PERFORMANCE OF DRIVERS IN TWO AGE RANGES USING LANE CHANGE COLLISION AVOIDANCE SYSTEMS IN THE NATIONAL ADVANCED DRIVING SIMULATOR

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ABSTRACT

Lane change collision avoidance systems (CAS) are designed to prevent crashes in lane change maneuvers by alerting the driver to hazards in the adjacent lanes of traffic. These systems detect surrounding vehicles that are on the sides and behind the vehicle, notify the driver through warning signals, e.g., a visual symbol in the side or rear view mirrors, and have the potential to reduce the fatalities and injuries associated with these collisions. Currently, these systems are being introduced into new vehicles; however, test data of driver performance using them remain limited.

The objective of this research is to examine driver behavior using lane change CAS to determine what leads to the safest driver behavior and to investigate if the use of a lane change CAS with only a proximity warning system (i.e., blind spot detector) provides sufficient warning to drivers. This study considers drivers in two age ranges with comparatively high crash statistics in these types of crashes: 16-21 years of age and 65 and older. Simulator test scenarios developed for the National Advanced Driving Simulator (NADS) at the University of Iowa are used to examine and compare five lane change CAS types: representative commercially-available proximity warning system, TRW proximity-only CAS system, TRW comprehensive system, a left (driver's) side convex mirror, and a baseline (standard vehicle mirrors). This paper reports on the evaluation of several lane change CAS types using the NADS. An analysis of results including a comparison of both age ranges and conclusions of the study are presented. Benefits for drivers were found for all systems tested.

INTRODUCTION

Lane change collision avoidance systems (CAS) are designed to prevent crashes in lane change maneuvers by alerting the driver to hazards in the adjacent lanes of traffic. From previous studies, it has been determined that many crashes during a lane change occur when drivers are unaware of hazards around their vehicle [1]. A CAS can detect surrounding vehicles that are in zones on the sides and behind the vehicle and notify the driver through the use of a warning signal such as an auditory message or a visual symbol in the side or rear view mirrors. Lane change and merge crashes account for approximately 10 percent of the total of all reported crashes in the General Estimates System (GES) data. To the extent that a CAS helps drivers avoid unsafe lane changes, it has the potential to reduce crashes.

The Space and Electronics Group of TRW developed a CAS consisting of two detection and warning subsystems [2]. The first subsystem, a proximity warning subsystem, detects vehicles in a defined proximity zone on the side of the vehicle including the region referred to as the blind spot. The second subsystem, the fast approach subsystem, detects vehicles further behind the vehicle than the proximity zone that are at high closing speeds approaching the proximity zone.

LANE CHANGE CAS TESTED

Five types of lane change CAS were tested: 1) TRW proximity only system (TRW) that detects vehicles in a defined proximity zone adjacent to and 9.1 m (30 ft.) behind the vehicle including the region referred to as the blind spot, 2) TRW proximity and fast approach system (TRWFA) that detects vehicles further behind the vehicle than the proximity zone that are at high closing speeds approaching the proximity zone, 3) a commercially available limited proximity warning system (LPWS) that typically covers an area approximately 3.5 to 4.2 m (12 to 14 ft.) to the side and up to 7.6 m (25 ft.) back from the external side view mirrors, 4) nonplanar mirror (left side aspherical convex mirror with 1400 mm (55.1 in) radius of curvature), and 5) baseline which is comprised of standard U.S. vehicle mirrors: planar on the driver's side, and a standard convex passenger side mirror. For a more complete description of CAS types used in this study, refer to reference [3]. For all of the CAS except the nonplanar mirror and baseline, the system display was a red triangle that appeared in the field of view in the driver's-side and passenger-side view mirrors when another vehicle is in a vehicle's path (Figure 1). The triangular symbol is lit when it is unsafe to change lanes. Figure 2 illustrates CAS type 4, the nonplanar convex mirror on the driver's side.

