Factors Moderating the Effectiveness of Rear Vision Systems: What Performance-Shaping Factors Contribute to Drivers' Detection and Response to Unexpected In-Path Obstacles When Backing?

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ABSTRACT

General Motors (GM) and the Virginia Tech Transportation Institute (VTTI) have partnered to conduct a series of studies characterizing the use and effectiveness of technologies designed to assist drivers while backing. A major emphasis of this research has been on Rear Vision Camera (RVC) systems that provide drivers with an enhanced view of the area behind the vehicle. RVC systems are intended to aid in positioning the vehicle when executing low-speed parking and backing-related tasks and are not necessarily well suited for detecting unexpected in-path obstacles (particularly if the RVC image is not coupled with object detection alerts issued to the driver). This GM/VTTI research has addressed both the physical and design properties of the RVC image (e.g., optical distortion, quality and clarity of information, amount of information, display size and location, etc.) as well as driver behavioral and perceptual aspects related to RVC use (e.g., driver reliance, impacts on drivers' mirror sampling patterns, frequency of use, duration of glances, ability to accurately judge distances, potential unintended consequences). This paper outlines the complex set of performance-shaping factors found to play a role in moderating the use of RVC systems and unexpected obstacle detection/avoidance performance, including user experience, display location, and driving scenario.

INTRODUCTION

Rear Vision Camera (RVC) systems transmit camera-based images to a display screen typically located in the center stack area of a vehicle to provide drivers with a view of the area immediately behind the vehicle to support vehicle positioning and driver search and detection of in-path obstacles when backing. These systems are designed to automatically engage and display images when the vehicle is shifted into reverse and generally present a wide-angle, color view of the rear area. RVC systems are intended to aid in parking and obstacle avoidance but do not provide an active warning to indicate the presence of rear obstacles. In other words, RVC systems are passive devices operating independently of active park aid systems, and although manufacturers currently offer vehicles with both types of systems, their integration has generally been limited.

Limited research has been performed to assess the effectiveness of backing countermeasure systems, including RVC systems, under naturalistic conditions. As a result, relatively little is understood about how drivers come to learn, use, and interact with such aids. A recent naturalistic study of RVC system owners found that drivers tend to integrate dash-mounted rear vision displays into their search pattern as part of their normal scanning routine under most but not all backing events and that access to the system can aid in obstacle detection and avoidance, showing a 28% reduction in crashes under a staged conflict situation [1]. In a broader analytic modeling effort to assess the safety benefit...
of backing countermeasures, funded by the National Highway Traffic Safety Administration (NHTSA) under the Advanced Crash Avoidance Technologies program, implementation of a prototype backing-crash countermeasure suite that included an RVC feature was found to theoretically result in up to a 32% overall reduction in backing crashes [2]. This work also found that the performance associated with the use of an RVC system in particular (measured in terms of a driver's ability to detect an in-path obstacle) varied substantially based on a variety of factors (e.g., backing scenario and maneuver type), with effectiveness estimates ranging from 10 to 39%. These studies highlight the wide performance variation often associated with these types of systems, the complexity of predicting effectiveness, and the understanding of driver reliance on and use of RVC systems.

This paper details work performed by General Motors (GM) and the Virginia Tech Transportation Institute (VTTI) characterizing the use and effectiveness of technologies designed to assist drivers while backing, specifically RVC systems. The research outlines the complex set of performance-shaping factors found to play a role in moderating the use of RVC systems and unexpected obstacle detection/avoidance performance, including user experience, display location, and driving scenario.

METHOD

This paper integrates and synthesizes results associated with a series of independent research studies performed by GM/ VTTI during the past decade. Although each study was designed to address a specific issue related to the design, development, and use of RVC systems, their combined results provide an opportunity to explore gross-level effects that may moderate and shape driver interactions with these systems. Six studies are highlighted (refer to Table 1 in the Appendix) with emphasis devoted to the driver's ability to detect and avoid rear obstacles using an RVC system when backing during a staged conflict situation, or surprise event, present within each study. The sections that follow present and describe the factors found to moderate obstacle detection and avoidance performance associated with RVC systems based on this set of studies.

