Effects of a Rearview Camera, Parking Sensor System, and the Technologies Combined on Preventing a Collision with an Unexpected Stationary or Moving Object

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ABSTRACT

An estimated 18,000 people are injured and 292 are killed every year in backover crashes. Rearview cameras and parking sensor systems may help to prevent these crashes, but only one study has compared their independent and combined effectiveness. The current study measured the effectiveness of a parking sensor system, a rearview camera, and a parking sensor system combined with a rearview camera at preventing a collision with a stationary or moving child-size obstacle in the path of a reversing vehicle. Overall, fewer collisions were observed among drivers with cameras (camera and camera-plus-sensor conditions) compared with drivers without cameras (no-technology and sensor conditions); this difference approached statistical significance. Few collisions with the moving object were observed. Significantly more collisions were observed in the stationary object condition than in the moving object condition. Drivers with the rearview camera alone had the lowest rate of collisions with the stationary object (56%). The parking sensor alone prevented only one crash with the stationary object. A parking sensor system combined with a rearview camera prevented more crashes with a stationary object than a parking sensor system alone, but not as many as the rearview camera alone. The rearview camera did not prevent crashes with the stationary object in every situation. Shade from a tree hampered detection, and some participants hit the stationary object even when they looked at the camera display. These and other situational and environmental factors may affect drivers' use of rearview cameras and their real-world safety benefits.

INTRODUCTION

Backing crashes not only cause considerable property damage but also can result in severe or fatal injury to pedestrians. An estimated 18,000 people are injured and 292 are killed every year in backover crashes; many of the victims are children younger than 5 years (Austin, 2008). In 2007, the U.S. Congress passed the Cameron Gulbransen Kids Transportation Safety Act, requiring the National Highway Traffic Safety Administration (NHTSA) to revise Federal Motor Vehicle Safety Standard 111 to expand the required vehicle field of view so that drivers can see areas immediately behind the vehicle (Cameron Gulbransen Kids Transportation Safety Act of 2007). The rulemaking has not been finalized, but automobile manufacturers already are equipping many vehicle models with ultrasonic sensors and rearview cameras to provide drivers with information about possible obstructions in the backing path.

Cameras and sensors dramatically improve the detectability and visibility of objects behind the vehicle. Kidd and Brethwaite (2013) measured blind zones in a 20-foot-wide by 70-foot-long area behind 21 2010-13 model year vehicles. The blind zone was defined as the area where a 12-15-, 30-36-, or 60-72-month-old child-size object was not visible to an average-size male driver using mirrors, looking through the driver side window, or looking through the rear window. On average, parking sensors reduced the blind zones for the different child-size objects by 12-48 percent, and rearview cameras reduced the blind zones by 72-99 percent.

Cameras and sensors can improve visibility behind the vehicle and help drivers detect objects, but they will prevent backovers only if drivers use the systems and respond appropriately to the information provided by the systems. A handful of controlled experiments have measured the effectiveness of parking sensors and rearview cameras at preventing collisions with small objects behind the vehicle. The studies typically have had participants' complete unrelated tasks to deceive participants about the true purpose of the study and reduce their expectations of a potential collision when backing. At some point, an object is placed behind the study vehicle in an area that is visible only with a rearview camera display or detectable by a sensor system. Whether or not the driver collides with the object in this "surprise event" is the measure of interest.

Llaneras, Green, Kiefer, Chundrlik, Altan, and Singer (2005) examined parking sensor systems to assess the relative effectiveness of four different types of audible warnings at preventing a backover. Across the four warning conditions, only 13 percent of participants avoided a toy coupe that moved behind the study vehicle as participants backed down a 150-foot path. One-third of participants had no discernible reaction to the warning and 44 percent applied the brakes. The majority of drivers who braked did not decelerate more than 0.1 g, suggesting that the brake application was precautionary and not intended to stop the vehicle. Participants were distracted by a secondary task during the backing maneuver, so these results may underestimate the benefits of a parking sensor system for fully attentive drivers.

Audible warnings from a parking sensor system may not evoke an avoidance response because warnings alone do not provide drivers with visual confirmation of a potential collision threat. A rearview camera provides visual information about the area behind the vehicle, and research suggests it is a more effective countermeasure for preventing backovers than a parking sensor system. Mazzae (2013) summarized the results from an unpublished study conducted by NHTSA in 2009 (E. Mazzae, personal communication, December 4, 2013) that compared drivers' reactions to a surprise object when using a parking sensor system, a rearview camera system with a 3.5-inch in-mirror display, a camera system with a 2.4-inch in-mirror display, two different types of rear convex mirrors, and no visibility aids. Every participant without a visibility aid and every participant with a rear convex mirror hit an object that popped up behind the vehicle while reversing. Ninety-three percent of participants with the parking sensor system hit the object, and half of the participants with a rearview camera system hit the object. These findings suggest a rearview camera is a superior backover countermeasure to a parking sensor system.

A subsequent study conducted by Mazzae (2010) also compared the effectiveness of different rearview camera systems and a parking sensor system at preventing backovers. In this study, a 35-inch tall image of a toddler popped up 14 feet behind participants' vehicles as they were reversing out of a garage near a child development center. Three-quarters of participants with the parking sensor system and 52-74 percent of participants with one of the three different rearview cameras hit the object. All of the technologies significantly reduced the number of collisions compared with participants who did not have

technology. Although fewer participants with cameras hit the object compared with participants with the sensor system, the differences were not statistically significant.

A rearview camera will only prevent a backover collision if the driver looks at the camera display at the appropriate time while backing. In the case of an emerging threat, like a child running behind the vehicle, the driver may need to look at the camera display multiple times while reversing to detect and avoid it. A common location for a rearview camera display is the center console. This is not a typical area that is scanned while backing and may require extended practice before it is inspected regularly while backing and used effectively.

One way to increase the use of a rearview camera may be to place the display in an area where drivers normally look while backing up, like the rearview mirror. Heckman, Kim, Lin, Rauschenberger, Young, and Lange (2012) examined the use of a 3.3-inch in-mirror, 4.1-inch center console, and 7.9-inch center console rearview camera display by drivers in six different backing maneuvers. The percentage of the time that drivers looked at the in-mirror display while backing was significantly greater than the time participants looked at either of the center console displays. A surprise event occurred during the last parking maneuver, in which participants had to avoid a 31-inch tall stationary object or a moving 32-inch tall object (Kim, Rauschenberger, Heckman, Young, & Lange, 2012). Participants with any of the rearview camera systems had significantly fewer collisions than participants who did not have a rearview camera. Participants with an in-mirror rearview camera system braked significantly faster after the object appeared in the camera display compared with participants using one of the two center console displays.

Audible warnings from a parking sensor system may increase the use and effectiveness of a rearview camera by directing the driver's attention to the camera display when the audible warning sounds (e.g., Hurwitz, Pradhan, Fisher, et al., 2010). Mazzae, Barickman, Baldwin, and Ranney (2008) compared the effectiveness of a rearview camera system alone and in combination with a parking sensor system at preventing a backover collision among Honda Odyssey owners. Drivers were continuously monitored and videotaped during their daily driving for 4 weeks. At the end of the study, participants pulled into a garage at the end of a test drive so that data could be downloaded from the vehicle. A 36-inch tall image of a toddler popped up 14 feet behind the vehicle when participants were backing out of the garage. Every participant without a camera or parking sensor system collided with the object, 58 percent of participants with a camera collided with it, and 85 percent of participants with a camera and parking sensor system collided with it.