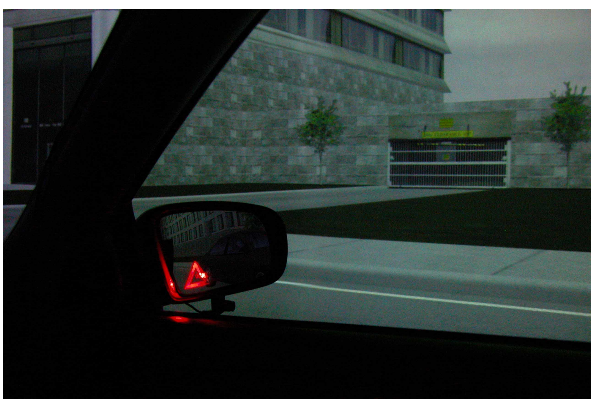

Figure 1. Example CAS simulation in NADS (View from driver's seat of TRW CAS).

SIMULATED LANE CHANGE CONDITIONS

A brief summary of simulated lane change conditions follows. There is additional background information presented in reference [3]. The lane change scenarios occur on non-junction segments of roadway without traffic control with 50 mph speed

Figure 2. View from driver's seat of nonplanar (convex) mirror in NADS.

limits. The status of the blind spot, the actions of the lead vehicle(s), and the direction of lane change defined the lane change scenarios. All three blind spot conditions have been combined with both sets of lead vehicle actions (described in the next section) and both left and right lane changes.

Blind Spot Status

There are three possible conditions of the blind spot. In the first, there is no vehicle in the blind spot. In the second, there is a vehicle in the blind spot and it is traveling at the same speed as the test vehicle. In the third, there is a fast approaching vehicle in the blind spot and it is traveling at a speed 30 mph (48 km/h) greater speed than the test vehicle. It is timed to be in conflict with the test vehicle during the lane change. This third condition for the blind spot status occurs only in the last trial (trial 5). This limitation has been imposed in keeping with estimates for the frequency of occurrence of fast approach vehicles since no on road or simulator data are available for actual driver behavior.

Scenario Development

In the study by Smith, Glassco, Chang, and Cohen [4] metrics defining last-second lane-change characteristics against data collected on a closed course, on the road, and in a simulator were developed. The closed course data were collected as part of the Crash Avoidance Metrics Partnership (CAMP) between General Motors and Ford. The scenarios are more fully described in reference [5]. Drivers approached a stopped lead vehicle, a lead vehicle moving at a constant slower speed, or followed a decelerating lead vehicle. They were asked to either pass the lead vehicle "at the last second they normally would to go around a target representing a vehicle in the adjacent lane" or "at the last second they possibly could to avoid colliding with the target."

The above data were used to design simulation scenarios. In addition, the closing speed has been pre-tested to ensure that the drivers are able to perceive that the vehicle is indeed closing and not staying at the same distance. Also, on-road pre-testing has identified that high profile vehicles in the rear of the test vehicle can occlude the view of the fast approaching vehicle. Therefore, no trucks, busses, or SUVs have been included in the simulated traffic.

Simulated Lead Vehicle Actions

There are two types of lead vehicle actions: 1) Lead Vehicle Braking - the vehicle ahead in the same lane as the test vehicle slows to a distance 50% of the distance that CAMP drivers selected as the hard steering distance to a stopped vehicle[3], and 2) Uncovered Slower Lead Vehicle - the vehicle ahead in the same lane as the subject vehicle makes a lane change to the adjacent lane and reveals (uncovers to the driver's view ahead) a slower lead vehicle when the test vehicle is at the distance 50% of the distance that CAMP drivers selected as the hard steering distance to a slower moving vehicle (driver at 60 mph and slower lead vehicle at 30 mph) [3].

Several outcomes to these lead vehicle actions are possible. In the event that the participant comes to a stop, traffic in the adjacent lane continues to flow by until the lane is cleared. In this case, the participant was asked by the researcher to go around the vehicle in front when the lane clears. If the participant does not change lanes, the slowing/stopped vehicle turns off the roadway. In the event that the participant waits for the lane to clear, the vehicle in the participant's blind spot moves past the participant thereby clearing the lane and enabling the participant to complete the lane change [3].

