

# The Effectiveness of a Rearview Camera and Parking Sensor System Alone and Combined for Preventing a Collision With an Unexpected Stationary or Moving Object

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**Objective:** This study measured the effectiveness of a parking sensor system, a rearview camera, and a sensor system combined with a camera for preventing a collision with a stationary or moving child-size object in the path of a backing vehicle.

**Background:** An estimated 15,000 people are injured and 210 are killed every year in backover crashes involving light vehicles. Cameras and sensor systems may help prevent these crashes.

**Method:** The sample included 111 drivers (55 men, 56 women), including 16 in the no-technology condition, 32 in the sensor condition, 32 in the camera condition, and 31 in the camera-plus-sensor condition. A stationary or moving child-size object was surreptitiously deployed in the path of participants backing out of a parking stall.

**Results:** A significantly smaller proportion of participants in the camera condition hit the stationary object compared with participants in the no-technology condition; however, this benefit was greatly reduced when the stationary object was partially or completely in the shade. Significantly fewer participants hit the moving object than the stationary object. The percentage of participants in the sensor, camera, and camera-plus-sensor conditions who hit the moving object was not different from the no-technology condition.

**Conclusion:** The camera was the only technology that was effective for preventing collisions with the stationary object. The variation in collision outcomes between the stationary- and moving-object conditions illustrates how the effectiveness of these technologies is dependent on the backing situation.

**Application:** This research can help the selection and development of countermeasures to prevent backovers.

**Keywords:** rearview cameras, backup cameras, parking sensors, backover crashes, backover prevention

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## **HUMAN FACTORS**

Vol. XX, No. X, Month XXXX, pp. 1–12

DOI: 10.1177/0018720814553028

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## **INTRODUCTION**

An estimated 15,000 people are injured and 210 people are killed every year in backover crashes involving light vehicles; many of the victims are younger than 5 years old (National Highway Traffic Safety Administration, 2014). Automobile manufacturers are equipping many vehicle models with ultrasonic sensors and rearview cameras to provide drivers with information about obstructions in the backing path and to help prevent backovers. A handful of controlled experiments have measured the effectiveness of sensors and cameras for preventing backovers. Llaneras et al. (2005) examined the relative effectiveness of four types of audible warnings from a sensor system for preventing a backover. Across the four warning conditions, only 13% of participants avoided a toy coupe that moved into the vehicle's path. One third of participants had no discernible reaction to the warning, and 44% applied the brakes.

Drivers may not have reacted to the audible warning from the sensor system because it did not provide visual confirmation of an obstruction, like a rearview camera does. Mazzae (2010) compared the effectiveness of three rearview cameras and a sensor system for preventing backovers. A 35-inch-tall image of a toddler popped up 14 feet behind participants' vehicles as they reversed out of a garage near a child development center. Participants with all of the technologies had significantly fewer collisions compared with participants without technology. Still, three quarters of participants with the sensor system and 52% to 74% of participants with one of the three different types of cameras hit the object; the differences between the systems were not statistically significant.

Audible warnings may increase the effectiveness of rearview cameras by directing the driver's attention to the camera display when an

imminent threat is detected (e.g., Hurwitz et al., 2010). Mazzae, Barickman, Baldwin, and Ranney (2008) compared the effectiveness of a rear-view camera system alone and in combination with a parking sensor system for preventing a backover among Honda Odyssey owners. Drivers were continuously monitored and videotaped during their daily driving for 4 weeks. At the end of the 4 weeks, a 36-inch-tall image of a toddler popped up 14 feet behind the vehicle when participants were backing out of a garage. Every participant without technology hit the object, 58% of participants with a camera hit it, and 85% of participants with a camera and sensor system hit it.

Mazzae et al.'s (2008) findings are surprising because combining a camera with a parking sensor system would be expected to have a synergistic result. The researchers found that twice as many participants with the combination of a camera and sensor as participants with a camera alone never looked at the camera display during the surprise event. Participants with the combination of a camera and sensor may have relied on the audible warnings from the sensor system to cue glances to the camera display instead of looking at the display regularly while backing.