Mazzae et al.'s (2008) findings are surprising considering that rearview cameras and parking sensor systems have been shown to prevent backovers independent of each other, although the magnitude of their independent effects differs. Combining the two systems would be expected to have a synergistic result, but the authors' findings suggest the opposite. Mazzae et al. examined participants' glance patterns during the surprise event and found that twice as many participants with a camera and sensor system as the number of participants with only a camera never looked at the camera display during the surprise event. Perhaps participants with a camera and parking sensor system relied on the

audible warnings to cue their use of the camera display instead of looking at the display regularly while backing. Parking sensor systems have limited range and may not reliably detect objects behind the vehicle (Mazzae & Garrott 2006), so this strategy is probably a suboptimal way of using a rearview camera. Additionally, many owners of parking sensor systems appear to have an inaccurate understanding of the system capabilities. Results from a telephone survey of early adopters of parking sensor systems and rearview cameras indicated the majority of drivers with parking sensor systems thought their system would detect objects in situations where it would not, like backing up at 10 mph and a pedestrian standing 10 feet behind the rear bumper (Jenness, Lerner, Mazor, Osberg, & Tefft, 2007).

Based on the research reviewed above, a rearview camera appears to be a more effective countermeasure for preventing backover crashes than either a parking sensor system or these two technologies combined. However, none of these studies tested the independent and combined effects of a rearview camera system and a parking sensor system in a single experiment. NHTSA has conducted four studies examining various countermeasures designed to increase rear visibility and prevent backovers using a single paradigm where a child-size object pops up in the backing path as the participant backs out of a garage, including three of the studies discussed above. Across the four studies, 30-74 percent of participants with some type of rearview camera crashed, 75-93 percent of participants with a parking sensor system crashed, and 85 percent of participants with a camera and sensor system crashed (see Tables 1 and 17 in Mazzae (2013) for a summary). However, the rear visibility characteristics of the study vehicle, functionality of the cameras and parking sensor systems, characteristics of the study samples, and object heights were different across the four studies and limit the strength of the conclusions about the relative effectiveness of all the countermeasures examined.

To date, only one study has examined a parking sensor system, a rearview camera, and the combination of these technologies (McLaughlin, Hankey, Green, and Kiefer, 2003). In this study, a pylon was placed 3 feet behind the participant's vehicle after the participant completed five parking tasks without technology, with a sensor system, with a rearview camera, and with a camera and sensor system. Every participant who did not have technology and every participant with a sensor system collided with the pylon. Sixty-seven percent of participants with a camera and 67 percent of participants with a camera and sensor system hit the pylon. However, McLaughlin et al. did not perform statistical comparisons between the four conditions.

The relative effectiveness of a parking sensor system, rearview camera, and both technologies combined at preventing backovers merits further investigation to help regulators and automobile manufacturers identify the most effective method of preventing backovers. In particular, it is critical to determine if combining a rearview camera with a parking sensor system is a less effective solution than a rearview cameras alone and to identify the reasons why combining these two systems would not be a more effective countermeasure than a camera alone.

The objective of the current study was to compare the effectiveness of having no technology, a parking sensor system, a rearview camera, or a camera and sensor system in preventing a collision with

a child-size object. The object was either stationary behind a reversing vehicle or moved into its path. Based on prior research, a rearview camera system alone and when combined with a sensor system was expected to reduce the likelihood of a collision with the moving or stationary object compared with no technology or the sensor system alone. The parking sensor system was not expected to significantly decrease the likelihood of a collision with the moving or stationary object compared with having no technology. Finally, a rearview camera alone was expected to prevent more collisions than when it was paired with a parking sensor system.

METHOD

Study vehicle and closed course

The study vehicle was a 2013 Chevrolet Equinox LTZ with safety and navigation packages. It was equipped with a rearview camera and an ultrasonic rear parking sensor system. The camera display was 7 inches wide diagonally and located in the center console. The camera display appeared in the center console approximately 1 second after the vehicle's transmission was placed in reverse. Guidelines designed to help the driver align the vehicle were not displayed. According to the vehicle owner's manual, the Equinox's rear parking sensor system operates at speeds less than 5 mph and detects objects up to 8 feet behind the vehicle. An audible warning (beep) was given when the object was detected, and the frequency of beeps increased as the vehicle moved closer to the object. The audible warning became a steady tone when the object was less than 1 foot away. A visual symbol in the camera display supplemented the auditory warning. The visual symbol was a yellow triangle with an exclamation mark inside, and it increased in size and changed from yellow to red as the vehicle moved closer to an object.

The study was conducted in an outdoor public parking lot at the StubHub Center in Carson, California. The parking lot was closed to vehicular traffic during testing. Testing took place only when a major event was not taking place at the StubHub Center and when there was no precipitation.

Study design

The study was a between-subjects design with two independent variables, backing technology and object type. Participants were assigned to one of four backing technology conditions (no-technology, rear parking sensor, rearview camera, camera-plus-sensor) based on the backing technology in their current vehicle or past experience with a sensor system. The no-technology condition served as a baseline comparison for the other three backing technology conditions; in this condition, the study vehicle's camera display was not visible and the parking sensor system was not active. The audible warning from the parking sensor system was active in the sensor condition, but the camera display was covered so the visual warning from the parking sensor system and the camera display were not visible. In the camera condition, the camera display was visible but the sensor system was not active. In the camera-plus-sensor condition, the sensor system was active and the camera display was visible, including the display of the visual symbol provided by the parking sensor system. A surprise backing event occurred at the

end of the study where an object was positioned in the path of the study vehicle as the participant reversed out of a parking stall. The object type was manipulated and was either a stationary object or moving object. Equal numbers of participants in each backing technology condition were randomly assigned to the stationary object condition or moving object condition. Participant gender was balanced within the eight possible combinations of backing technology and object type conditions. The surprise event is described in more detail below.

Participants

Participants were recruited from the Dynamic Research, Inc (DRI) participant database. The database consists of approximately 1,500 people who have participated in past DRI research studies. Individuals in the database were contacted by email or phone to determine interest and eligibility. To be eligible, participants had to be 18-60 years old and currently licensed drivers who had primarily driven a sport utility vehicle (SUV) for the past 6 months, drove at least 7,000 miles each year, and felt comfortable using a mobile phone and texting (not necessarily while driving). Interested individuals were then subjected to additional screening to determine their familiarity with rearview cameras and parking sensor systems. To be eligible for the experimental condition using a rearview camera, participants were required to have a center console rearview camera display in their SUV. To be eligible for the experimental condition using the rear review camera and sensor system, participants' SUVs had to be equipped with a center console rearview camera display and a rear parking sensor system. Due to difficulties with recruiting participants who currently drive an SUV equipped with just a parking sensor system, potential participants were eligible for the sensor condition if they did not currently drive an SUV with a rearview camera and had experience driving any vehicle with a parking sensor system. Approximately 1 out of every 15 screened participants met these eligibility requirements.

A total of 117 drivers participated in this study. Five participants were removed because of an invalid surprise event trial, and one participant was removed because he received the wrong experimental condition. The final sample consisted of 111 drivers (55 men, 56 women). Sixteen participants were in the no-technology condition, 32 in the sensor condition, 32 in the camera condition, and 31 in the camera-plus-sensors condition. Participants were 18-58 years old, with a mean of 36 years (*SD* = 11).

Protocol

A ruse was used to disguise the true purpose of the study. After arriving at the study location, participants provided informed consent and completed a questionnaire about their current health and driving history. During the intake process, participants were told that the purpose of the study was to evaluate an in-vehicle infotainment system.

