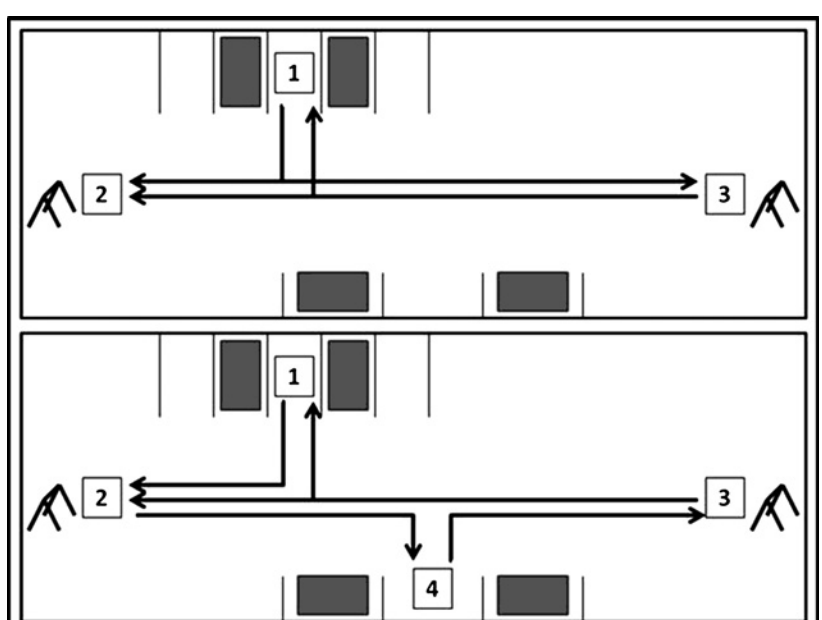

Figure 1 Diagram of vehicle path for trials 1—8.

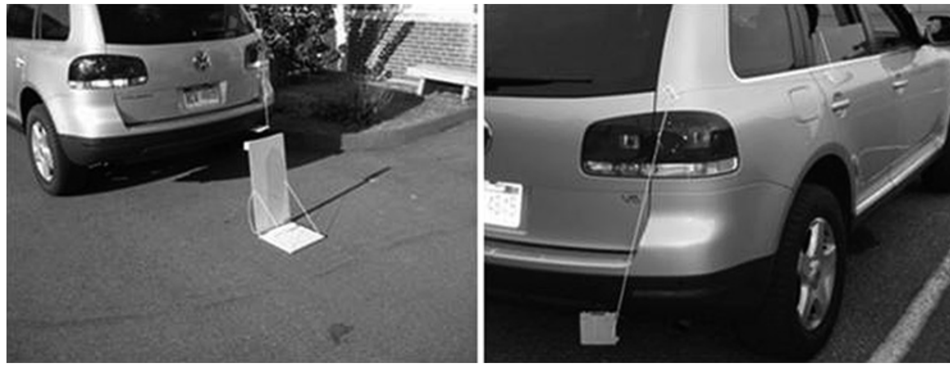

Figure 2 Simulated crash decoy (left), hinged flap for rear audible sensor activation (right).

required to reverse in a straight line for a distance of approximately 200 ft.

Look

Looked at the rear-view backing camera display in the first or second glance.

Difference score

A statistical tool used for estimating the difference between two population means.

Experimental design and procedure

All participants completed 16 trials, each of which included a series of parking manoeuvres. The trials took place over 2 days (eight trials per day) occurring no more than 10 days apart. The first day contained two groups of trials, group 1 containing trials 1–3, and group 2 containing trials 4–8. Three unexpected crash scenarios were introduced during trial 7 of day 1 and trials 3 and 7 of day 2. Table 1 displays the organisation of trials across days and the sequence of unexpected crash scenarios. The experimental participants were provided with a parking aid system, whereas the control participants were not. One researcher was present providing instructions to the driver from the front seat, while a second researcher viewed the experiment from the boundary of the test facility.