Given this prior research, a camera appears to be a more effective countermeasure for preventing backover crashes than either a sensor system or these two technologies combined. However, only one study has examined all of these technologies in a single experiment (McLaughlin, Hankey, Green, & Kiefer, 2003). In this study, a pylon was placed 3 feet behind the participant's vehicle after the participant completed five parking tasks. Every participant without technology and every participant with a sensor system hit the pylon. Sixty-seven percent of participants with a camera and 67% of participants with a camera and sensor system hit the pylon. However, McLaughlin et al. (2003) did not report statistical comparisons of collision outcomes among the four conditions.

The relative effectiveness of a sensor system, camera, and both technologies combined for preventing backovers merits further investigation to identify the most effective method of preventing backovers. In particular, it is critical to determine if combining a camera with a sensor

system is a less effective solution than a camera alone and, if so, to identify the reasons why this is the case. The objective of the current study was to compare the effectiveness of a sensor system, a camera, or both a camera and sensor system for preventing a collision with a stationary or moving child-size object.

## METHOD

### Study Vehicle and Closed Course

The study vehicle was a 2013 Chevrolet Equinox LTZ equipped with a rearview camera and a rear ultrasonic parking sensor system. Both systems were original vehicle equipment. The camera display was 7 inches diagonally and located in the center console. Guidelines designed to help the driver align the vehicle were not displayed. According to the owner's manual, the Equinox's sensor system operated at speeds less than 5 mph. A functional test of the sensor system showed it could detect a 42.7-inch-tall by 4.5-inch-wide pylon up to 5 feet behind the rear bumper (Kidd & Brethwaite, 2014); this distance was less than the 8-foot range stated in the owner's manual. An audible warning (beep) sounded when the object was detected, and the frequency of beeps increased as the vehicle moved closer to the object before becoming a steady tone when the object was less than 1 foot away. It did not provide directional information. A visual symbol in the camera display supplemented the auditory warning. It was a yellow triangle with an exclamation mark inside that increased in size and changed from yellow to red as the vehicle moved closer to an object. The position of the symbol in the camera display was in the approximate location of the detected 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 during only daytime hours when a major event was not taking place and 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 based on the backing technology in their current vehicle or past experience with a sensor system. In the no-technology condition, the camera display was not visible and the sensor system was not active. The audible warning from the sensor system was active in the sensor condition, but the camera display and visual symbol provided by the sensor system 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 visual symbol provided by the sensor system.

A surprise event occurred at the end of the study in which either a stationary or moving object was deployed in the backing path of the study vehicle. 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.

### Participants

Participants were recruited from the Dynamic Research, Inc., participant database. To be eligible, participants had to be 18 to 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). Additional screening was conducted to determine each participant's familiarity with cameras and sensor systems. Participants in the camera condition were required to have a center console camera display in their SUV. Participants in the camera-plus-sensor condition were required to have a center console camera display and a sensor system in their SUV. Participants in the sensor condition either had only a sensor system in their SUV or currently drove an SUV without a camera but had experience driving any vehicle with a sensor system.

There were 117 participants. Five participants were removed because of an invalid surprise event trial. One was removed because he

received the wrong experimental condition. The final sample consisted of 111 drivers (55 men, 56 women). There were 16 participants in the no-technology condition, 32 in the sensor condition, 32 in the camera condition, and 31 in the camera-plus-sensor condition. Participants were 18 to 58 years old, with a mean of 36 years ( $SD = 11$ ). Fewer participants were assigned to the no-technology condition than the other backing technology conditions because every participant without backing technology was expected to hit the stationary or moving object in the surprise event.

### Procedure

At the beginning of the study, participants adjusted the seat, steering wheel, and mirrors to their liking. They drove a single lap around the perimeter of the parking lot to become comfortable with operating the vehicle and adjusted the seat, steering wheel, and mirrors again if needed. A research assistant was seated in the right front passenger seat during the entire study.

Participants were told that the purpose of the study was to evaluate an in-vehicle infotainment system. Participants completed three sets of tasks unrelated to the actual study objective to disguise the true purpose of the study. First, participants performed six parking maneuvers five times. Participants pulled forward into a parking stall, backed out of a parking stall, parallel parked, backed into a parking stall, and reversed into a parking stall 50 feet behind the vehicle. Next, participants drove around the perimeter of the parking lot while manually tuning the radio, changing the settings on the climate control system, playing a track on a CD, and reading information displayed by the navigation system. Last, participants parked the vehicle in a parking stall and manually tuned the radio, entered a destination into the navigation system, and selected a song from a playlist on a digital music player connected to the infotainment system while wearing occlusion goggles. The goggles obscured the view of the infotainment system for 1.5 s every 1.5 s per the international standard for using the occlusion method to assess the visual demand of an in-vehicle system (International Organization for Standardization, 2007).