Next, participants were seated in the vehicle and instructed to adjust the seat, steering wheel, and mirror positions to their liking and to buckle the seatbelt and use it whenever the vehicle was in motion. A research assistant was seated in the right front passenger seat during the entire study.

Participants drove a single lap around the perimeter of the parking lot (about one-third mile) to become comfortable with the vehicle. Participants were instructed to travel 10-15 miles per hour and obey the rules of the road. After the drive, participants were instructed to adjust the seat, steering wheel, and mirror positions a second time if needed.

The study was comprised of four parts. First, participants completed a series of parking maneuvers in the parking lot five times (see Figure 1). This gave participants the opportunity to become comfortable with maneuvering the vehicle in different parking situations and to become familiar with the vehicle's backing technology (if available). Participants completed the following parking maneuvers in order: (1) pulling forward into a parking stall, (2) backing straight out of a parking stall, (3) parallel parking between two columns of cones set approximately 24 feet apart, (4) backing toward a 32-gallon plastic trash container centered at the rear of the parking stall, and (5) reversing into a parking stall approximately 50 feet behind the vehicle. The parking stalls in the parking lot were approximately 8 feet wide and 18 feet deep. Participants placed the vehicle in park after finishing each maneuver.

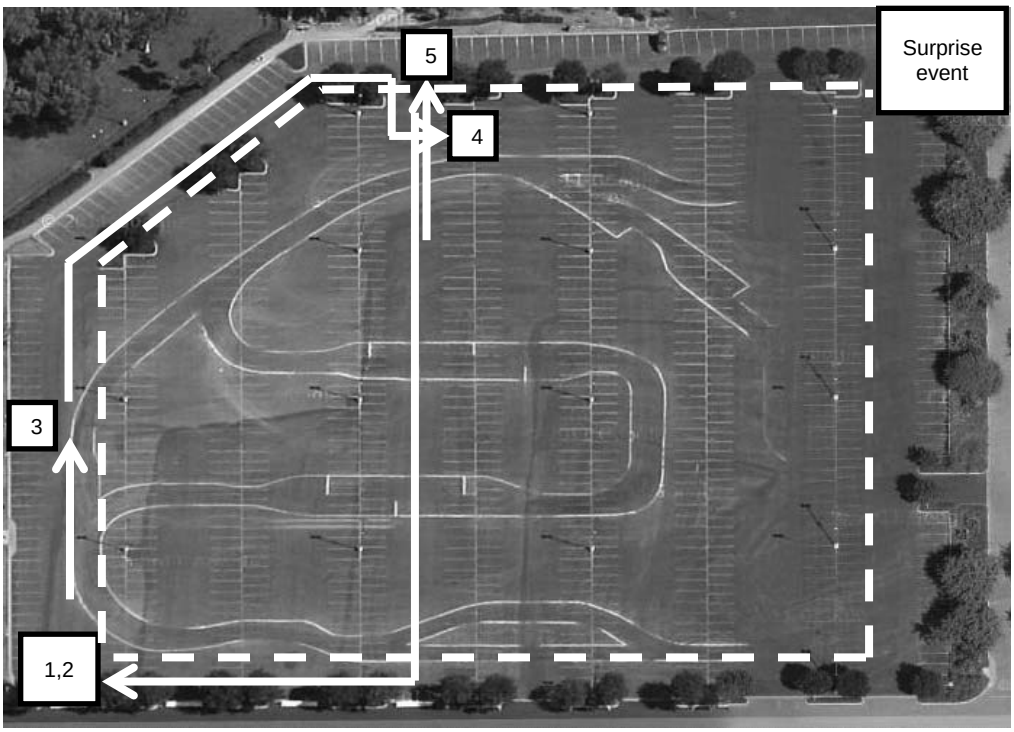

Figure 1. An overhead view of the parking lot. The parking maneuvers are numbered in order according to the description in the text and the course path is indicated by the solid white line. The course around the perimeter of the parking lot (dashed white line) and the location of surprise event also are marked.

Next, participants drove around the perimeter of the parking lot while performing the following four secondary tasks: manually tuning the radio, changing the settings on the heating and air conditioning system, locating a CD in a holder on the sun visor and playing a specific track, and reading route

information displayed in the navigation system display. Before beginning the drive, participants were given step-by-step instructions while the vehicle was stationary on how the tasks were to be performed and three to five practice trials depending on the participant's comfort level with the tasks. Participants then performed five trials of the tasks while driving continuously around the perimeter of the parking lot. Details for each task trial were provided on index cards placed on the steering wheel. Participants were instructed to drive 15 mph and to say "done" after completing each trial.

After completing all the secondary tasks while driving, participants parked the vehicle in a parking stall and performed the following three secondary tasks using the in-vehicle infotainment system: manual radio tuning, entering a destination into the on-board navigation system, and selecting a song from a playlist on a portable mp3 player connected to the infotainment system. Index cards with details for each trial were placed on the steering wheel. Participants performed these tasks while wearing occlusion goggles that obscured the view of the infotainment system for 1.5 seconds every 1.5 seconds as specified by the Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices (Office of the Federal Register, 2012). Participants were given step-by-step instructions on how to perform each task followed by three to five practice trials, and then five trials of the tasks were performed. Afterwards, participants were instructed to reverse the vehicle out of the parking stall and return to where they had parked their personal vehicle.

A surprise event occurred when participants reversed out of the parking stall. Either a stationary object or a moving object was deployed into the vehicle's backing path. The object was a 3-inch thick foam cut out of a child-size crash test dummy mounted on a remote-controlled mobile platform (Figure 2). The total height was 30.2 inches, which corresponds to the 50th percentile standing height of a 12-15-month-old child (Tilley, 2002).

Figure 2. Object in the surprise event

The layout of the surprise event is shown in Figure 3. The stationary object was placed 15 feet behind the end of the parking stall at the centerline of the study vehicle while the participant was interacting with the infotainment system when parked. The moving object started 15 feet behind the end of the parking stall and 10 feet laterally from the vehicle's centerline toward the driver's side of the vehicle. The starting position of the moving object was blocked from the participant's view by a cargo van or large pickup used by experimenters to transport equipment and parked in the first parking stall in the row perpendicular to the parking stall where the study vehicle was parked. The van's front bumper was placed about 3 feet behind the front-edge of the curb at the edge of its parking stall. The moving object was set in motion at approximately 2 mph by an experimenter via remote control when the rear of the study vehicle reached the end of the parking stall. The object came to rest at approximately the centerline of the study vehicle. The moving object emerged from behind the experimenter's vehicle approximately 1 second after it started moving and reached the intended stopping point behind the centerline of the vehicle in 3.4 seconds.