EFFECTS OF EXPERIENCE WITH RVC SYSTEMS

Evidence suggests that the level of experience with and exposure to RVC systems is a major determinant of performance, with increasing experience generally leading to higher levels of performance. Llaneras et al. [3] varied the amount of experience (or exposure) drivers had with a dash-mounted RVC system prior to a surprise event trial (backing in the presence of an unexpected obstacle) across three conditions: low exposure (naïve users with 4 practice trials), moderate exposure (naïve users with 12 practice trials), and high exposure (system owners with 12 practice trials). Performance under an unexpected conflict situation (a surprise event) was used to evaluate the effectiveness of the aid in terms of facilitating the detection of an unexpected rear obstacle. This event took place as drivers were backing out of a parking space once the evaluation phase of the study was “over.” Unknown to the driver, a traffic cone was placed behind the vehicle (a 36-inch-tall cone, placed 4 feet directly behind and along the centerline of the vehicle) before the driver started to back; the only means of detecting the cone was through the use of the available aids. The amount of experience drivers had with the RVC system prior to experiencing this surprise conflict event was varied.

As shown in Figure 1, results found avoidance rates were associated with the amount of practice with the RVC system, suggesting a pattern of improved detection and avoidance with increasing levels of experience. System owners (drivers whose personal vehicles were equipped with an RVC system and presumably those with the most exposure) were found to have the greatest avoidance rate (50%, or 3 out of the 6 drivers), while novice users (those with very little experience with the aid; limited to 4 parking and backing trials) were observed to have the least avoidance rate (14%, or 3 out of 21 drivers). Although these trends were not statistically significant \[ \chi^2(2,46) = 3.59, p = 0.16 \], they illustrate a potentially important phenomenon regarding driver reliance and use related to aids in general and RVC systems in particular. That is, drivers may require some basic level of experience with these systems before widespread benefits begin to emerge. In the case of RVC systems, this means drivers will need to integrate the displays into their normal scan patterns and at the appropriate times.

Figure 1. Avoidance rates by exposure level, collapsed across type of aid (Llaneras et al., 2008).

Figure 2 (in Appendix) provides a broader perspective on this issue by compiling data from a number of GM-sponsored backing studies (and available literature) using dash-mounted RVC systems during comparable surprise event scenarios where drivers backed the vehicle in the presence of an unknown rear obstacle. These data demonstrate a similar trend showing increasing rates of avoidance with additional practice and exposure. For instance, naïve users with little
practice using RVC systems (e.g., 4 practice trials) were found to have relatively low avoidance outcomes. Providing naïve users with additional practice (e.g., 12 trials, as in the case of Llaneras et al., 2008, and McLaughlin et al., 2001) increases avoidance rates (30 to 33% avoidance). Moderate practice (approximately 20 trials) under Llaneras et al. [4] was found to increase avoidance rates to 46%, and avoidance rates as high as 65% were observed when drivers were afforded extensive practice with 37 trials [5]. Thus, drivers appear to benefit from increased exposure or practice with dash-mounted RVC systems as indicated by the increasing levels of performance associated with greater practice.

Interestingly, data also found that elevated performance levels are also possible under conditions with no previous exposure or practice with dash-mounted RVC systems. As illustrated in Figure 2, naïve users backing with the RVC system for the first time (no prior practice or exposure to the system) demonstrated extremely high avoidance rates: 88% under a static conflict and 50% under an incurring conflict situation, rates well above the levels found with drivers in previous studies who received extended practice and even system owners. This study [6] found unusually high reliance upon and use of the RVC system, both before and while backing, leading to substantially higher-than-expected rates of detection and avoidance. Since this conflict trial represented the driver's first exposure and opportunity to use the RVC system, drivers appear to have been primed to rely on the aid, resulting in a novelty effect, which in turn led to artificially high performance levels. The implication here is clear: reliable and stable estimates of system effectiveness must take into account the amount of practice or exposure drivers have to these types of aids. Performance associated with naïve system users is likely to vary from that of experienced system owners. Studies must also be aware of the presence of artifacts or other contaminants leading to biased or artificial levels of performance.