The direction of the lane change is based on the participant making successful left and right lane changes in response to the lead vehicle actions. Participants are given instructions to change lanes when forced by traffic conditions and to stay in the new lane until forced again by traffic. Lane changes have been in either the right or the left direction. The active lane-change CASs provide similar warnings for either direction. The test convex mirror is mounted only on the left (driver's) side [3].

EXPERIMENTAL DESIGN

The experiment is a split plot (i.e., combination between and within subject design). The between subjects independent variables are age and CAS. There are two levels of age: 16-21 years old, and > 65 years old. There are four CAS systems to be compared to the baseline: TRW proximity (TRW), TRW proximity and fast approach (TRWFA), LPWS, and convex mirror. There are 4 participants per age group by CAS condition. Each participant drove a baseline and one of the four CASs. The within subjects variables have been trial, blind spot status, lead vehicle actions, and lane change direction [3]. For more specific information on the NADS regarding this experiment see reference [3].

Trial 1 is a baseline and is used for comparison against the four remaining trials of CAS (trials 2 through 5). All other independent variables (e.g., where forcing events occur) were random with equal occurrences across subjects. To decrease predictability of events, each trial began at a different point in the driving database [3]. The remaining trials varied from 2 through 5 for the four CAS systems to be evaluated. Note also that 8 younger driver participants completed trial 6 – participants brought back to the simulator again to drive trial 5 in order to increase the amount of data for analysis for the fast approach vehicle condition.

Dependent Variables

The dependent variables were grouped for analysis by kind, i.e., number (frequency of lane changes), proportion, distance, time, angle, and rate. Chi Square analyses were calculated for number data. To minimize the pyramiding of alpha effect, proportion, distance, time, angle, and rate data were analyzed using manovas. Two dependent variables did not fit into the above grouping and therefore were analyzed separately. These two variables were correctness of action based on illumination of CAS and degree of conflict accepted.

Participant Selection

The experiment included 32 male subjects in one of two age categories: 16 to 21 years old (mean 18, SD 1.713) and 65 years old or more (mean 74, SD 5.414, range: 66-83); sixteen subjects in each category. Subjects had to have valid driver's licenses and were all recruited from the vicinity of Iowa City or Cedar Rapids, Iowa. Subjects were paid $10 per hour for their participation. In addition, all subjects were selected for visual acuity, color vision, and contrast detection in the normal range. Male drivers were selected since they had the highest crash involvement in lane change crashes for both groups. The younger age category subject selection criterion was based on crash data from Eberhard et al. [7] and the need to analyze how younger drivers perform critical driving tasks [8]. The second age category was included because of a concern that technology may overload the sensory and perceptual capabilities of older drivers [8]. Although older drivers are not overrepresented in lane change merge accidents, they are in side impacts [9]. This may be due to changes in visual perception, judgment, and attention. These would also affect lane change and merge performance. The older category as a group has fewer crashes and a lower crash involvement rate (than the younger group). However, both groups have similar fatality rates per 1000 licensed drivers. Virtually all behavior slows with age, with performance decrements being more pronounced as task complexity and cognitive demands increase. Making decisions becomes more difficult, as does changing a course of action once a commitment has been made [8]. Therefore, it was expected that older drivers would have more crashes with short decision times and rapidly changing environments. Conversely, it was expected that younger drivers would have more crashes at higher speeds and smaller gap distances.

ANALYSIS OF RESULTS

In the design of the experiment, 1408 lane change events were planned. In addition, 8 younger drivers returned to drive the alternate fast approach scenario since there were insufficient data for analysis in the original data set adding 96 potential lane changes for a total potential data set of 1504. As a result of subject driver's actions, lane change scenarios did not always occur as planned (Table 1). First, there were not equal numbers of events for each of the four types of CASs (312 TRW, 324 TRWFA, 288 LPWS 324 Nonplanar Mirror,). Second, there were incomplete data for events, specifically, only 928 (61.7%) lane changes occurred as planned and had decision and execution phase data as well as eye tracker data. "No event" and "invalid event" data (399 and 5 occurrences, respectively) were not included in the analyses. Rejected lane change data were analyzed separately from accepted lane change data. A rejected lane change consisted of decision phase data only. The decision phase started at lead vehicle braking and continued until the driver turns the steering wheel. Missing decision phase, execution phase, and eye tracker data were treated as missing data in the analyses of the remaining data. In addition, there were insufficient data to determine the effects of subject due to the small number of subjects per CAS condition (4 per condition were planned) combined with the missing data. Finally, since there were only 155 valid lane change events during the baseline condition with an additional 12 events that were valid but without complete eye tracker data, difference scores were not calculated since a missing datum from either the baseline or the CAS trials would have resulted in loss of the non-missing datum.