Figure 1. Child-size object (yellow with black markings).

At the end of these tasks, participants were instructed to back out of the parking stall to return to where they had parked their personal vehicle. A surprise event occurred when participants were backing out of the parking stall in which a stationary object or a moving object was deployed into the vehicle's path. The object was a 3-inch-thick foam cutout of a child-size crash test dummy mounted on a remote-controlled platform (Figure 1). The object was yellow with black markings. The height of the cutout and platform was 30.2 inches, which corresponds to the 50th percentile standing height of a 12- to 15-month-old child (Tilley, 2002).

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 (Figure 2). The findings from a

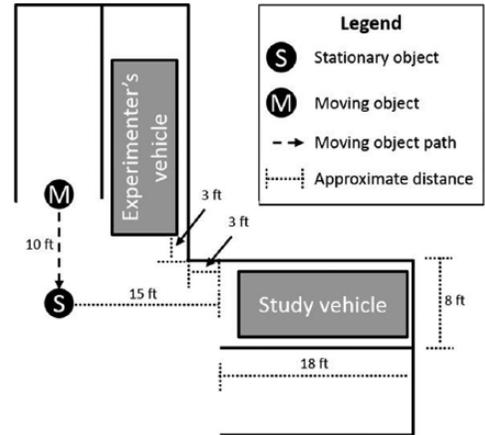


Figure 2. Surprise event layout.

recent study indicated that a 50th percentile male driver sitting in a 2013 Chevrolet Equinox would not be able to see the object at this distance in the vehicle mirrors or by glancing over his right shoulder (Kidd & Brethwaite, 2014). This distance is also similar to the distance used in previous research (Mazzae, 2010, 2013; Mazzae et al., 2008).

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 to transport equipment. The moving object was set in motion at approximately 2 mph (2.9 feet per second) by an experimenter via remote control when the rear of the study vehicle reached the end of the parking stall and came to rest at approximately the centerline of the study vehicle. Once behind the vehicle, the stationary object and the moving object were detectable only by looking at the camera display or via a warning from the sensor system.

After participants had either struck the object or avoided it by coming to a complete stop, they were instructed to place the study vehicle in park. Participants then were debriefed about the true purpose of the study and completed several poststudy questionnaires. The study protocol was approved by the institutional review board of Dynamic Research, Inc.

## Dependent Measures

Collision or avoidance was recorded for each surprise event trial. A video camera was mounted on the study vehicle's rear bumper to verify collision outcomes. 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 the center console were manually coded from the video recordings. Glances to this area by participants in the camera and camera-plus-sensor conditions were assumed to be to the camera display.

For participants in the sensor and camera-plus-sensor conditions, two coders independently recorded whether the participant's initial response after the audible warning from the sensor system 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 when there was no discernible response after the warning. A third coder was consulted to resolve any disagreements between the two coders.

## Data Analysis

The differences in the proportion of surprise event trials with a collision between the sensor, camera, and camera-plus-sensor conditions and the baseline no-technology condition were assessed using chi-square tests. Chi-square tests also were performed to examine camera use by participants in the camera condition and camera-plus-sensor condition and first responses to the audible warning from the sensor system among participants in the sensor condition and camera-plus-sensor condition. The phi coefficient ( $\Phi$ ) describes the magnitude of association between variables in a  $2 \times 2$  contingency table and was used as a measure of effect size for each chi-square test. A phi coefficient of 0.10, 0.30, and 0.50 indicates a small, medium, and large effect size, respectively (Cohen, 1988). A 95% confidence interval was constructed for each proportion (reported as a percentage) using the uncorrected Newcombe-Wilson method (Newcombe, 1998) to aid interpretation and provide information about precision (Cumming, 2014). Alpha was set at 0.05 for all analyses.