EFFECTS OF DISPLAY LOCATION

Another factor influencing performance relates to the location or placement of the RVC system display. Llaneras et al. [3] contrasted the performance of several RVC system configurations that varied the location of the display and the camera field-of-view (FOV). There were two display locations: 1) A 7-inch (measured diagonally) monitor mounted on the center stack area and 2) A 3.5-inch monitor embedded within the left portion of the inside rearview mirror. The images provided by these views were only available when the vehicle was placed in reverse (when the image embedded in the inside rearview mirror was not available, the mirror surface in that area returned to a reflective surface). A surprise event scenario was used to assess the degree to which the aids contributed to the drivers' abilities to detect and respond to rear in-path hazards; an obstacle (a 3-foot traffic cone) was placed behind the vehicle (centered 4 feet from the rear bumper) in advance of a backing maneuver.

As shown in Figure 3, dash-mounted versions of the RVC system (with the display located in the center console) yielded an overall avoidance rate of 20 percent. These rates were observed to increase to 45% by locating the RVC display within the rearview mirror. Although detection performance among the three RVC system implementations varied with higher performance associated with the RVC with rearview mirror inset display condition, no statistically significant differences in detection rates were found as a result of display location or FOV. As discussed later, other factors were found to interact with display location. Nevertheless, the observed trends in detection performance suggest that incorporating the RVC display within the rearview mirror is an effective design allowing drivers to detect and respond to unexpected in-path obstacles under the situations tested.

This study also varied the amount of practice drivers received with the RVC system prior to the surprise conflict event. Figure 4 details the observed avoidance rates during the surprise event scenario by both display location and exposure level. It shows how performance across display location is affected by the amount of exposure. Although breaking down the cases in this manner yields sample sizes that are too small for reliable analysis, several aspects are noteworthy. First, avoidance rates across each type of aid tend to increase with increasing exposure, suggesting that performance improves with usage. Second, the RVC system with a rearview mirror inset display condition yielded avoidance rates of 33% even with low exposure levels; this level of performance was comparable to that achieved with moderate exposure using the in-dash display counterpart. Furthermore, the RVC system with a rearview mirror inset condition led to the single highest observed avoidance rate across all countermeasures. Thus, while both applications (dash and rearview mirror inset displays) were shown to benefit from increased exposure (showing increasing detection rates with greater practice), the...
rearview mirror inset produced relatively high initial levels of performance even under the low exposure condition.

Together, these findings suggest that integrating the RVC system display into the rearview mirror (a location consistent with a driver's typical scan pattern) is an effective design and can provide immediate benefits with minimal exposure or practice, at least under the conditions and settings evaluated in this study. It is important to caution, however, that the performance trends associated with the rearview mirror inset display are in need of validation using a broader range of environments and conditions. Results may not necessarily generalize to other situations with objects varying in contrast and location. In other words, lower contrast obstacles located in the periphery of the display may not be as readily detected as the centrally located, high contrast target used in the present study.

The studies presented in Figure 5 exposed naïve (inexperienced system users) drivers to two common pedestrian backing conflicts, one involving a stationary pedestrian (static scenario) and the other a moving pedestrian (incurring scenario). While the sample sizes and goals across studies differ, data from the surprise event scenarios suggest that the type of conflict scenario impacts a driver's ability to avoid the hazard, with the incurring pedestrian scenario posing a greater challenge compared to static scenarios where the obstacle is present before backing is initiated. Evidence from Llaneras et al. [6], for example, found that avoidance rates dropped significantly from 94% under the static scenario to 63% for the incurring scenario [Chi-Square (1) = 4.57, p<0.03]. Comparable patterns were found for the two other referenced studies suggesting that reliance on the RVC system after backing has commenced is generally insufficient to detect and avoid incurring obstacles.