Table 1. Frequency of data points obtained.

Data Point Condition	Frequency
No event	399
Rejected lane change-only decision phase data	9
Lane change-decision and execution phase data	928
Rejected lane change but no eye data	15
Lane change but no eye data	122
Lane change event but no execution phase eye data	12
Lane change event but no decision phase eye data	9
Lane change-decision phase started before lane change	5
Invalid event	5
Total	**1504**

Number Dependant Variables

Chi Square tests of association were calculated for the following three dependent variables: 1) number of rejected lane changes, 2) number of near warning lane changes, and 3) number of completed lane changes. The independent variables were age, type of lane change CAS, trial, blind spot status, lead vehicle action, and lane change direction. Baseline data were not included in the analyses since the CAS was not active. There were 13 significant associations.

For rejected lane changes, there were significant associations with type of CAS, blind spot status, and lane change direction. For type of CAS, most of the rejected lane changes occurred with the LPWS. For blind spot status, there were no rejected lane changes for the fast approaching vehicle. For lane change direction, participants rejected more lane changes left than right.

For the number of near warnings, there were significant associations with age, type of CAS, trial, blind spot status, and lead vehicle action. For age, there were both more lane changes that were not near warnings for younger (160) than for older (134) drivers and more occurrences of multiple near warning lane changes (i.e., $\geq$ 5 near warning lane changes) for younger than for older drivers. For type of lane change CAS, participants were rarely within one second of a warning for the nonplanar mirror. For trial, greater numbers of near warnings occurred in trials 5 and 6, both of these included the fast approach blind spot status events. Note also that only eight participants completed trial 6, all were younger drivers brought back to increase the amount of fast approach data for analysis. For blind spot status, there were higher numbers of near warning lane changes when no vehicle was in the blind spot.

For lead vehicle action, there were larger numbers of near warning lane changes for braking than for uncovering a slower moving vehicle.

For completed lane changes, there were significant associations with age, type of CAS, trial, blind spot status, and lead vehicle action. For age, younger drivers had higher numbers of occurrences of fewer completed lane changes (i.e., 0, 1, or 2 completed) lane changes than older drivers. For the type of lane change CAS, the lowest numbers of completed lane changes (i.e., 0 and 1) occurred in with the nonplanar mirror. For trial, there were additional lane change events in trial 5 and 6 that were added in the count. These added events were related to the fast approach vehicle in the blind spot condition. Also trial 6 was completed only by 6 of the younger drivers who were called back in hopes of collecting additional fast approach data. The highest number of no lane completed lane changes occurred in trial 5. For blind spot status, 11 of the 40 lane changes were not completed for the fast approach vehicle condition. Finally, there were fewer no completed lane changes occurring in the uncovering a slower moving vehicle condition than in the braking lead vehicle condition.

