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Issues Related to the Use and Design of a Backing Rear Cross Traffic Alert System

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M. Lucas Neurauter and Robert E. Llaneras
Virginia Polytechnic Inst. & State Univ.

Brian Li and Charles Green
General Motors Company

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ABSTRACT

Alternative implementations of a Rear Cross Traffic Alert (RCTA) system intended to actively notify drivers of the presence of rear cross-path traffic when backing were evaluated in naturalistic settings. The feature is one of several emerging technologies designed to assist drivers when backing - in this case, enhancing drivers' awareness of traffic approaching from the rear. The study allowed performance under a range of RCTA system driver interface implementations to be contrasted with conventional and wide Field of View (FOV) Rear Vision systems. Evaluations were conducted using a sample of 70 drivers under naturalistic settings and environments with repeated exposures to backing tasks. The study also made use of a staged conflict situation with a confederate vehicle in order to more precisely quantify driver behavior and system usage across drivers under controlled conflict situations. Contrasts among the experimental configurations allowed for comparisons across the major system design factors, including the use and location of visual warnings, auditory alerts, and Rear Vision system FOV. Results found that use of RCTA systems, which include an audible warning component and Rear Vision screen, reduced backing encroachments into the path of approaching traffic by up to 44%, and enabled drivers to respond faster to the presence of cross traffic as compared to Rear Vision Only systems. Although drivers in this study preferred implementations with a wide camera FOV (180-degree span), related work in this area suggests that preference for camera FOV may be dependent on driver task and functions (e.g., parking, extended backing, trailer hitching, etc).

INTRODUCTION

This study investigated performance benefits and driver behavior associated with the use of an Active Rear Cross Traffic Alert (RCTA) system intended to notify drivers of the presence of rear cross-path traffic when backing. This feature is one of several emerging technologies designed to assist drivers when backing - in this case, enhancing drivers' awareness of traffic approaching from the rear. The system's longer and wider sensing range and active alerting function potentially offers enhanced detection performance over conventional rear vision systems in situations where cross traffic is present.

While all conditions included Rear Vision, driver performance with Active RCTA variants (i.e., those with audible and visual overlay or icon alerting components) was characterized and compared to performance with Rear Vision Only variants (“Passive” RCTA). In addition, both wide (180°) and regular (130°) Field of View (FOV) rear vision system combinations were considered, amongst other system variations. The study recruited 70 drivers, each of whom were exposed to one of the RCTA system combinations, depending upon the experimental condition. The study made use of a staged conflict situation with a confederate vehicle in order to quantify driver behavior and system usage under controlled conflict situations. Evaluations were also conducted using naturalistic settings and environments (e.g., shopping center and mall parking lots, etc.) with repeated exposures to backing tasks, allowing opportunities to capture naturally occurring events.

METHOD

The study approach relied heavily on the use of naturalistic environments in order to capture representative behaviors and to provide visually rich and demanding situations in which to immerse drivers. Alternative implementations of Active RCTA and Rear Vision Only systems were evaluated by varying, between subjects, the type and form of aid available to drivers during backing tasks. Drivers participated in a single 2-3 hour experimental session in which they performed route-following and destination-entry tasks using a navigation system as a means to conduct naturalistic assessments of the RCTA system. System evaluations were also conducted via use of a staged conflict situation occurring before the naturalistic drive, and post-drive subjective evaluations. The study also allowed relationships between driver age and gender to be explored.

HMI CONFIGURATIONS

Seven HMI configurations were evaluated, varying the presence of an Active RCTA (audible beep versus no beep), the presence of a visual warning, the location of the visual warning (rear vision system graphical overlay or outside mirrors), the FOV of the rear vision system (130-versus 180-degree FOV), and whether the rear vision system FOV was automatically switched. Given the complexity of the design, a full-factorial was not used; instead, a subset of HMI configurations was selected for assessment. Contrasts among the seven configurations allowed for comparisons across the major design factors using a between-subjects design involving 70 drivers, 10 assigned to each HMI configuration. All seven configurations tested included the Rear Park Assist (RPA) feature and some form of Rear Vision system, while only four of the groups included the Active RCTA alert. It should be noted that Rear Vision Only conditions with a wide FOV were considered by the research team as Passive Rear Cross Traffic Assistance systems due to their increased sight lines down the traffic aisles, which afforded drivers the opportunity to use the display to detect cross traffic. Groups were balanced by driver age (35-50 and 60+ years) and gender.