**EFFECTS OF BACKING SCENARIO**

Backing crashes occur under a range of different situations, conditions, and environments encompassing pedestrian, vehicle, and fixed object crashes [2]. Studies performed by GM/VTTI have characterized driver performance with backing countermeasure systems across a variety of conflict situations and backing maneuvers. The studies have also demonstrated the effects associated with the type of backing scenario. One distinguishing feature is whether or not the scenario involves a static object (present before the backing maneuver is initiated) versus a dynamic incurring object, which emerges during the backing process. Both conflict scenarios present unique challenges, yet each requires the driver to rely on the available aids for detecting the presence of the obstacle located within the vehicle's “blind spot” area. This work has found that the timing of glances to the RVC system display plays a critical role in determining a driver's ability to detect and avoid hazards, particularly for incurring conflict situations arising once the vehicle has started to back.

**SUMMARY/CONCLUSIONS**

Rear Vision Camera (RVC) systems are useful aids, allowing precise vehicle maneuvering for parking and trailer hitching tasks. Their effectiveness relative to the detection and avoidance of unexpected hazards and obstacles was investigated and synthesized during a series of studies revealing a number of important aspects moderating their effectiveness. Dash-mounted versions of an RVC system (with the display located in the center console) were found to yield large variations in performance with overall avoidance rates ranging from 10 to 88% during unexpected conflict events captured across a range of studies performed by GM/VTTI. The amount of exposure, or practice, afforded drivers explains much of the variance in performance, as does the location of the display and type of conflict scenario.

Studies indicate a pattern of improved detection and avoidance with increasing levels of exposure or experience, suggesting that performance improves as drivers learn to
integrate the RVC display into their normal scan patterns. System owners (i.e., drivers whose personal vehicles are equipped with an RVC system and presumably those with the most exposure) were generally found to have the greatest avoidance, while novice users (i.e., those with very little experience with the RVC system) were observed to have the least avoidance. Performance was also observed to increase up to an average of 45% in some cases by locating the RVC display within the rearview mirror. This display location was also found to yield relatively high initial performance levels even with little practice suggesting that integrating the RVC system display within the driver's typical scan pattern can provide immediate benefits with minimal prior exposure under the situations tested. Consistent patterns also emerged suggesting that the effectiveness of RVC systems is also influenced by the type of backing scenario or conflict. For example, scenarios where a pedestrian walks into the path of a backing vehicle (incurring scenario) appear more challenging compared to situations where the pedestrian is present at the onset of backing (static scenario).

One possible concern with the use of any type of supplemental vision system (including an RVC system) is that drivers might come to over rely on these systems, altering their behavior in ways that may otherwise compromise safety such as reducing the search behavior using direct glances or mirrors. Behaviors of specific concern include failing to make or reducing the incidence of direct looks over the shoulder and glances to the rearview mirror to check for potential threats. In the studies referenced here, including naturalistic studies [1] and the widely varied controlled scenario studies, no evidence was found for these types of unintended consequences.

REFERENCES


CONTACT INFORMATION

Individuals seeking additional information regarding this work may contact Eddy Llaneras at (540) 231-1524 or via e-mail at ellaneras@vtti.vt.edu.

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## Table 1. Description of GM/VTTI studies examining driver performance using RVC systems.