Proportion Dependant Variables

Manovas were calculated for the following four dependent variables: 1) proportion of lane changes in which driver relies on mirrors, 2) proportion of lane changes in which driver relies solely on CAS, 3) proportion of lane changes in which driver relies or interacts with CAS in a series (not interweaved with other driver tasks but dedicated to the CAS), and 4) proportion of lane changes in which driver relies or interacts with CAS in parallel (use of CAS interweaved with other driver tasks). The independent variables were age, type of lane change CAS, trial, blind spot status, lead vehicle action, and lane change direction. However, since data were collapsed across the last three independent variables to calculate the proportions three manovas were calculated: 1) age, type of CAS, trial, and blind spot status; 2) age, type of CAS, trial, and lead vehicle action; and 3) age, type of CAS, trial, and lane change direction. Note this precluded examining the five-way interactions as well as the six-way interaction. Further, none of the baseline data were used since there was no lane change CAS in the baseline trials. Nor were the data from trial 6 used in the first three analyses since these data were collected from only 8 of the 32 subjects. Trial 6 data were used in the fourth manova using the fast approach data and only examining the effects of age and type of lane change CAS. These data were analyzed separately to avoid violating the homogeneity of variance assumption given the small number of fast approach data. Specifically, there were only 38 fast approach events for which all the data were available and four for which there was lane change but no eye tracker data. The other 33 fast approach events were classified as “no events”.

In keeping with a conservative analysis approach, only the unique combinations of these significant effects were further analyzed. None of the four dependent variables showed a significant age effect. The effect of type of CAS was significant on the proportion of lane changes in which driver relies or interacts with CAS in a series ($F (3, 17) = 8.043$, $p = 0.001$, power = 0.968. The highest proportion was for the two TRW systems and the lowest was for the nonplanar mirror (Figure 3). For the interaction of blind spot status and type of CAS, there was only one significant effect. Again it was on the proportion of lane changes in which driver relies or interacts with CAS in a series ($F (3, 17) = 7.899$, $p = 0.002$, power = 0.997. There were a higher proportion of lane changes in which the driver interacted with the CAS in series when there was a vehicle in the blind spot for the three active CASs (Figure 4).

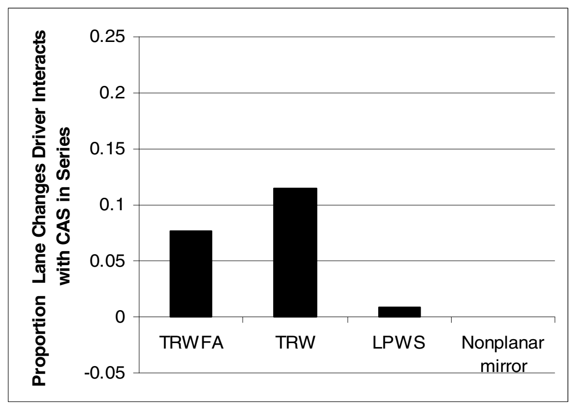

Figure 3. Proportion of lane changes in which driver relies or interacts with CAS in a series as a function of CAS type.

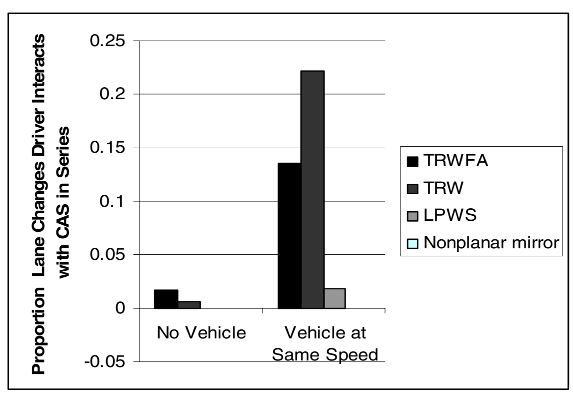

Figure 4. Proportion of lane changes in which driver relies or interacts with CAS in a series as a function of CAS type and blind spot status.

A second manova was calculated from these four dependent variables: 1) proportion of lane changes in which driver relies on mirrors, 2) proportion of lane changes in which driver relies solely on CAS, 3) proportion of lane changes in which driver relies or interacts with CAS in a series, and 4) proportion of lane changes in which driver relies or interacts with CAS in parallel. The independent variables were age, type of CAS, trial, and lead vehicle action. There were only two significant effects: type of CAS between subjects and trial, lead vehicle action, and type of CAS within subjects. Again in keeping with a conservative approach only the unique combination was further analyzed. Only one significant effect was for the proportion of lane changes in which driver relies on mirrors ($F (9, 54) = 1.869$, $p = 0.077$, power = 0.761. For the braking lead vehicle and all but trial 1 for the uncovered slower vehicle, the largest proportion of lane changes in which the driver relied on mirrors was for the TRWFA (Figure 5).