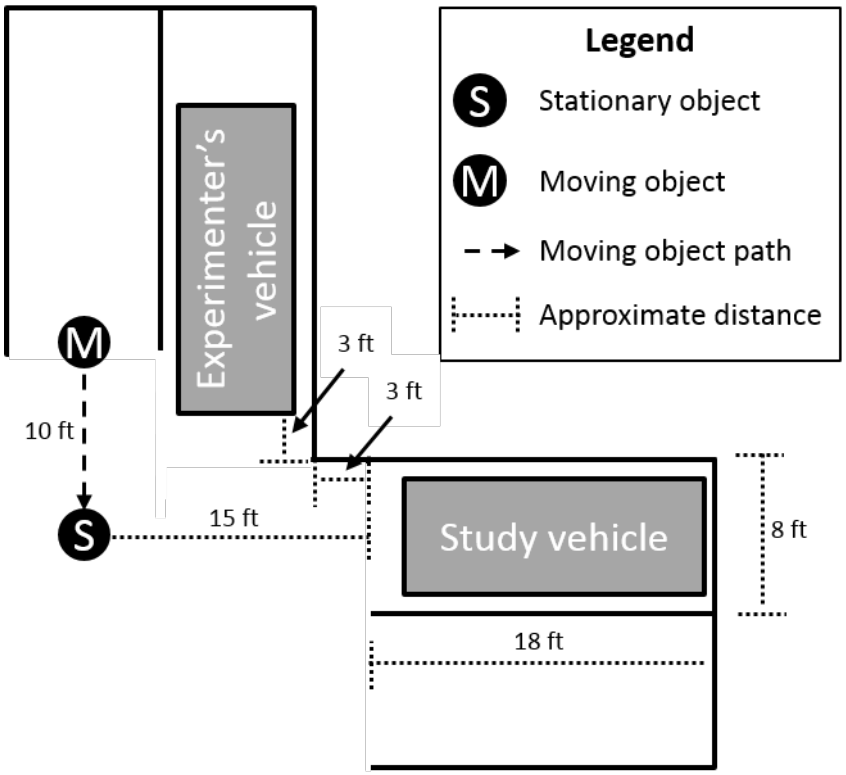

Figure 3. Surprise event layout

The distance from the study vehicle's rear bumper to the object depended on how far participants pulled into the parking stall. If the study vehicle's front tires were flush with the curb at the front of the parking stall, then the object would have been about 19 feet from the rear bumper of the study vehicle. A prior study measuring rear visibility in 21 2010-13 model year vehicles reported that a 30.2-inch tall child-size object was not directly visible to a 50th percentile male driver up to 34 feet behind the rear bumper of a 2013 Chevrolet Equinox (Kidd & Brethwaite, 2013). Thus, both the stationary object and the moving object, once behind the vehicle, were only visible in the rearview camera display and could be detected by the parking sensor system once the vehicle's rear bumper was 8 feet away.

Participants were instructed to place the study vehicle in park after they had struck the stationary or moving object or avoided it by coming to a complete stop. Participants were debriefed about the true purpose of the study after the surprise event. Then final stopping distance in trials where the object was avoided and sight distance in all trials was measured. Finally, participants in the sensor, camera, and camera-plus-sensor conditions completed the Van Der Laan Acceptance scale (Van der Laan, Heino, & De Waard, 1997) to assess perceived utility and satisfaction of the camera and/or sensor system, and made subjective judgments about rear visibility, detection range of the sensor system, and/or visibility range of rearview camera. These data are not reported in this paper. The study protocol was approved by Dynamic Research, Inc.'s Institutional Review Board.

Dependent measures

The primary dependent measure was collision or no collision with the stationary or moving object. Final stopping distance was recorded in trials where the object was avoided as the distance from the study vehicle's rear bumper to the object. Sight distance was measured for each participant and was the distance from the study vehicle's rear bumper to the point where the entire head of the object was visible in the rearview mirror.

Three video cameras were unobtrusively mounted in the interior of the vehicle to capture the forward road scene, instrument cluster and center console, and the driver's face. Eye glances to various locations around the vehicle during the surprise event were manually coded from the video recordings. Eye glance coding began when the vehicle was shifted into reverse and ended when the vehicle collided with the object or came to a complete stop. The frequency of glances to the following areas of interest were coded: rearview camera display, rearview mirror, driver side window and mirror, passenger side window and mirror, over the left shoulder, over the right shoulder, and forward roadway. The duration of a single glance was defined as the time from the moment the direction of gaze moved towards an area of interest to the moment it moved away per SAE J2396 (SAE International, 2000). A fourth video camera was mounted on the study vehicle's rear bumper to capture the rearward path and verify collision or avoidance outcomes.

The first responses to the audible warning from the parking sensor system were manually coded for participants in the sensor and camera-plus-sensor conditions. Two independent coders recorded if the participant's initial response after the audible warning was to apply the brakes, glance to a new location, or apply the brakes and glance to a new location. The coders also recorded instances where the participant did not exhibit any discernible response after the warning. A third coder was consulted to resolve any disagreements between the two coders.

Data Analysis

Logistic regression modeling was used to determine if the different backing technologies affected the outcome of the surprise event (no collision, collision). Participant gender, participant age, object type (stationary or moving), sensor presence (none, present), camera presence (none, present), and the various two- and three-way interactions between object type, sensor presence, and camera presence were used to predict the log odds of a collision in the surprise event. Participant age was rescaled to be centered around the minimum age of the study sample (18 years).

Chi-square tests were computed to assess the statistical significance of differences in the proportions of participants in the camera condition and participants in the camera-plus-sensor condition who used the camera in different circumstances during the surprise event. This statistical approach was also used to examine participants' first response to the audible warning from the sensor system during the surprise event for participants in the sensor and camera-plus-sensor conditions. A Fisher's exact test

was performed instead of chi-square test when the expected frequency in any given cell was less than five.

The percentages of all eye glances made to the forward roadway, rearview mirror, driver side window and mirror, over the left shoulder, over the right shoulder, to the passenger side window and mirror, camera display, or other locations during the surprise event were computed and then combined into four locations around the vehicle based on the area where the field of view provided information. The forward area included forward glances; the driver side area included glances to the driver side window and mirror and glances over the left shoulder; the rearward area included glances over the right shoulder, to the rearview mirror, and to the camera display; and the passenger side area included glances to the passenger side window and mirror. A multivariate analysis of variance (MANOVA) was used to examine if the percentages of all glances used to see forward of the vehicle, to the driver side, behind the vehicle, and to the passenger side varied as a function of object type, sensor presence, camera presence, and the interactions between these variables. Follow-up analysis of variances (ANOVAs) were performed for each location to further examine significant effects found in the MANOVA. A separate independent samples *t*-test was performed to compare the percentage of all glances to the camera display made by participants in the camera condition with participants in the camera-plus-sensor condition.

Partial eta squared (η_p^2) was calculated as the measure of effect size for each ANOVA. Partial eta squared values equal to 0.01, 0.06, and 0.14, correspond to small, medium, and large effect sizes, respectively (Cohen, 1988). Cohen's *d* was calculated as a measure of effect size for the independent samples *t*-test. Cohen's *d* values of 0.2, 0.5, and 0.8 correspond to small, medium, and large effect sizes, respectively. All statistical analyses were performed using SAS 9.3.

RESULTS

Backing crashes

In total, 54 of the 111 participants (48.6%) collided into either the stationary or moving object. Nine participants crashed in the no-technology condition (56.3%), 21 in the sensor condition (65.6%), 11 in the camera condition (34.4%), and 13 in the camera-plus-sensor condition (41.9%). A smaller percentage of men (43.6%) collided into the stationary or moving object compared with women (53.6%). The proportion of participants who collided with the stationary object (79%) was more than 4 times greater than the proportion who collided with the moving object (18%).

The percentage of participants in each backing technology condition who hit the stationary object or the moving object is shown in Figure 4. Every participant in the no-technology condition and all but one participant in the sensor condition hit the stationary object. Only three-quarters of participants in the camera-plus-sensor condition and slightly more than half of participants in the camera condition hit the stationary object. In contrast, fewer than 13 percent of participants in the no-technology condition, camera condition, and camera-plus-sensor condition hit the moving object while nearly 40 percent of participants in the sensor condition hit the moving object.