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of Drivers</th>
<th>Backing Scenario Surprise Event and Obstacle</th>
<th>Location of RVC System Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>McLaughlin et al., 2001</td>
<td>N= 29</td>
<td>Single static scenario with an enhanced pylon placed 3 feet behind the vehicle.</td>
<td>Dash, center-mounted. Varied type of aid, to include Park Assist (PA)-only, Rear Vision (RV)-only, and PA with RV.</td>
</tr>
<tr>
<td>Lee et al., 2003</td>
<td>N= 48</td>
<td>Single static scenario with an enhanced pylon placed 3 feet behind the vehicle at different lateral locations.</td>
<td>Dash, center-mounted. Varied integration of RV and PA.</td>
</tr>
<tr>
<td>Llaneras et al., 2006</td>
<td>N= 36</td>
<td>Two conflict scenarios: a static scenario in which a traffic cone is placed 5 feet behind the vehicle and an incurring scenario where a child’s ride-on toy incurs into the path of a moving vehicle at close range.</td>
<td>Dash, center-mounted. Integrated within a suite of backing countermeasures, including PA, Backing Warning, and Automatic Braking.</td>
</tr>
<tr>
<td>Llaneras et al., 2008</td>
<td>N= 41</td>
<td>Single static conflict scenario where a 36-inch-tall, high contrast (orange) cone was placed 4 feet directly behind and along the centerline of the vehicle before the backing event.</td>
<td>Two locations: dash, center-mounted and installed within rearview mirror. Also varied camera field-of-view.</td>
</tr>
<tr>
<td>Llaneras et al., 2009</td>
<td>N= 48</td>
<td>Two conflict scenarios: a static scenario in which a pedestrian is stationed 15 feet behind the vehicle and an incurring scenario where the pedestrian walks into the path of a moving vehicle (located 15 feet from the rear bumper at the start of the maneuver).</td>
<td>Two locations: dash, center-mounted and installed within rearview mirror. Also varied presence of speech warning.</td>
</tr>
<tr>
<td>Perez et al., 2009</td>
<td>N= 69</td>
<td>Five different scenarios encompassing pedestrian, vehicle, and fixed-object conflicts. Three scenarios involved a stationary test object and two involved a moving, or incurring, pedestrian. Obstacles varied in distance to rear bumper at maneuver onset, ranging from 5 to 15 feet.</td>
<td>Dash, center-mounted. Integrated within a suite of backing countermeasures, including PA, Backing Warning, and Automatic Braking.</td>
</tr>
</tbody>
</table>
### Figure 2. Avoidance rates as a function of experience (practice) with RVC: comparison across studies with dash-mounted RVC systems. Unless indicated, all scenarios involved a static object present at varying distances before backing was initiated.

<table>
<thead>
<tr>
<th>Scenario / Years / Exposure</th>
<th>Novices, No Practice</th>
<th>Novices, Increasing Amounts of Practice</th>
<th>System Owners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Llaneras et al, 2009, Static, n=8 (0 Trials)</td>
<td>88%</td>
<td>50%</td>
<td>65%</td>
</tr>
<tr>
<td>Llaneras et al, 2009, Incurred, n=8 (0 Trials)</td>
<td></td>
<td>10%</td>
<td>50%</td>
</tr>
<tr>
<td>Llaneras et al, 2008, Low Exposure, n=10 (4 trials)</td>
<td></td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>Llaneras et al, 2008, Moderate Exposure, n=10 (12 trials)</td>
<td></td>
<td>33%</td>
<td></td>
</tr>
<tr>
<td>McLaughlin et al, 2001, n=15 (12 trials)</td>
<td></td>
<td>46%</td>
<td></td>
</tr>
<tr>
<td>Llaneras et al, 2006, n=35 (20+ trials)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Lee et al, 2003, n=48 (37 trials)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Llaneras et al, 2008, n=6 (Owners, 12 trials with vehicle)</td>
<td></td>
<td>65%</td>
<td>42%</td>
</tr>
<tr>
<td>Llaneras et al, 2008, Incurred, n=12 (Owners)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. This process requires a minimum of three (3) reviews by industry experts.

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