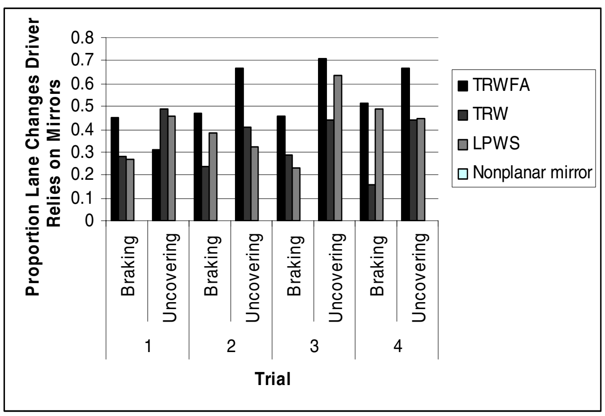

Figure 5. Proportion of lane changes in which driver relies on mirrors as a function of type of CAS, lead vehicle action, and trial.

The third manova was calculated for the effects of age, type of CAS, trial, and lane change direction on: 1) proportion of lane changes in which driver relies on mirrors, 2) proportion of lane changes in which driver relies solely on CAS, 3) proportion of lane changes in which driver relies or interacts with CAS in a series, and 4) proportion of lane changes in which driver relies or interacts with CAS in parallel. There were no significant effects.

Finally, given the small amount of fast approach data, these were analyzed separately in a fourth manova to avoid violating the homogeneity of variance assumption. Of special concern were the 3 data points obtained for the LPWS. There were no significant effects of either age or type of CAS on any of the four dependent variables for the fast approach blind spot status condition.

Distance Dependant Variables

Five distances were planned to be used as dependent variables: 1) lateral gap, 2) longitudinal gap, 3) side mirror subject vehicle to front bumper second vehicle distance, 4) range, and 5) lane deviation. However, since all vehicles were simulated to be the same size, longitudinal gap and side mirror subject vehicle to front bumper second vehicle distance were highly correlated. Therefore, the side mirror based distance was eliminated from further analysis. Range was defined as the square root of the sum of the longitudinal distance squared and the lateral distance squared. The distance used was that between the nearest points on the two vehicles [4]. Next “No event” and “invalid event” data were eliminated from the analysis. Initial planning called for difference scores between baseline and each of the four trials in which the participant drove with a lane change CAS to be calculated. There were large amounts of missing baseline data (70.7% for lateral gap, longitudinal gap, and range and 32.4% for lane deviation). This would have limited the amount of data to be analyzed to only those cases for which there were both baseline and CAS data. Therefore, baseline data were not included in the analyses. Further, given the small number of valid fast approach events, these were analyzed separately and used to examine only the between subjects independent variables of age and type of CAS.

A four-way manova was calculated on lateral gap, longitudinal gap, range, and lane deviation. The independent variables were age, type of lane change CAS (between subjects), trial, lead vehicle action, and lane change direction (within subjects). Blind spot status was not used as an independent variable because lateral gap, longitudinal gap, and range data were only calculated if a vehicle was present in the blind spot. There were insufficient data to perform the analysis therefore the data were collapsed across the independent variable of least interest – trial. There were six significant effects. In keeping with a conservative analysis approach, only the highest order effect that includes all lower order effects was further analyzed. In this case, the highest order effect is the four-way interaction. There were no significant effects on any of the four dependent variables. Therefore the two two-way interactions were examined. Likewise there was no significant interaction of type of CAS and age on any of the four dependent variables. There was no significant main effect of age. There was, however, a significant main effect of type of lane change CAS but only on one dependent variable, lane deviation (F (3, 44) = 3.788, p = 0.017, power = 0.779). The effect, shown in Figure 6, showed the greatest deviation for the nonplanar mirror and the least deviation for the LPWS. A Scheffe post hoc analysis indicated that only the nonplanar mirror and LPWS were significantly different. There was a significant lead vehicle action by lane change direction interaction on one dependent variable – longitudinal gap (F (1, 44) = 6.250, p = 0.016, power = 0.686). The largest longitudinal gap was for the breaking lead vehicle