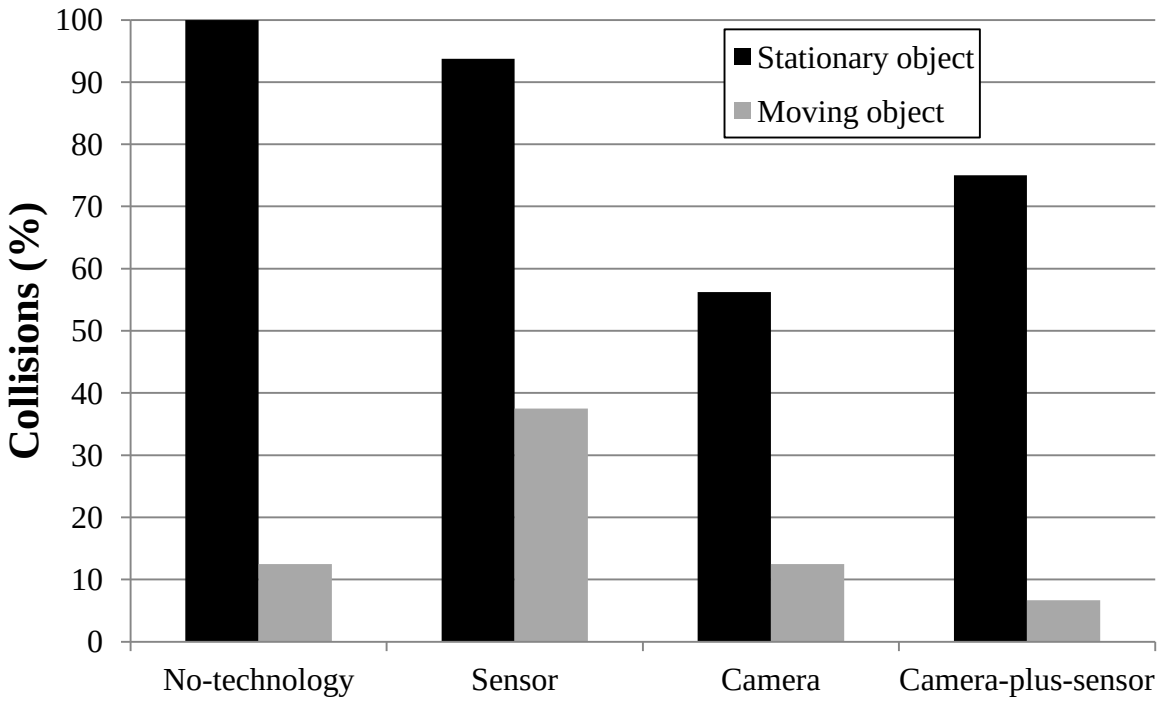

Figure 4. Percentage of participants in each backing technology condition who collided with the stationary object or moving object.

A series of logistic regressions were performed modeling the log odds of a collision with gender, participant age, object type, sensor presence, camera presence, and the various two- and three-way interactions between object type, camera presence, and sensor presence. The three-way interaction between object type, camera presence, and sensor presence was not statistically significant in the full model and dropped. In a subsequent model, the three two-way interactions between object type, camera presence, and sensor presence were not statistically significant. The camera presence by sensor presence interaction term was omitted from the final model, but the object type by camera presence and object type by sensor presence interaction terms were retained to account for the different patterns of collisions observed across the different technology conditions when the object was stationary and when it was moving (Figure 4).

The results of the final logistic regression modeling the log odds of a collision with gender, participant age, object type, sensor presence, camera presence, the interaction between object type and sensor presence, and the interaction between object type and camera presence are shown in Table 1. There was a significant main effect of object type; the odds of a collision with the stationary object were more than 61 times greater than the odds of a collision in the moving object condition when holding all other variables constant. The main effect of camera approached significance. The odds of a collision for participants with a camera (camera condition and camera-plus-sensor condition) were 73 percent less than the odds for participants without cameras (no-technology and sensor conditions) when holding all other variables constant. The main effects of gender, age, sensor presence, and the interactions between

object type and sensor presence and between object type and camera presence were not statistically significant.

Table 1. Logistic regression analysis of gender, age, object type, sensor presence, camera presence, object type by sensor presence, and object type by camera presence on the log odds of a collision in the surprise event.

Predictor	Parameter estimate	Standard error	Effect (%)	p-value
Constant	-1.88	0.92		
Gender (1 = female, 0 = male)	0.79	0.53	120.8	0.13
Age in years (centered at 18 years)	0.01	0.02	1.1	0.63
Object type (1 = stationary, 0 = moving)	4.14	1.32	6,152.7	< 0.01
Sensor presence (1 = present, 0 = none)	0.54	0.79	71.2	0.50
Camera presence (1 = present, 0 = none)	-1.30	0.77	-72.6	0.09
Object type x sensor presence	0.10	1.07	10.7	0.92
Object type x camera presence	-1.22	1.35	-70.5	0.37

Final stopping distance was examined in the 57 surprise event trials where the object was avoided. An object type (2) x sensor presence (2) x camera presence (2) three-way between-subjects ANOVA was performed on final stopping distance. There was a significant main effect of object type ($F(1,50)=9.8$, $p < 0.01$, $\eta_p^2 = 0.16$). On average, participants who avoided the moving object (M = 9.7 feet, SD = 3.6) stopped 78 percent further from it than participants who avoided the stationary object (M = 5.4 feet, SD = 5.3). No other main effects or interactions were found (all ps > 0.3).

Camera use and object avoidance

Seventy-five percent of participants in the camera condition and 67 percent of participants in the camera-plus-sensor condition looked at the camera display at least once during the surprise event. This difference was not statistically significant, $\chi(1)=0.1$, $p = 0.7$. Data from participants in the camera and camera-plus-sensor conditions were combined to examine camera use in the surprise event trials.

The stationary object was only visible in the camera display and could be seen as soon as the camera display appeared after the vehicle's transmission was placed in reverse. Twenty of the 32 participants (63%) with cameras looked at the camera display at least once during the surprise event with the stationary object; nine of these 20 participants (45%) collided with the object. All 12 participants who had a camera but did not look at the display collided with the object. The proportion of participants with cameras who did not look at the display and collided with the stationary object was significantly different from the proportion who looked at the camera at least once and collided with the stationary object (Fisher's exact test, $p < 0.01$).

An exploratory analysis was conducted to examine camera use by participants in the camera-plus-sensor condition during surprise event trials where the stationary object was detected by the parking sensor system and an audible warning was given. An audible warning was given in 15 of 16 trials. Nine of the 15 participants who received an audible warning did not look at the camera display before the warning; all nine hit the stationary object including two who looked at the camera display after the warning

was given. Six participants looked at the camera display at least once before the audible warning and three collided with the stationary object. The proportion of participants in the camera-plus-sensor condition who looked at the camera display at least once before hearing the audible warning and hit the stationary object was significantly different from the proportion who did not look at the display at least once before hearing the audible warning and had a collision (Fisher's exact test, $p < 0.05$).