A logistic regression was performed to assess the independent and combined effectiveness of a

sensor system, camera, and both technologies combined for preventing collisions in the surprise event. The log odds of a collision were modeled with participant age, participant gender, object type (stationary, moving), sensor presence, camera presence, and the various two- and three-way interactions between object type, sensor presence, and camera presence. Participant age was rescaled to be centered around the minimum age of the study sample (18 years). Centering is often used to deal with multicollinearity in multiple regression models that include interaction terms (Tabachnick & Fidell, 2007) but also is used to make the interpretation of a parameter more meaningful. Odds ratios and 95% confidence intervals for each parameter were calculated using the PROC LOGISTIC procedure in SAS 9.3. When the 95% confidence interval associated with an odds ratio includes 1, then the parameter does not significantly affect the odds of an outcome (i.e., a collision in the surprise event). If the odds ratio and associated 95% confidence interval are less than 1, then the parameter is associated with a decrease in the odds of a collision in the surprise event. Odds ratios greater than 1 indicate the parameter is associated with a significant increase in the odds of a collision in the surprise event. Cox and Snell's  $R^2$  and  $-2 \log$  likelihood ( $-2LL$ ) were used to assess model fit.

## RESULTS

### Backing Collisions

In total, 54 of the 111 participants (49%, 95% CI [40, 58]) hit the stationary or moving object. A larger percentage of participants in the sensor condition (66%, 95% CI [48, 80]) than in the no-technology condition (56%, 95% CI [33, 77]) hit the object, but the difference between these conditions was not statistically significant (Table 1). Fewer participants in the camera and the camera-plus-sensor conditions (34%, 95% CI [20, 52], and 42%, 95% CI [26, 58], respectively) hit the object compared with the no-technology condition, but neither difference was statistically significant.

The percentages of participants in each backing technology condition who hit the stationary object or the moving object are shown in Figure 3. There was a significant difference between

**TABLE 1:** Chi-Square Tests Comparing the Outcome of the Surprise Event for the Sensor, Camera, and Camera-Plus-Sensor Conditions to the No-Technology Condition Overall, in Stationary Object Trials Only, and in Moving Object Trials Only

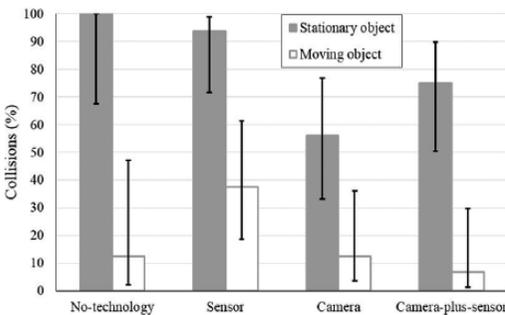
Statistical Comparison	Chi-Square Test
All surprise event trials	
Sensor vs. no technology	$\chi^2(1) = 0.4, p = .53, \Phi = 0.09$
Camera vs. no technology	$\chi^2(1) = 2.1, p = .15, \Phi = 0.21$
Camera-plus sensor vs. no technology	$\chi^2(1) = 0.9, p = .35, \Phi = 0.14$
Stationary object trials only	
Sensor vs. no technology	$\chi^2(1) = 0.5, p = .47, \Phi = 0.15$
Camera vs. no technology	$\chi^2(1) = 4.9, p = .03, \Phi = 0.45^*$
Camera-plus sensor vs. no technology	$\chi^2(1) = 2.4, p = .12, \Phi = 0.32$
Moving object trials only	
Sensor vs. no technology	$\chi^2(1) = 1.6, p = .20, \Phi = 0.26$
Camera vs. no technology	$\chi^2(1) = 0, p = 1.0, \Phi = 0.0$
Camera-plus sensor vs. no technology	$\chi^2(1) = 0.2, p = .63, \Phi = 0.10$

Note.  $\Phi$  = phi coefficient.  
 \* $p < .05$ .

the proportion of participants in the camera condition and the proportion of participants in the no-technology condition who hit the stationary object (Table 1). The percentage of participants with collisions in the camera condition was 44 percentage points less than in the no-technology condition. There was no significant difference in the proportions of participants who hit the stationary object between the sensor condition and no-technology condition or between the camera-plus-sensor condition and no-technology condition. There were no significant differences between the

sensor, camera, or camera-plus-sensor conditions and the no-technology condition when the object was moving.