The top panel of figure 1 displays the path of the vehicle during the first group of three trials (starting at position 1, backing to 2, moving forward to 3, backing to 2, moving forward to 1 and stopping), whereas the bottom panel shows the vehicle path during the second group of five trials (the difference in group 2 was parallel parking required between positions 2 and 3). The same sequence of eight trials was used on day 2.

Experimental drivers were exposed to three unexpected crash scenarios; one involving a decoy surreptitiously placed by a researcher in the driver's blind spot behind the vehicle while in position 1 (short-backing combined rear-view camera–sensor crash scenario), and two involving remote sensor activation while the driver was backing out of position 1 (short-backing sensor crash scenario) and position 3 (long-backing sensor crash scenario). These crash scenarios were counterbalanced across trial 3 on day 1, trial 3 on day 2 and trial 7 on day 2, as well as across participants. Figure 2 shows an image of the decoy (left) and remote sensor activation system (right). Each control driver was also exposed to the same three crash scenarios with the same day/trial configuration.

A hit was defined by the object being knocked over. The sensor activation system was designed to be triggered by the researcher in the vehicle without the knowledge of the experimental participant.

Figure 3 ASL Mobile Eye.

Equipment

Data were collected with an ASL Mobile Eye (Eye Tracker) and the qualitative observations were recorded by two researchers. The eye tracker (see figure 3) records a simultaneous image of the driver's visual field and pupil, which are then processed to generate a set of cross hairs that overlay a digital image of the driver's visual field. This allowed for the identification of fixation points, glance sequencing and duration. The data collected from the eye tracker were analysed frame by frame to determine where drivers were glancing after putting the car into reverse and after the sensor warning sounded.

Quantification of camera use

Drivers' use of the rear-view camera was defined in terms of glances. Glance location was classified into seven categories: mirrors (right, left, rear); windows (right, left, rear) and rear-view camera display. The first five glances after the participant put the car into reverse at position 1 (figure 1) were examined for all 16 trials. In addition, the first three glances after the alarm was triggered were recorded. If drivers glanced down at the rear-view camera display, it was categorised as 'looking at the camera'.

RESULTS

Camera analyses

At the start of the short-backing sensor–camera trials, it is of interest whether the driver looks at the camera soon after putting the car into reverse Eight drivers looked at the camera on the first

Table 2 Relationship between looking at the camera and crashing

	Do not crash	Crash
Look at camera	7	1
Do not look at camera	1	26

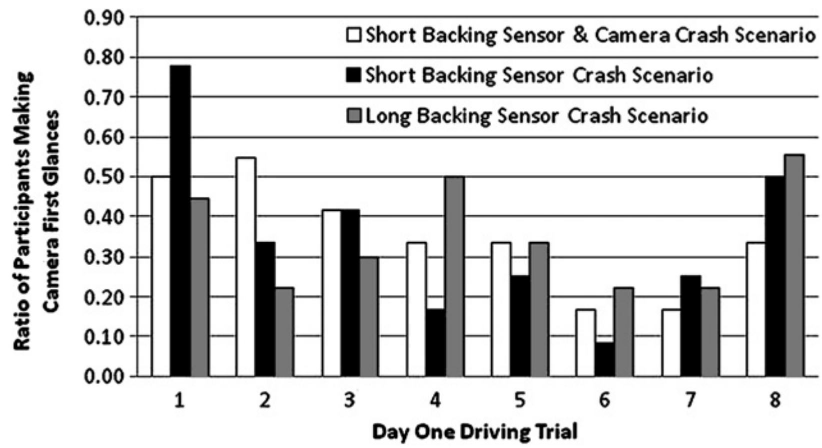

Figure 4 Rear-view camera first glances as a function of experimental trial and condition.

or second glance, whereas 27 drivers did not look at the camera on the first or second glance (one participant could not be calibrated). Three questions relating to the efficacy of camera systems remain.

First, it needs to be determined whether drivers who initially looked at the camera in the short-backing camera—sensor trials were any less likely to crash than drivers who did not look at the camera (see table 2). Although 87.5% of the drivers who looked at the camera did not crash, only 3.7% of the drivers who did not look at the camera initially did not crash. Fisher's exact test indicates that one can reject the hypothesis that there is no association between looking at the camera and crashing ($p<0.001$).