Review of the video recordings from the surprise event trials with the stationary object revealed that the object was in a shadow cast by a nearby tree in some trials. Additional analyses were conducted to determine if the shade influenced the outcome of these surprise event trials. The stationary object was partially or completely in the shade in 11 of the 32 trials where participants with cameras encountered the stationary object. The proportion of participants in the camera condition where the stationary object was in the shade (37.5%) was not significantly different from the proportion of participants in the camera-plus-sensor condition (31.2%) ($\chi(1)=0.1$, $p = 0.7$). Of the 11 trials where the object was in the shade, 10 participants (90.9%) with cameras hit the stationary object. Seven of these participants glanced at the camera at least once, and six of these participants crashed (85.7%). Eleven participants (52.4%) hit the stationary object in the 21 trials where the object was not in the shade; 13 of these participants glanced at the camera display at least once while backing, and three of these participants crashed (23.1%). Among participants with cameras who looked at the camera display at least once during the surprise event, the proportion of trials where participants hit the stationary object was significantly greater when the object was in the shade compared with when it was not (Fisher's exact test, $p < 0.05$).

The moving object was briefly visible before it moved behind the vehicle in the driver side mirror, when looking through the driver window, or when glancing over the left shoulder. Once behind the vehicle, the moving object was only visible in the rearview camera display. Glances to the rearview camera display and driver mirror/window or over the left shoulder were examined to see if having a rearview camera influenced how the moving object was detected. Forty-five participants avoided the moving object. Sixteen of the 17 participants without cameras (no-technology and sensor conditions) detected the moving object by looking through the driver side window, at the side mirror, or over their left shoulder. One participant in the sensor condition stopped after hearing the audible warning even though she did not see the moving object. Twenty-eight participants with cameras avoided the moving object. Twenty-five (89%) looked at the camera display at least once, and 20 (80%) of them stopped the vehicle after looking at the display. The other five participants who looked at the camera display and the three participants with cameras who did not look at the camera display stopped the vehicle after seeing the moving object through the driver side window, in the side mirror, or over their left shoulder; this was a significantly smaller proportion than the proportion of participants without cameras who stopped the vehicle after seeing the moving object in one of these fields of view (Fisher's exact test, $p < 0.001$).

Responses to audible warning from the parking sensor system

The parking sensor system emitted an audible warning in 38 of 63 trials where the system was active. The proportion of trials with an audible warning was similar for participants in the sensor condition (63%) and participants in the camera-plus-sensor condition (58%). Participants saw the object and applied the brakes prior to the audible warning in five of the 38 trials where a warning was given. In one other trial, the parking sensor system detected cones lining the parking stall at the beginning of the surprise event before the moving object appeared, but an audible warning was not given later in the trial when the vehicle approached and then collided with the moving object. These six trials were excluded from the analyses below.

The distribution of participants in the sensor condition who did not immediately respond to the warning, applied the brakes, glanced to a new location, or applied the brakes and glanced to a new location was not significantly different from the distribution of participants in the camera-plus-sensor condition who initially responded to the warning in one of these four manners (Fisher's exact test, p = 0.1). Half of participants in either the sensor condition or camera-plus-sensor condition did not initially respond to the warning by braking and/or discernibly glancing to a new field of view. Of the 16 participants who initially responded to the warning, one applied the brakes (6.3%), six discernibly glanced to a new field of view (37.5%), and nine applied the brakes and glanced to a new field of view (56.3%). Seven of the 10 participants' who applied the brakes in response to the warning collided with the moving or stationary object.

In the 25 surprise event trials where the sensor system did not provide an audible warning, the participant saw the object and stopped the vehicle before the object was within the range of the parking sensor system in 20 trials (80%). The object was moving in 19 of these trials, and one participant in the camera-plus-sensor condition saw the stationary object in the camera and stopped the vehicle out of the range of the parking sensor system in the other trial. It was unclear why a warning was not provided in the remaining five trials.

Visual scanning during the surprise event

A MANOVA was conducted to examine if the percentage of glances directed to viewing four areas around the vehicle (forward, driver side, rearward, passenger side) varied as a function of object type, sensor presence, camera presence, and the interactions between these three variables. The MANOVA revealed a significant main effect camera presence (Wilk's λ=0.70, $F(4,100)=10.6$, $p<0.001$). The interaction between camera presence and sensor presence approached significance (Wilk's λ =0.92, $F(4,100)=2.2$, $p=0.08$). The main effect of object type and the other interaction terms were not statistically significant.

A series of sensor presence (2) x camera presence (2) between-subjects ANOVAs were performed to examine differences at each of the four locations around the vehicle. Alpha in the four follow-up ANOVAs was adjusted using Bonferroni's correction to control for Type I Error (adjusted alpha = 0.0125). The main effects of camera presence on the percentage of glances to areas on the driver side of

the vehicle ($F(1,107)=7.3$, $p < 0.01$, $\eta_p^2 = 0.06$) and the percentage of glances rearward that included those to the camera display ($F(1,107)=32.0$, $p < 0.001$, $\eta_p^2 = 0.23$) were statistically significant. Figure 5 shows the proportion of glances during the surprise event that were made to different areas around the vehicle for participants with cameras (camera and camera-plus-sensor conditions) and participants without cameras (no-technology and sensor conditions). On average, the proportion of glances directed to the driver side of the vehicle by participants with cameras was about 24 percent less than the proportion made by participants without cameras. The proportion of glances made by participants with cameras to areas behind the vehicle was 2.5 times greater than the proportion by participants without cameras. No significant differences were found in the proportion of glances directed to the front of the vehicle or to the passenger side of the vehicle as a function of sensor presence, camera presence, or the interaction between these variables.

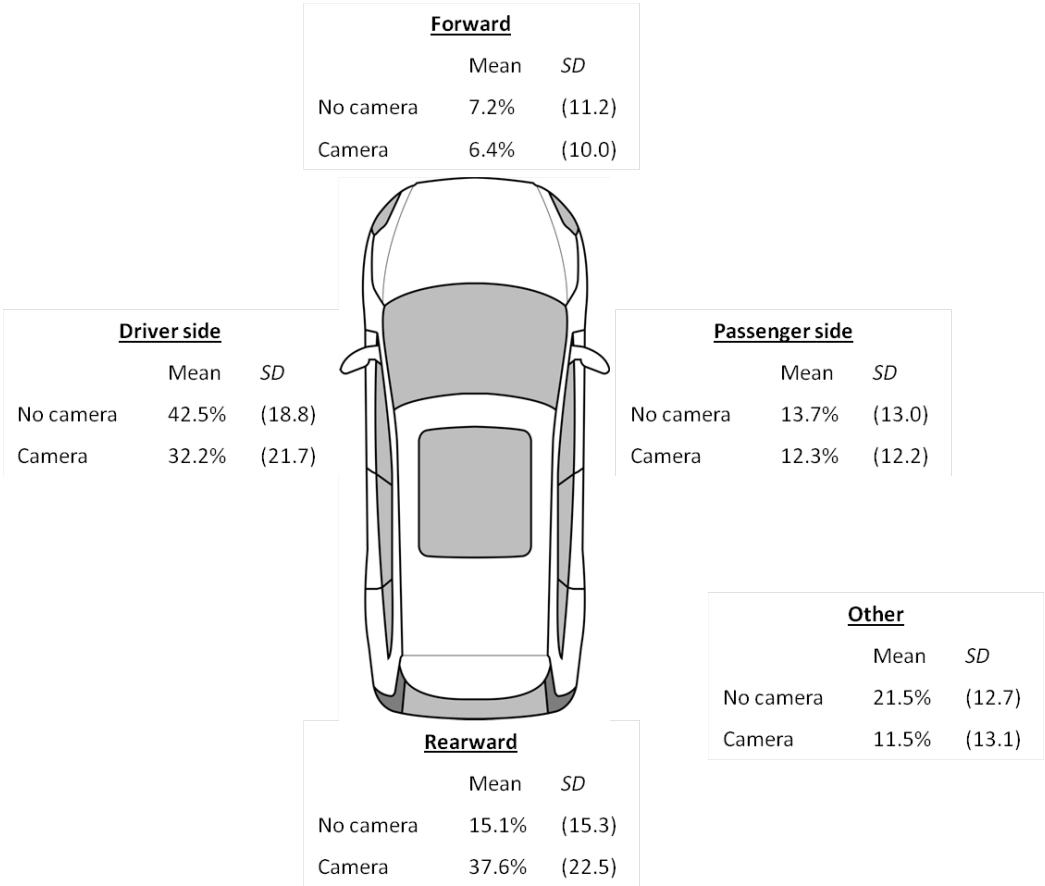

Figure 5. Percentage of all glances during the surprise event directed to areas forward, to the driver side, rearward, and to the passenger side of the vehicle by participants without cameras (no-technology and sensor conditions) and with cameras (camera and camera-plus-sensors conditions).