A series of logistic regressions was performed modeling the log odds of a collision with gender, age, object type, sensor presence, camera presence, and the 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 was dropped. In a second model, the three two-way interactions between object type, camera presence, and sensor presence were not statistically significant. The Camera Presence  $\times$  Sensor Presence interaction term was omitted from the final model, but the Object Type  $\times$  Camera Presence and Object Type  $\times$  Sensor Presence interaction terms were retained to account for different patterns in collisions observed across the four technology conditions in the moving and stationary conditions. There were no statistically significant differences in model fit among the first two models and the final model (full model vs. final model,  $\Delta-2LL = 3.22, df = 2, p = .2, \Delta R^2 = -.02$ ; second model vs. final model,  $\Delta-2LL = 0.2, df = 1, p = .7, \Delta R^2 = 0$ ). The moving object was briefly visible in the



*Figure 3.* Percentage of participants in each backing technology condition who hit the stationary object or moving object. Error bars indicate 95% confidence intervals.

**TABLE 2:** Logistic Regression Analysis Predicting the Log Odds of a Collision From Gender, Age, Object Type, Sensor Presence, Camera Presence, Object Type  $\times$  Sensor Presence, and Object Type  $\times$  Camera Presence

Predictor	$\beta$	OR [95% CI]	<i>p</i> Value
Gender (1 = female, 0 = male)	0.79	2.21 [0.79, 6.2]	.13
Age in years (centered at 18 years)	0.01	1.01 [0.97, 1.06]	.63
Object type (1 = stationary, 0 = moving)	4.14	62.52 [4.68, 834.66]	< .01
Sensor presence (1 = present, 0 = none)	0.54	1.71 [0.37, 8.03]	.50
Camera presence (1 = present, 0 = none)	-1.30	0.27 [0.06, 1.25]	.09
Object Type $\times$ Sensor Presence	0.10		.92
Moving Object $\times$ Sensor Presence		1.71 [0.37, 8.0]	
Stationary Object $\times$ Sensor Presence		1.89 [0.46, 7.86]	
Object Type $\times$ Camera Presence	-1.22		.37
Moving Object $\times$ Camera Presence		0.27 [0.06, 1.25]	
Stationary Object $\times$ Camera Presence		0.08 [0.01, 0.71]	
Constant	-1.88		

Note.  $N = 111$ . OR = odds ratio ( $e^{\beta}$ ); CI = confidence interval.

driver-side mirror, through the driver window, or over the left shoulder, whereas the stationary object was not. So to investigate the impact of this observation further, the two-way interaction terms were used to estimate the effects of camera presence and sensor presence for both stationary and moving objects separately.

A test of the final logistic regression model against a constant-only model indicated that the set of predictors reliably distinguished between collisions and avoidances in the surprise event ( $-2LL = 94.42$ ,  $\chi^2(7) = 59.21$ ,  $p < .001$ ,  $R^2 = .41$ ). The odds of hitting the stationary object were about 63 times higher than the odds of hitting the moving object when holding all other variables constant (Table 2). The odds of hitting the object for participants with a camera (camera and camera-plus-sensor conditions) were 73% lower than the odds for participants without cameras (no-technology and sensor conditions) and were 71% higher for participants with a sensor system (sensor and camera-plus-sensor conditions) than the odds for participants without a sensor system (no-technology and camera conditions); however, the effects of camera presence and sensor presence were not statistically significant. The interaction between object type and camera presence was not statistically significant; however, it is noteworthy that the odds

of hitting the stationary object for participants with a camera were significantly less than the odds of a collision for participants without a camera after accounting for the other variables. The upper limit of the 95% confidence interval associated with the odds ratio for this effect was less than 1. Gender, age, and the interaction between object type and sensor presence had little effect on the odds of hitting the object.

### Glances to the Camera Display and Object Avoidance

Seventy-five percent of the 32 participants in the camera condition and 67% of the 31 participants in the camera-plus-sensor condition looked at the camera display at least once during the surprise event. The difference in proportions between these two conditions was not significantly different,  $\chi^2(1) = 0.4$ ,  $p = .52$ ,  $\Phi = 0.08$ , so glance data for participants in the camera and camera-plus-sensor conditions were combined in the following analyses.

The stationary object was visible only in the camera display and could be seen as soon as the camera image appeared after the vehicle's transmission was placed in reverse. Twenty of the 32 participants with cameras (camera and camera-plus-sensor conditions) looked at the camera display at least once during the surprise event

with the stationary object; 9 of these participants hit it (45%, 95% CI [26, 66]). All 12 participants who had a camera but did not look at the display hit the object (100%, 95% CI [76, 100]); this proportion was significantly greater than the proportion of participants with cameras who looked at the display and hit the stationary object,  $\chi^2(1) = 10.1, p < .01, \Phi = 0.57$ .