As noted, four of the seven HMI configurations included an Active RCTA feature designed to actively alert drivers to the presence of cross traffic when backing. Although the means by which this information was communicated to drivers varied across the four Active RCTA conditions, all included a non-visual alert using a chime consisting of three successive beeps. Two visual warning indicators were used, one exclusively associated with the rear vision system display, and the other inset within the outside mirrors. Each used a different icon to represent the presence of cross traffic. The first consisted of a triangular overlay presented on the Rear Vision display, and took the form of a red symbol (representative of the ISO warning sign) which flashed and indicated the direction of the incurring cross traffic via use of an arrow. The second visual warning used the existing Side Blind Zone symbol in the outside mirrors. Both of these visual warnings are depicted in Figure 1.

Figure 1. Rear Cross Traffic Visual Warnings. Left Depicts the Rear Vision System Overlay, and the Image on the Right Illustrates the Outside Mirror Application using the Side Blind Zone Icon

PROCEDURE

A total of 70 licensed drivers, ages 35 to 76, participated in this study. Drivers were split into two age groups, Middle (ages 35-50, mean age of 43.8) and Older (ages 60+, mean age of 66.3), balanced by gender. Study participants took part in a single 2 to 2.5 hour experimental session which included a structured drive and post-session assessment of each of the seven HMI configurations. Drivers were not initially informed of the true purpose of the study; a ruse was used to lead drivers to the impression that they were evaluating an aftermarket route navigation system. The session was broken up into the following parts and events:

1. Vehicle Familiarization. Participants were escorted to the vehicle and provided an overview of the basic controls and resident vehicle features; this included an overview of the Park Assist, Rear Vision display, Side Blind Zone Alert, and an aftermarket navigation system. Drivers were initially instructed that the purpose of the study was to evaluate the navigation system's ease-of-use.

2. Staged Cross-Traffic Event. Drivers experienced a staged cross-traffic conflict as they executed the backing maneuver of exiting the parking space at the Virginia Tech Transportation Institute (VTTI), while under the impression that they were headed to their first programmed destination. The vehicle was situated so that drivers had to back out of a perpendicular parking space in order to exit the parking lot. Since the vehicle was flanked by two large sport utility vehicles (SUVs) parked in the adjacent spaces, direct sight distance during this maneuver was limited, making it more difficult for drivers to detect approaching cross traffic. As drivers backed out of the parking space, a confederate vehicle entered the parking aisle and drove toward the participant's vehicle (approaching from the passenger side) during the backing maneuver (Figure 2).

Figure 2. Staged Event; Dark colored sedan in parking row (far left) is research vehicle, and white sedan in travel lane was used as the confederate and served as cross traffic

3. Naturalistic Drive. The naturalistic drive afforded the opportunity to capture driver responses to naturally occurring cross traffic and backing conflicts under the various HMI configurations (treated here as a between-subjects factor wherein each driver experienced a single HMI configuration). This drive constituted the majority of the experimental session and had drivers follow a structured route to four commercial businesses (Wal-Mart, Cracker Barrel, Lowe's, and Kroger) using the information provided by the route navigation system. Upon arrival at each location, drivers parked the car and answered a series of usability questions related to the navigation system. Once complete, drivers programmed the navigation system for the next location and exited the parking space; this typically meant backing the vehicle out of the space. A confederate vehicle was also available to stage cross-traffic events at each location, if needed.

4. Post-Drive Questionnaire. Once back at VTTI, drivers were informed of the true purpose of the study and were debriefed about their backing experiences during the course of the naturalistic drive in an effort to assess the extent to which drivers became aware of and relied on the Active RCTA and/or Rear Vision system to detect and avoid cross traffic.