Finally, the proportion of all glances made to the camera display by participants in the camera condition and camera-plus-sensor condition were examined. A larger proportion of the glances made by participants in the camera condition (M = 25.5%, SD = 19.3) were to the camera display, compared with

the proportion of all glances made by participants in the camera-plus-sensor condition directed to the camera display (*M* = 19.8%, *SD* = 15.3). This difference was not statistically significant ($t(61)=1.3$, $p = 0.2$, Cohen's $d = 0.33$).

Demographic differences between groups

Variation in age, sight distance, and seated eye height between participants in each backing condition were examined, as these factors may influence visibility and the outcome of the surprise event trial. The mean and standard deviation of age, sight distance, and seated eye height for participants in each backing technology condition is shown in Table 2. A series of object type (2) x sensor presence (2) x camera presence (2) between-subjects ANOVAs were performed to determine if participant age, sight distance, and seated eye height varied significantly by object type, sensor presence, camera presence, or the interactions between these variables. No significant main effects or interactions were found (all *p*s > 0.15).

Table 2. Mean (SD) of age, sight distance, and seated eye height for participants in each backing technology condition.

Backing technology condition	Age	Sight distance (ft)	Seated eye height (in.)
No-technology	35.4 (12.4)	33.9 (6.2)	29.7 (1.6)
Sensor	34.9 (11.9)	35.8 (8.8)	30.1 (1.5)
Camera	38.1 (10.7)	34.5 (7.8)	29.8 (1.5)
Camera-plus-sensor	35.1 (9.9)	33.4 (5.6)	29.9 (1.6)

DISCUSSION

This study compared the effectiveness of a parking sensor system, a rearview camera, and the combination of the two technologies at helping backing drivers avoid a child-size object. Based on prior research, fewer participants with a rearview camera were expected to collide with the object than participants without technology and participants with a parking sensor system. This hypothesis was supported. Participants with a rearview camera (camera or camera-plus-sensors conditions) had fewer collisions overall than participants without a rearview camera (no-technology or sensor conditions), and were 73 percent less likely to hit the stationary or moving object. This finding is consistent with past research that has found benefits of having a rearview camera alone or in combination with a parking sensor system on preventing backovers (Hurwitz et al., 2010; Mazzae et al., 2008; Mazzae, 2010, 2013; Kim et al., 2012).

The parking sensor system was not expected to prevent crashes since previous research found it was only marginally better than having no technology at all (Llaneras et al. 2005; McLaughlin et al., 2003). Consistent with this expectation, the odds of avoiding the child-size object for participants with a parking sensor system were not significantly different from the odds for participants without technology. Furthermore, a larger percentage of participants in the sensor condition hit the moving object than participants in the no-technology condition; this pattern is counterintuitive considering a parking sensor system is designed to prevent collisions.

Drivers in the sensor condition may have relied too heavily on the parking sensor system and made fewer glances around the vehicle, including to the driver side where the moving object was briefly visible. However, participants in the sensor condition made a similar percentage of glances to the driver side and other areas around the vehicle during the surprise event as participants in the no-technology condition, so this hypothesis does not seem to be supported. Another possibility is that participants in the parking sensor condition associated the audible warning with the wrong object. They may have thought that the experimenter vehicle or another object in view was being detected by the parking sensor system. Half of participants with a parking sensor system, including those who also had a rearview camera, made no discernible response to the audible warning, which suggests that many did not think there was an imminent threat of colliding with an unobserved object.

Although experimental studies have consistently found that parking sensor systems do not help drivers avoid backovers, there is some evidence that these systems may be reducing loss in the real world. The Highway Loss Data Institute (HLDI, 2011a; 2012) compared the rates of different types of insurance claims for Buick and Mercedes-Benz vehicle models with a parking sensor system with the claim rates of the same vehicle models that did not have a parking sensor system. Consistent with experimental research, there were no significant differences in collision and property damage liability claim rates for Mercedes-Benz models with a parking sensor system compared with models without the system. However, on average, Buick models with a parking sensor system had significantly lower collision claim rates and property damage liability claim rates than Buick models without a parking sensor system. Both studies were not able to determine whether or not a parking sensor system was active in a crash and lacked detailed crash information to determine if the insurance claims involved a reversing vehicle. It is unknown to what extent these factors limit the findings. Future research should continue to evaluate if parking sensor systems reduce loss and injury in the real-world.

Fewer collisions were observed when the parking sensor system was combined with a rearview camera compared with the parking sensor system alone. The proportion of participants in the camera-plus-sensor condition who hit the object was 36 percent smaller than the proportion of participants in the sensor condition who hit the object. However, results from an exploratory analysis of glance behavior suggests that the parking sensor system provided no added value to the rearview camera. Every participant in the camera-plus-sensor condition who did not look at the camera display before hearing an audible warning from the parking sensor system hit the stationary object and, only half who looked at the camera display before hearing the audible warning hit the object.

The parking sensor system may have been more useful when combined with a rearview camera if it provided an earlier warning. The audible warning from the parking sensor system in the current study had a range of 8 feet and only prevented a few collisions even when participants in the sensor and camera-plus-sensor condition first responded to the warning by braking. An earlier warning would give drivers more time to search the rearview camera display for a possible object in the backing path.

As hypothesized, the combination of a parking sensor system and rearview camera was not as effective as a rearview camera alone; the proportion of participants in the camera condition that hit the object was 22 percent smaller than the proportion of participants in the camera-plus-sensor condition. The difference in collisions between these two conditions was not statistically significant, but the pattern of results is consistent with findings reported across four NHTSA studies (see Mazzae, 2013) and by McLaughlin et al. (2003). Thus, there is converging evidence that combining a parking sensor system with a rearview camera is not as effective at preventing backovers with a child-size object compared with a rearview camera alone.

It is unclear why this is the case. It is possible that combining a parking sensor system with a rearview camera may be less effective than a rearview camera alone because drivers use the camera display less when they have a parking sensor system. A smaller proportion of participants in the camera-plus-sensor condition looked at the camera display at least once during the surprise event compared with the participants in the camera condition, and a smaller proportion of their glances during the surprise event were to the camera display. Neither of these differences was statistically significant but both are consistent with observations reported in Mazzae and Barrickman's (2008) study of backing maneuvers during daily driving. Camera use and visual scanning patterns in the presence and absence of a parking sensor system during normal backing situations is a topic for future research.