Second, was the number of drivers who failed to look at the camera a function of their failing to recognise the utility of the camera in backing or a function of being desensitised to its importance across trials. The number of participants initially looking at the camera on day 1 as they began the backing trial was analysed and is displayed in figure 4.

Figure 4 shows that the frequency with which drivers glanced at the camera first while backing out of a parking space generally decreases over time until the point at which a crash scenario occurs (trial 7). This is a decrease of almost 88% in the case of the short-backing sensor condition. To determine whether there was an overall decrease in the frequency with which individuals looked initially at the camera, we compared these frequencies on trial 1 (57.4%) and trial 6 (15.7%) across all three backing conditions (the percentages are given in figure 5). An individual was given a one if he or she looked initially at the camera and a zero otherwise. An analysis of the difference scores (trial 1 score—trial 6 score) indicated that the mean was significantly different from zero ([$t(23) = 2.515$, $p < 0.025$)], suggesting the percentage of initial glances decreases across trials.

Third, were drivers exposed to the crash scenario on day 1 trial 7 more likely to use the camera on trial 8? If camera usage increases after a crash scenario, it would suggest drivers recognised the potential utility of the camera. Drivers would either have heard the alarm (assuming they continued backing) or seen the crash decoy in the rear-view camera. The analysis indicated that drivers in trial 8 were more likely to glance at the camera system than during trial 7 ($t(32) = 2.101$, $p < 0.05$). It was also considered if after hearing a warning for the first time, drivers were less likely to look at the camera on the eighth trial than they were on the first trial. An analysis of the difference scores indicated that such was not the case ($t(25) = 0.704$).

Sensor analyses

It was important to determine whether drivers alerted by the sensors to the presence of an object behind the vehicle look at the camera display. The results are displayed in table 3. As shown, approximately half of the participants were observed glancing at the camera after hearing the sensor (glancing refers to the first or second glance after the audible warning directed at the camera display). The resulting hypothesis was that this frequency was significantly larger than might be expected by chance alone. Given that glances were aggregated into seven categories, if drivers are equally likely to glance at any one of the seven areas, the probability of glancing at the rear-view camera by chance alone is equal to 0.265 ($1/7 + 1/7 + 1/49$). The hypothesis that the proportion glancing at the camera was different from chance was significant for two of the three backing conditions (combined camera—sensor, $z = 3.604$, $p < 0.001$; short-backing sensor only, $z = 2.440$, $p < 0.02$; long-backing sensor only, $z = 1.540$).

Control analyses

Control subjects were required to perform the same parking manoeuvres the experimental subjects were, but without a parking aid system. To verify that the experimenter did not alert the subjects to the presence of the obstacle placed behind

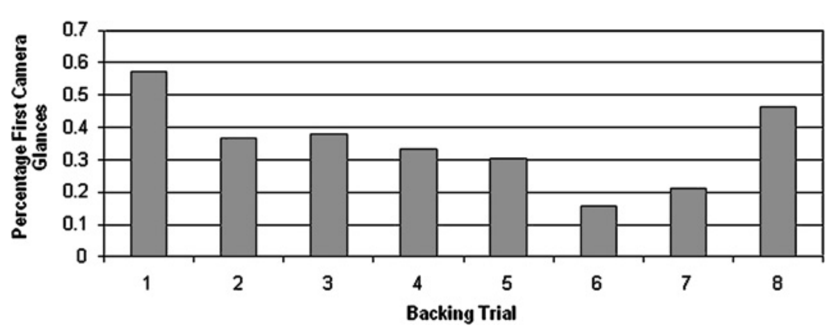

Figure 5 Rear-view camera first glances as a function of experimental trial.