5. Head-to-Head HMI Evaluations. Participants were exposed to all seven HMI configurations during a series of structured backing events as a means of gathering additional information on driver preferences across the alternative configurations. Drivers repeatedly exercised each system configuration as they backed the vehicle in the presence of cross traffic. Perceptions about system likes/dislikes, effectiveness, usefulness, and design factors were captured for each HMI configuration using a structured questionnaire. Thus, each driver experienced all seven HMI configurations with presentation order counterbalanced across subjects.

RESULTS

Results suggest that in both staged and naturalistic events, the presence of an Active RCTA led to significant reductions in the frequency with which drivers were observed to encroach into the path of cross traffic. Similarly, under the more-controlled staged event, brake reaction times (BRTs) suggest that participants were able to both respond to and detect cross traffic sooner in an Active RCTA condition. Although performance advantages between the four Active RCTA conditions were not apparent, a clear front-runner emerged through the subjective HMI comparisons at the end of the test.

ENCROACHMENTS

To assist with analysis, a common reference point was identified and characterized as the last point prior to encroachment into the path of the cross-traffic vehicle. This point, identified as the last video frame within which the cross-traffic vehicle was fully visible, was based on the recorded video using below-bumper mounted cameras aimed down the traffic aisles. Driver behavior was categorized as an encroachment if the research vehicle was still in motion.

Analysis was initially performed to examine encroachment rates for: 1) Rear Vision Only conditions, and 2) Active RCTA conditions. Results found that 88% of drivers without Active RCTA were observed to encroach compared to only 49% for drivers with Active RCTA, a significant reduction of 44% (Chi-Square (1) = 9.97, p = 0.0016), as shown in Figure 3. Although not illustrated, it is important to note that no differences were found when comparing encroachment frequencies between the Rear Vision Only 130- and 180-degree conditions (both at 88% encroachment).

Analysis of cross-traffic events under naturalistic environments revealed similar findings. Cross traffic was present in approximately 65% of the 280 observed naturalistic backing events. In general, results supported findings observed during the staged backing event, with encroachments into the path of cross traffic more frequent for drivers with Rear Vision Only versus those with an Active RCTA by a significant margin; 31% vs. 51%, respectively (Chi-Square (1) = 6.25, p = 0.0124).