Despite consistent evidence from controlled experiments that rearview cameras are effective at preventing backovers, there is scant evidence about their performance in the real world. NHTSA performed a naturalistic driving study where the backing maneuvers of 37 drivers of 2007 Honda Odyssey minivans were recorded for 4 weeks during normal daily driving (Mazzae et al., 2008). Six minor backing collisions with another vehicle or stationary object were observed among all 37 drivers during the 4 weeks of recorded driving. Five crashes involved drivers of vehicle with a rearview camera, and four of these vehicles also had a parking sensor system. HLDI compared rates of different types of insurance claims in select Mazda and Mercedes-Benz vehicle models with a rearview camera with the same vehicle models without a camera (HLDI, 2011b; 2012). Changes in claim rates were directionally inconsistent across coverage types, and statistically significant reductions in collision claim and property damage liability claim rates were not observed. A significant 22 percent reduction in the rate of high-severity bodily injury liability claims was observed for Mazda vehicles with a rearview camera compared to the same vehicles without one, but this finding was inconsistent with a non-significant 15 percent increase in high-severity bodily injury liability claims observed for Mercedes-Benz vehicles with a rearview camera. High-severity bodily injury liability might be indicative of collisions with non-vehicle occupants, but given the mixed findings the real-world crash benefits of rearview cameras are undetermined at this time.

There are several reasons why the benefits of rearview cameras observed in this and other controlled experiments may be smaller or even non-existent in the real world. First, controlled experiments have evaluated rearview cameras in conditions (e.g., situations where the object can only be seen using a rearview camera) designed to estimate their maximum benefit, but real-world situations may

not be this clearcut. For example, environmental conditions can degrade the quality of an image from a rearview camera. In this study, almost every participant with a rearview camera hit the stationary object when it was partially or completely in the shade. The shade may have reduced the clarity of the object in the display and made detection more difficult. Glare from the sun also may have impaired the use of the camera display. Precipitation and darkness are other environmental factors that can degrade the quality of camera images and likely reduce their potential safety benefits.

Drivers may not see potential hazards in the camera display even when the image is not degraded. The stationary object was visible in the camera display during the entire surprise event; yet, three of 13 participants who looked at the camera display while backing and without shade still hit the stationary object. It is possible that these participants only made one or more cursory glances to quickly inspect the display instead of allowing themselves sufficient time to process the image in more detail. Alternatively, these drivers may have examined the wrong areas of the visual scene shown in the display. They may have focused on their location relative to the experimenter vehicle or their relative location to other known objects nearby and failed to adequately search the display for objects in the backing path and in other areas.

The potential safety benefits of rearview cameras also may be dependent on the specific backing maneuver or other situational factors. The distribution of glances around the vehicle varies by the type and complexity of the backing maneuver (Huey, Harpster, & Lerner, 1995), and the likelihood of noticing and avoiding an unexpected object may be related to the way visual attention is distributed. In the surprise event, the experimenter vehicle was located on the driver side of the participant's vehicle. Participants frequently looked to the driver side of the vehicle presumably to maintain awareness of their location relative to the experimenter vehicle. A similar number of participants without cameras as participants with cameras detected and avoided the moving object when it emerged from behind the experimenter vehicle, but did so through different means. Participants without cameras saw the object by glancing over their left shoulder, through the driver window, or glancing to the driver side mirror, while the majority of participants with cameras saw the moving object in the camera display. A different pattern of results may have been observed if the moving object entered the backing path from the passenger side of the vehicle; fewer participants without cameras would likely have avoided a moving object from the passenger side and a stronger benefit of camera presence would likely have been found.

There were several limitations in this study. First, none of the participants owned a Chevrolet Equinox, so participants had minimal or no prior experience with the rearview camera and/or parking sensor system and the visibility characteristics of the vehicle. The screening procedures were designed to recruit participants whose primary vehicles were SUVs like the study vehicle and who had experience with the technologies that they would be using in the study. Participants also completed 25 parking maneuvers at the beginning of the study to help them become comfortable with the visibility characteristics and dimensions of the vehicle, and familiarize them with the parking sensor system and/or

rearview camera. Despite these procedures, participants' visual scanning patterns may not have reflected the distribution of their visual attention in their own vehicles while backing.

Driveways are the most common area where backover crashes occur, and many backovers occur in single-family residential areas (Austin, 2008). The surprise event in this study occurred when drivers were backing out of a parking stall in a closed parking lot. The visual scanning patterns and use of the different technologies observed in this study may not reflect scanning and use when a driver is backing out of a driveway where small children may be present. Mazzae (2010) evaluated the use of a parking sensor system and three rearview camera systems by drivers backing out of a garage in a daycare parking lot. This setting was intended to simulate a situation where drivers are backing up in an area where children are present. The proportions of participants with a parking sensor system (75%) or one of the three rearview camera systems (62%) who collided with a surprise pop-up stationary object differed from the proportions of participants with a parking sensor system (94%) or rearview camera (56%) who hit the stationary object in this study, but the results were directionally similar. Additionally, the proportion of participants with a rearview camera who looked at the camera display at least once while backing up (68%) in Mazzae's study was similar to the proportion observed among participants with a rearview camera (63%) in surprise event trials with a stationary obstacle in the current study. This suggests that the visual scanning patterns in the surprise event trials with the stationary object in this study may be reasonably representative of drivers backing out of a garage in the vicinity of small children. However, the study participants' expectations about the likelihood of a potential object behind the vehicle while backing likely is not representative.

Finally, the effects observed for the parking sensor system, the rearview camera, and the two technologies combined may not generalize to other implementations of these technologies. For instance, drivers with rearview camera systems with in-mirror displays use them more often than drivers with camera systems with displays in center consoles (Heckman et al., 2012); consequently, systems with in-mirror displays may be more effective at preventing backovers than systems with center console displays (Kim et al., 2012; Mazzae, 2010). However, the image size of in-mirror displays are typically smaller than center console displays, and it may be difficult for drivers to perceive objects in smaller displays. NHTSA has proposed minimum image size requirements in its proposed rulemaking for rear visibility (Office of the Federal Register, 2010). Lastly, parking sensor systems typically provide some type of visual reference that indicates where an object has been detected relative to the vehicle. This information was not available in the current study for participants in the sensor-only condition. It is possible this information would have increased the benefit of the sensor-only system. Additional research is needed to evaluate different design characteristics of backing systems to identify the features that optimize their use.

CONCLUSION

The current study measured the effectiveness of a parking sensor system, a rearview camera, and a parking sensor system combined with a rearview camera at preventing a collision with a stationary

or moving child-size object. Drivers with cameras (camera and camera-plus-sensor conditions) hit the stationary or moving object less often than drivers without cameras (no-technology and sensor conditions); this difference approached statistical significance. Significantly more drivers hit the stationary object than the moving object; few collisions with the moving object occurred. The rearview camera was the most effective in preventing backovers with a stationary object; only 56% of participants in the camera condition collided with the stationary object, whereas every participant in the no-technology condition hit the stationary object. The parking sensor system alone prevented only one crash with the stationary object. It prevented more crashes with the stationary object when combined with a rearview camera (75% crashed), but the combination of these technologies did not prevent more collisions with the stationary object than a rearview camera alone.

Although the rearview camera reduced backovers compared with the no-technology condition and sensor-only condition, it did not prevent collisions in every situation. Shade limited the detection of the child-size object when drivers looked at the camera display while backing, and, even when the stationary object was not in the shade, several drivers who looked at the camera still hit it. Additionally, the rearview camera did not provide any additional benefit in the moving object condition compared to no technology; the object was avoided as often by participants without cameras using glances and mirrors as by participants with cameras. Environmental conditions and situational factors are two possible factors that could influence the real-world safety benefits of rearview cameras.

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