Review of the video recordings from the surprise event trials with the stationary object revealed that in 11 of the 32 trials involving participants who had cameras (camera and camera-plus-sensor conditions), some or all of the base of the stationary object was positioned in the shadow from a nearby tree. The difference between the proportions of trials in which the stationary object was in the shade for participants in the camera condition and participants in the camera-plus-sensor condition was not significantly different,  $\chi^2(1) = 0.1, p = .71, \Phi = 0.07$ . The shade may have affected the contrast of the stationary object in the camera image, so the outcome of the surprise event in trials with and without shade was examined for participants with cameras who looked at the camera display at least once while backing. In the 11 stationary object trials in which shade was present, 7 participants glanced at the camera at least once, and 6 of them hit the stationary object (86%, 95% CI [49, 98]). In the 21 trials in which the stationary object was not in the shade, 13 participants glanced at the camera display at least once, and 3 of them hit the object (23%, 95% CI [8, 27]). Participants who looked at the camera display at least once hit the stationary object significantly more often when it was in the shade than when it was not,  $\chi^2(1) = 7.2, p < .01, \Phi = 0.60$ .

Excluding the stationary object trials in which shade was present did not appreciably change the pattern of results observed for the camera and camera-plus-sensor conditions compared with the no-technology condition. Forty percent (95% CI [17, 69]) of participants in the camera condition and 64% (95% CI [35, 85]) of participants in the camera-plus-sensor condition hit the stationary object in trials in which shade was not present, but only the camera condition was significantly different from the no-technology condition (100%, 95% CI [57, 100]): camera versus

no technology,  $\chi^2(1) = 5.0, p = .03, \Phi = 0.58$ ; camera plus sensor versus no technology,  $\chi^2(1) = 2.4, p = .12, \Phi = 0.39$ .

The moving object was briefly visible in the driver-side mirror, through the driver window, or over the left shoulder before it moved behind the vehicle, where it was visible only in the camera display. Sixteen of the 17 participants (94%, 95% CI [73, 99]) without cameras (no-technology and sensor conditions) who avoided the moving object 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. In contrast, fewer than one third of participants with cameras detected the moving object through the driver-side window, in the side mirror, or glancing over their left shoulder (29%, 95% CI [15, 47]); this proportion was significantly smaller than what was observed for participants without cameras,  $\chi^2(1) = 18.3, p < .001, \Phi = 0.64$ . Most of the 28 participants with cameras who avoided the moving object stopped the vehicle after looking at the camera display (71%, 95% CI [53, 85]).

### Responses to the Audible Warning From the Parking Sensor System

The parking sensor system provided an audible warning in 38 of 63 trials in which the system was active (sensor and camera-plus-sensor conditions). The participant saw the object and stopped the vehicle before the object was within the range of the sensor system in 20 of the 25 trials in which an audible warning was not provided. In 1 of the 38 trials in which a warning was given, the sensor system detected cones lining the parking stall and emitted a warning but did not give a warning later in the trial when the vehicle approached the moving object. Hence, the system detected the object in 86% (37/43) of the trials in which the object was within its range. Participants saw the object and were applying the brakes prior to the audible warning in 5 of the 37 trials in which a valid warning was given. These 5 trials were excluded from the analyses.

Half of the 32 participants (95% CI [34, 67]) in the sensor condition or camera-plus-sensor

condition who received a valid warning 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, about half applied the brakes and glanced to a new field of view (56%, 95% CI [33, 77]), slightly more than one third glanced to a new field of view (38%, 95% CI [19, 61]), and one participant applied the brakes (6%, 95% CI [1, 28]). There was no significant difference between the percentage of participants in the sensor condition whose first response was to apply the brakes alone or in addition to glancing to a new location (22%, 95% CI [9%, 45%]) and the percentage of participants in the camera-plus-sensor condition who responded in the same manner (43%, 95% CI [21%, 67%]),  $\chi^2(1) = 1.6, p = .21, \Phi = 0.22$ . Most participants who applied the brakes still hit the moving or stationary object (70%, 95% CI [40, 89]).

## DISCUSSION

This study examined the effectiveness of a parking sensor system, a rearview camera, and the combination of the two technologies in helping drivers avoid a stationary or moving child-size object. Overall, none of the technologies led to a statistically significant reduction in the log odds of colliding with the object after other factors were accounted for. However, the effects of the technologies were inconsistent across the two backing situations, and separate analyses of each backing situation suggested that the camera was effective for preventing collisions with the stationary object.