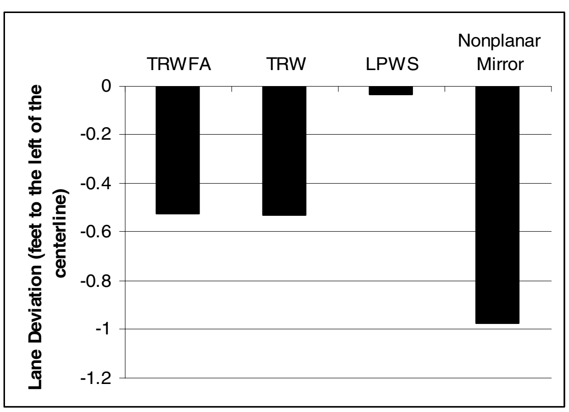

Figure 6. Distance from the centerline as a function of type of CAS.

for right lane changes. The shortest was for the braking lead vehicle for left lane changes. The longitudinal gap for the uncovered slower vehicle was approximately the same (Figure 7).

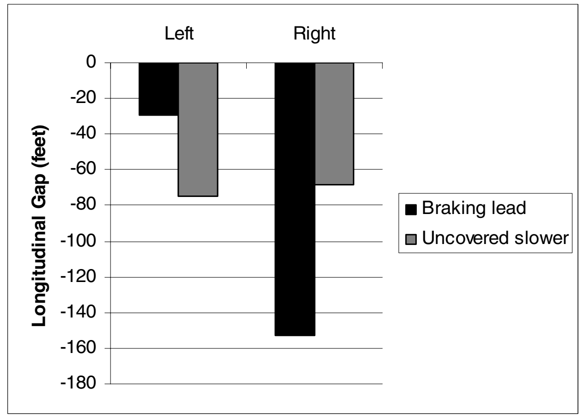

Figure 7. Longitudinal gap as a function of lead vehicle actions.

A two-way manova was calculated for the fast approach data. The independent variables were age and type of CAS. The dependent variables were lateral gap, longitudinal gap, range, and lane deviation. The two main effects were significant: type of CAS and age. Type of CAS had significant effects on three of the four dependent variables: longitudinal gap (F (3, 40) = 3.019, p = 0.041, power = 0.667), range (F (3, 40) = 2.860, p = 0.049, power = 0.641), and lane deviation (F (3, 40) = 5.104, p = 0.004, power = 0.893). Longitudinal gap was largest for the TRWFA and smallest for the nonplanar mirror (Figure 8). Range was smallest for the LPWS and largest for the TRWFA (Figure 9). Scheffe post hoc analyses indicated that the lane deviation associated with the nonplanar mirror was significantly larger than that of any of the other four lane change CASs (Figure 10). For the main effect of age, there was a significant effect on only one dependent variable: range (F (1, 40) = 5.734, p = 0.021, power = 0.647). Range was significantly longer for older drivers (Figure 11).

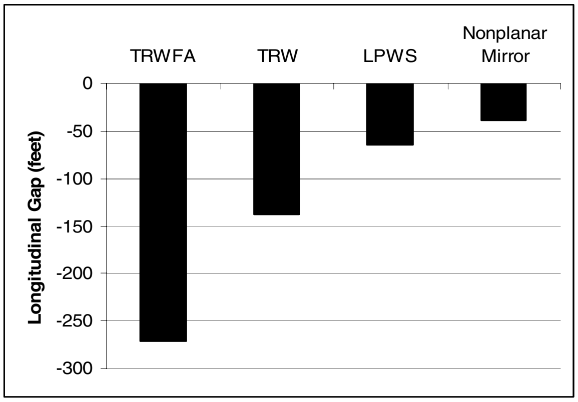

Figure 8. Longitudinal gap as a function of type of CAS.