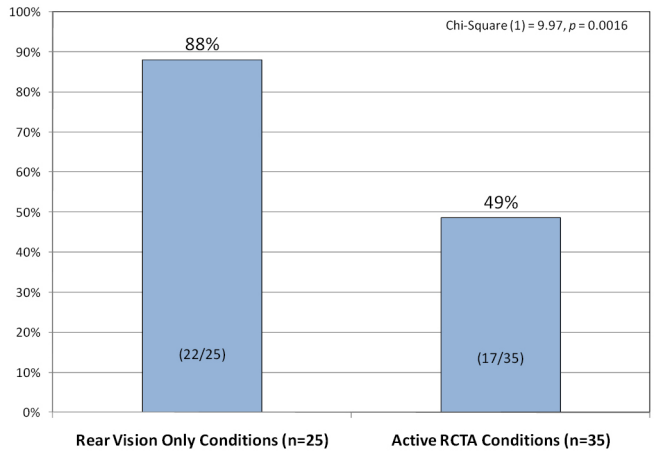

Figure 3. Staged Event Encroachment, Active RCTA vs. Rear Vision Only Conditions

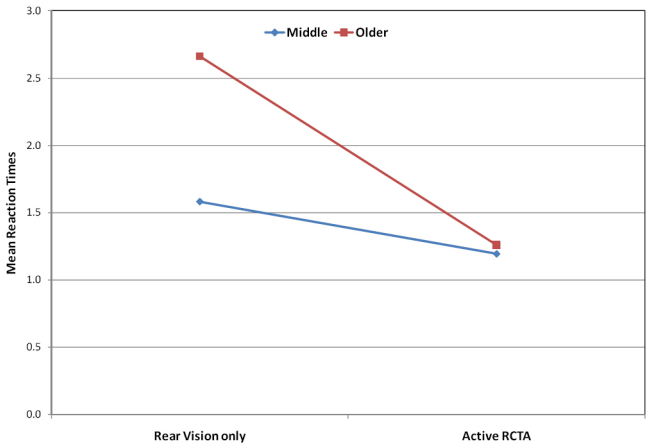

Figure 4. Brake Reaction Times by Age Group

BRAKE REACTION TIMES

Drivers with an Active RCTA were also found to have a BRT advantage over the Rear Vision Only configurations. BRTs were calculated relative to an RCTA Triggering Point (set as time 0). This signal point was generated and flagged in the raw data files whether or not an actual alert was issued (i.e., whether or not the variant was an Active RCTA variant). The presence of an Active RCTA provided an observable advantage over the Rear Vision Only conditions, reducing reaction times from an average of 2.1 seconds down to 1.2 seconds ($F(1,45) = 12.54$, $p < 0.0010$). It is important to remind readers that for the Rear Vision Only conditions drivers were not reacting to a stimulus; rather, their response resulted from direct detection of the cross-traffic threat. No differences in BRTs were found across Active RCTA configurations, suggesting that participants were benefitting primarily from the shared auditory component.

Age Differences

Differences between the two age groups were investigated across the measures discussed up to this point. Ultimately, the interaction effect between the age groups for type of RCTA (active versus passive) was significant for BRTs ($F(1,45) = 5.10$, $p < 0.0292$). The means illustrated in the following chart (Figure 4) suggest that without an Active RCTA (Rear Vision Only), older drivers are slower to respond to cross-traffic threats as compared to the middle-aged group. These differences are not apparent once an Active RCTA is introduced into the environment, suggesting that the inclusion of an Active RCTA normalizes age response times.

SUBJECTIVE EVALUATIONS

Drivers were also systematically exposed to all seven HMI variants in a staged setting, evaluating each on the basis of usefulness, effectiveness, ease of understandability, and likes/dislikes. Once all evaluations were finished, drivers also rank-ordered the seven variants, designating their top three and least-preferred candidate configurations. The raw ranking scores were combined into a composite score for each configuration. Composite scores were calculated by combining the percentage of drivers who ranked a particular configuration as #1 or #2 (the top two) and then subtracting the sum by the percentage of drivers who ranked that particular configuration as last (worst). As shown in Figure 5, drivers overwhelmingly preferred the Active RCTA configuration with the chime and Rear Vision graphical overlay, coupled with the wide FOV Rear Vision (180-degree FOV). The least popular configuration was the Rear Vision Only system with normal view (130-degree FOV).

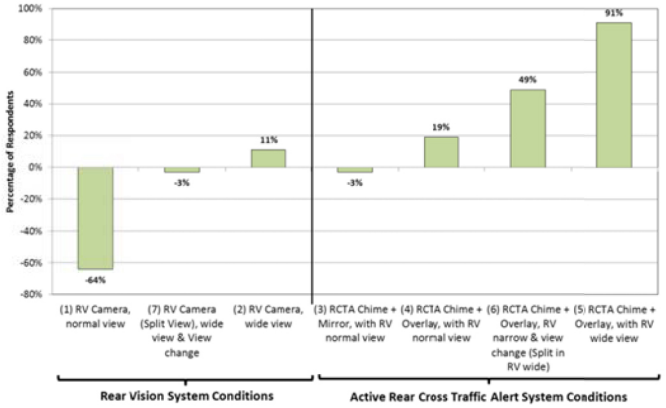

Figure 5. Composite Head-to-Head Rankings Across Variants

HMI LIKES AND DISLIKES

Open-ended items captured what system design elements and aspects each driver liked and disliked about the configuration. As shown in Figure 6, drivers overwhelmingly liked the use of non-visual alerts to actively warn of the presence of cross traffic, and the wide FOV afforded by the 180-degree camera which provided a broader, more encompassing view of the area behind and to the sides of the vehicle when backing. Over one-quarter of the drivers (27%, or 19 out of 70) also commented that they liked the graphical overlay presented on the Rear Vision display which used a flashing red triangle with arrows to highlight the presence of cross traffic. Drivers also liked the use of the Rear Vision system which provided the ability to see and confirm the presence of cross traffic.