The stationary object scenario was an ideal situation for measuring the maximum safety benefits of the camera, sensor, and the combination of these technologies because the object was detectable only by looking at the camera display or via a warning from the sensor system. The camera condition was the only backing technology with a significantly smaller proportion of collisions than the no-technology condition when the object was stationary behind the vehicle. Furthermore, the logistic regression analysis indicated that there was a statistically significant reduction in the odds of hitting the stationary object when a camera was present compared with when it was not. Together, these

findings replicate previous research that has shown rearview cameras are effective for preventing backovers (Mazzae, 2010, 2013; Mazzae et al., 2008) and sensor systems are not (Llaneras et al., 2005; McLaughlin et al., 2003).

The beneficial effects of a rearview camera could have been larger if it were not for instances when participants failed to notice the stationary object in the camera display. One factor was the presence of shade. Almost every participant with a rearview camera hit the stationary object when it was partially or completely in the shade. Shade may have reduced the contrast of the object in the camera image, thereby making it less noticeable. Other environmental factors that affect image contrast (e.g., luminance) or degrade image quality (e.g., precipitation or dirt on the camera lens) also could hamper visual search for potential hazards in the camera image.

Three of 13 participants who looked at the display while backing still hit the stationary object when shade was not present. This finding is consistent with observations made by Perez et al. (2011), who reported several instances in which drivers looked at the camera display when an object was present and did not make a discernible response. The reason underlying detection failures in these cases is not clear, but detection may have been improved if cues were given to guide attention to the relevant area of the display (e.g., Goh, Wiegmann, & Madhavan, 2005). Participants in the camera-plus-sensor system received a visual cue in the approximate location of the display where a target was detected by the sensor system; however, there was not enough data to examine the efficacy of this cue.

In contrast to previous research (Hurwitz et al., 2010), a camera combined with a sensor did not result in a reliable reduction in collisions with the stationary object compared with the no-technology condition. There is some evidence to suggest that participants in the camera-plus-sensor condition may have relied on the sensor system to detect objects rather than inspecting the camera display. 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. The difference

between proportions was small and not significantly different, but the pattern is consistent with observations reported in Mazzae et al.'s (2008) study.

The sensor system was not effective at preventing collisions with the stationary object. One issue was that the warning from the sensor system did not reliably induce an avoidance response (e.g., Llaneras et al., 2005). Only half of the drivers in the sensor condition and camera-plus-sensor condition made a discernible response to the audible warning, and even fewer applied the brakes. Participants may have been more likely to respond to the audible warning if the expected probability of a backing collision was greater (e.g., Bliss, Gilson, & Deaton, 1995). The study took place in a closed parking lot with no apparent potential for collisions, so participants may not have thought the warning indicated an imminent threat of colliding with an unknown object.

Another issue with the sensor system was that most participants did not avoid the object even when they applied the brakes in response to the warning. Participants may not have applied the brakes with the intent to stop the vehicle (e.g., Llaneras et al., 2005) due to a low expected probability of a collision or because the warning did not convey an appropriate sense of urgency (e.g., Edworthy, Loxley, & Dennis, 1991; Marshall, Lee, & Austria, 2007). Alternatively, the detection range of the sensor system may not have given drivers enough time to stop the vehicle even when a sufficient amount of brake force was applied (Mazzae & Garrott, 2006). The beneficial effect of the sensor system may have been larger if it had a longer range and an earlier warning.

A summary of research conducted by General Motors and the Virginia Tech Transportation Institute indicated that the likelihood of hitting an object was higher for a moving object entering the backing path than for a stationary object (Llaneras, Neurauter, & Green, 2011), but the current study demonstrated the opposite pattern. The odds of hitting the moving object were significantly lower than the odds of hitting the stationary object. Furthermore, the proportion of participants in the no-technology condition who hit the moving object was not reliably different

from the proportion of participants who hit the moving object observed in each of the other backing technology conditions. This pattern of results differs from the findings from a recent study in which almost all drivers without a rearview camera hit a child-size object that entered the backing path from the passenger side while they were backing out of a garage, whereas only 69% of drivers with a rearview camera hit it (Mazzae, 2013).