Table 3 Glances at camera after sensor triggered

Crash scenario	Glanced at camera	Did not glance	Did not transpire
Short-backing camera—sensor	15	11	9
Short-backing sensor	16	20	9
Long-backing sensor	12	19	4

the vehicle, the control participants also had a crash decoy placed behind the vehicle. If the experimenters were doing something to alert the experimental participants to the presence of the decoy, the control participants would be equally alerted. None of the 10 control participants avoided a crash in the 30 situations to which they were exposed to the decoy, whereas eight of the 35 experimental participants avoided a crash.

DISCUSSION

This study demonstrated that in rear-view camera-equipped vehicles, 20% of drivers looked at the camera before backing, and of those 88% did not crash. Of those who did not look at the camera before backing, 46% looked at the camera after the sensor warned the driver of a potential backing crash.

This study indicates that drivers not only attend to an audible warning, but also will look at a camera if it is available after the audible warning is sounded. Evidence also suggested that when used correctly (drivers glance at the system at the appropriate time) rear-view cameras can mitigate backing crashes, particularly when paired with an appropriate audible warning system.

Earlier studies of rear-view camera systems demonstrated only a modest efficacy in mitigating backing crashes. Previously, it was unclear whether the large number of participants who crashed did not look at the rear-view camera or looked at the rear-view camera, but did not see an obstacle. This research indicated that drivers who looked at the rear-view camera were very likely to avoid a crash while those who crashed did not use the rear-view camera. The prevalence of backing crashes with rear-view camera systems is a function of drivers not utilising the camera system. In this study, drivers looking at the rear-view camera display decreased from 54.7% on trial one to 15.7% on trial six. These results suggest that if drivers could be trained to use rear-view camera systems as a matter of habit, a large decrease in backing collisions would result.

Previous studies had indicated that drivers behaved in ways that suggested that they were alerted to a potential hazard when the audible warning sounded, but the reaction was too late to avoid a crash. In our second aim, we asked whether sensor systems could improve driver use of the rear-view camera. We found that the proportion of drivers looking at the rear-view camera immediately after the beep was significantly greater than one would have expected by chance alone. This suggests that if an obstacle had actually been behind the driver in the sensor-only trials and visible in the rear-view camera system the driver would have applied the brakes. Rear-view camera systems could thus prove to be a useful complement to sensor systems.

What is already known on this subject

- Rear-view backing cameras alone have not produced marked reductions in backing crashes in field experiments.
- Sensor systems alone do not mitigate backing crashes; however, they do affect driver awareness of a pending backing crash.

What this study adds

- This study expands on the understanding of why cameras have not produced a marked improvement in backing collisions. It is not that drivers look at the rear-view camera display but do not recognize recognise potential hazards, because almost all drivers who look are not involved in a backing crash. Remarkably, they rarely look at the rear-view camera display.
- This study indicates that drivers not only attend to an audible warning, but also will look at a camera if it is available.
- This study provides evidence suggesting that when used appropriately (drivers glance at the system at the appropriate time) backing cameras can successfully mitigate the occurrence of backing crashes, particularly when paired with an appropriate audible warning system.

LIMITATIONS

This study was concerned with how drivers interact with rear-view backing camera systems. The results were not intended to design better rear-view backing camera systems or a driver training programme for the system, both of which are critical to the long-term success of backing crash prevention. The subject demographics prevented any meaningful statistical analysis across gender or age.

NEXT STEPS AND PREVENTION IMPLICATIONS

This study provided evidence to support several research initiatives. Knowing that backing crashes can be reduced if the rear-view camera display is utilised yields the question, 'what driver education strategy will result in the optimal utilisation of the rear-view camera by drivers?' Research should also be conducted on improved integration of the audible warning and rear-view camera. This work should concentrate on measuring naturalistic backing speeds and driver reaction times to establish guidelines for the optimal sensor system footprint.

In summary, the results of this research suggest that a rear-view camera system that was utilised more frequently by drivers would significantly reduce back-over collisions.

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Competing interests None.

Ethics approval This study was conducted with the approval of the UMass Amherst Internal Review Board.

Contributors All authors contributed substantially to all phases of the research including the development of experimental methodology, data analysis, conducting of experimental trials and documentation of results.

Provenance and peer review Not commissioned; externally peer reviewed.

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