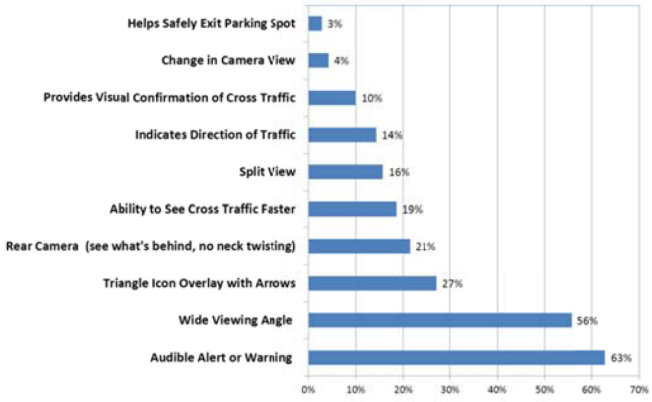

Figure 6. Design Elements and Aspects Drivers Liked. Percentage of Drivers Reporting Each Aspect.

Drivers also identified system features and design aspects they found to be less desirable or simply disliked. Characteristics related to the Rear Vision system were among the most prominent design elements identified by drivers as undesirable; these include camera FOV, display perspectives, and the use of visual overlays. Thirty-four percent of drivers did not like the standard camera views (with 130-degree FOV), or the split-screen perspectives (which many found to be distracting or disorienting). Rear Vision displays which failed to include a graphical overlay (flashing red triangle with directional arrows) were not received as well as displays that included this feature. Systems which lacked the use of a non-visual alert were among the least preferred, with 34% of drivers indicating they desired an active non-visual alerting cue. Some drivers (21%, or 15 out of 70) also found the visual icons placed on the outside mirrors to be of little use for this application given their location and low conspicuity.

SUMMARY/CONCLUSIONS

This study investigated performance benefits and driver behavior associated with the use of an Active Rear Cross Traffic Alert system intended to notify drivers of the presence of rear cross-path traffic when backing. The study made use of a staged conflict situation with a confederate vehicle in order to quantify driver behavior and system reliance under controlled conflict situations as well as in naturalistic settings and environments (e.g., shopping center and mall parking lots, etc.) with repeated exposures to backing tasks, allowing opportunities to capture naturally occurring events. Emphasis was devoted to assessing the degree to which the Active RCTA system or a wide FOV camera system aids drivers in avoiding conflicts with cross traffic while backing.

Results offered a clear preference for inclusion of an Active RCTA, along with a clear front-runner within the Active RCTA conditions; i.e., Active RCTA with visual icons presented as a graphical overlay in the Rear Vision display, coupled with the wide Rear Vision FOV. Objectively, in both staged and naturalistic events, the presence of an Active RCTA led to significant reductions in the frequency with which drivers were observed to encroach into the path of cross traffic, by up to 44% and 39%, respectively. Similarly, under the more-controlled staged event, BRTs measured under Active RCTA conditions were approximately half that of Rear Vision Only conditions, suggesting that participants both detected and responded to cross traffic sooner. Results also did not find performance advantages between the four Active RCTA conditions, supporting an earlier conclusion that the non-visual design feature was the key component in achieving the desired behavioral response in this environment. Finally, evidence did suggest, at least under the controlled staged event, that the presence of an Active RCTA normalized differences in reaction time between the two age groups, affording older drivers a substantial performance benefit.

CONTACT INFORMATION

Individuals seeking additional information regarding this work may contact Luke Neurauter at (540) 231-1522, or via email at lneurauter@vtti.vt.edu.

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