The moving object may have been easier to avoid in this study than in Mazzae's (2013) study because the immediate surroundings in the surprise event may have biased participants' visual scanning patterns in the direction of the moving object. The experimenter vehicle blocked the view of the moving object at the beginning of the surprise event but also may have drawn participants' gaze to this location because it was the most salient object near the backing path. There were no reasons to suggest that participants in Mazzae's (2013) study would have looked to one side of the vehicle more than the other as they navigated the vehicle out of the garage. The disparity between the current findings and Mazzae's (2013) findings suggests how the timing and distribution of glances to traditional fields of view play a key role in the detection of an object moving toward the vehicle's backing path and the potential beneficial effect of a rearview camera.

A recent study found that drivers may be less likely to use the vehicle mirrors and make fewer glances to different areas around the vehicle after extensive use of sensor- or camera-based backing technology (Rudin-Brown, Burns, Hagen, Roberts, & Scipione, 2012). Participants with a rearview camera (camera and camera-plus-sensor conditions) were less likely to detect the object using the vehicle mirrors or shoulder glances than participants without a camera (no-technology and sensor conditions). The differences in detection patterns between drivers with and without cameras are consistent with Rudin-Brown et al.'s findings.

The performance of the sensor system, camera, and the two technologies combined may not be representative of how other implementations of these technologies would perform in the same situation. For instance, camera images

are examined more frequently when the image is in the rearview mirror compared with center console displays (Heckman et al., 2012); consequently, systems with in-mirror displays may be more effective for preventing backovers than systems with center console displays (Kim, Rauschenberger, Heckman, Young, & Lange, 2012; Mazzae, 2010). Additionally, the auditory warning from some sensor systems provides directional information or a visual reference indicating the location and distance of the detected object. The auditory warning from the sensor system in the current study did not provide directional information, and visual information about the location of the detected object was unavailable to participants in the sensor condition. This information may have made the sensor system more effective. Additional research is needed to evaluate the design characteristics of sensor systems, cameras, and the combination of these technologies to identify the features that optimize their use and effectiveness.

There were several other study limitations. First, none of the participants owned a Chevrolet Equinox, so participants had minimal experience with the specific camera, sensor system, and visibility characteristics of the vehicle. Efforts were made to ensure participants were familiar with the vehicle and its features. Participants' primary vehicles were SUVs, they had experience with the technologies that they would be using, and they completed parking maneuvers at the beginning of the study. However, it is unclear whether driving behavior and use of the backing technology actually reflected actual behavior and use of the technology in participants' own vehicles. Second, this study did not control for shade or other unknown environmental factors that could have affected camera use or sensor system performance.

Finally, many of the statistical comparisons suffered from low statistical power and failed to reach statistical significance. For example, the main effect of camera presence in the logistic regression analysis failed to reach statistical significance at the 0.05 level even though the odds of a collision were 73% lower when a rearview camera was present compared with when it was not. There were about 39% fewer collisions overall among participants in the camera condition and 25% fewer collisions among participants

in the camera-plus-sensor condition compared with the no-technology condition. The National Highway Traffic Safety Administration (2014) estimated that rearview cameras could save 58 to 69 lives each year assuming that the technology was 28% and 33% more effective for preventing backovers than not having the technology. Although having a rearview camera did not lead to a statistically significant decrease in the odds of a collision relative to not having it, the technology led to an appreciable reduction in the likelihood of a collision, and the practical significance of saving lives should not be overlooked.

### ACKNOWLEDGMENTS

The authors thank the staff at Dynamic Research, Inc., for their assistance with data collection. The authors thank Anne McCartt, Chuck Farmer, and Eric Teoh at the Insurance Institute for Highway Safety for providing comments and feedback on earlier drafts. This work was funded by the Insurance Institute for Highway Safety within the scope of the first author's employment with them, and as such copyright is owned by the Insurance Institute for Highway Safety.

### KEY POINTS

- This study measured the effectiveness of a parking sensor system, a rearview camera, and a parking sensor system combined with a rearview camera for preventing a collision with a stationary or moving child-size object.
- Fewer participants hit the moving object than the stationary object, and the effects of the technologies were inconsistent across these two backing situations.
- The camera alone was effective for preventing collisions with a stationary object compared with not having technology, but this benefit was greatly reduced when the object was in the shade.
- None of the technologies provided a safety benefit relative to not having technology when the object was moving.

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Date received: March 12, 2014

Date accepted: August 26, 2014