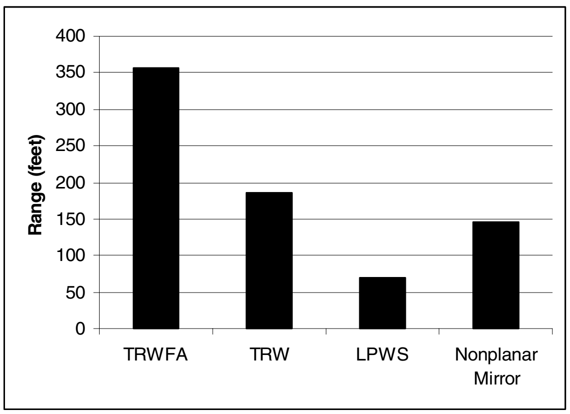

Figure 9. Range as a function of type of CAS.

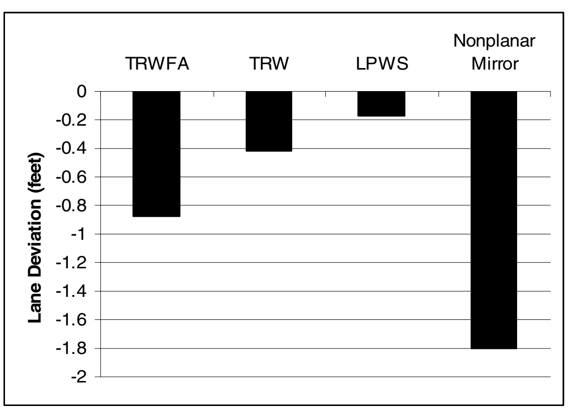

Figure 10. Lane deviation as a function of type of CAS.

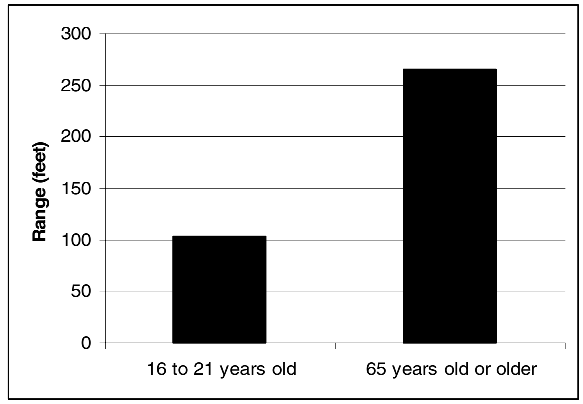

Figure 11. Range as a function of age.

CONCLUSIONS

From the results obtained, some benefits of a CAS were observed for each of the systems. The main advantages found in this study for the two TRW systems were that drivers interacted with the TRW CASs more than the LPWS or nonplanar mirror. This was especially true when the vehicle in the blind spot was traveling at the same speed as the subject driver's vehicle. Drivers relied on the TRWFA most frequently and that was consistent across trials and for both lead vehicle action conditions. Also, the two TRW systems had the largest longitudinal gap and range, another advantage. However, the driver's lane deviation from the centerline was greater for the two TRW systems than for the LPWS, a slight disadvantage for the TRW systems. The largest deviations from centerline and lane deviation distances were obtained from drivers using the nonplanar mirror. Drivers also relied on the nonplanar mirror the least in making lane change decisions, clearly a safety behavior disadvantage over the other systems. The only benefit observed for the LPWS over the other systems was in obtaining the least lane deviation from drivers. However in light of these results, there were no consistent advantages singling out any one CAS examined over the remaining four.

Regarding the age of driver, the only significant effect was found on the dependant variable, range. As expected, the distance was more than double for drivers in the 65 years and older age group than with the 16-21 year olds. Note that the results presented here were obtained from male drivers selected due to their higher involvement in these types of crashes. Differences between male and female drivers were not examined and therefore can not be generalized from the results.

With the introduction of turn signal indicators embedded in passenger and driver side mirrors, mirror systems have become increasingly complex. The interaction of a CAS with these types of mirror systems should be considered in future evaluations of lane change systems to accurately capture driver performance response.

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