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The Effects of Conformal and Non-Conformal Vision Enhancement Systems on Older Driver Performance

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ABSTRACT

The purpose of this research was to systematically examine the effects of two types of vision enhancement system (VES) displays on younger and older driver performance in a variety of contexts. Limitations of previous research on VES and head-up displays (HUD) are briefly introduced. Twenty-four younger and 24 older drivers used either a conformal or a non-conformal VES display while driving in a fixed-base driving simulator. Within each block of trials, traffic scenarios were used to test driver performance: everyday driving, intersection approaches, emergency events, and failure of the VES. Conformal imagery directly highlights aspects of the traffic environment, whereas non-conformal displays are coupled to environmental events, but not superimposed on them. In all driving scenarios, conformal displays had a performance advantage over non-conformal displays. These advantages, however, depend on what is highlighted and whether or not a highlight covers or obscures important information about the environment. The perceived benefits of VES systems are in situations where visibility is limited by weather (e.g., fog, snow, rain), time of day (e.g., night, dusk), or roadway geometry (e.g., curves, railway crossings). Implications of the results for the design of conformal and non-conformal VES, and for future research, are discussed.

INTRODUCTION

The purpose of VES is to increase a driver's ability to see critical hazards (e.g., pedestrians and bicyclists), hazardous objects (e.g., guardrails and black ice), and the roadway (e.g., edge lines), especially during low visibility conditions (i.e., thick fog, rain, snow, and nighttime) (1, 2). VES are implemented in HUDs which present information on the forward field of view of drivers (i.e., on the windshield), or in a dash-mounted display (3, 4).

Conformal imaging is represented by imagery in a HUD that is overlaid on the traffic environment, so that the image is optically superimposed on the object it augments (4, 5). The conformal image offers an additional source of information (about the object) for the driver. As conformal images are overlaid on the external environment, it is essential that placement be at reliably close focal distances to the objects as seen by drivers (6). Conformal imaging is different from non-conformal HUDs. Non-conformal HUDs are collimated at a depth of 2.5 to 4 m on the road in front of the driver (4), and to date have typically presented speed, turn, or hazard signal information, but may also contain information about the traffic environment such as cars and pedestrians.

Gish and Staplin (4) conducted a comprehensive review of vehicle HUD literature. Commonly cited variables are the physical features of the HUD such as legibility and brightness (7) and the spatial configuration (8). In general, it takes less time to retrieve information in a HUD than a HDD (i.e., head-down display, or instrument panel) (9) though such studies operate on the assumption that the information presented requires speeded, accurate response by the user. VES do not necessarily require such responses (especially in the case of conformal VES) rather the intent is to provide advance warning and to aid the driver in interactions with the external environment by helping drivers in the early detection of critical objects.

The nature of the HUD representation through specialized optics makes them prone to such adverse effects as distortion, luminance contrast differences, dark adaptation inhibition, and object misrepresentation (10, 11). HUD users also risk cognitive capture wherein display imagery demands an undue amount of attention (4, 6). Cognitive capture occurs when there is inefficient switching of attention between the HUD and the external environment. Inefficient switching is of paramount importance as it may result in missed external objects and/or delayed responses. Cognitive capture may have implications in the driving context where emergency events occur rapidly and within close proximity to the driver. Gish and Staplin (4) suggest that conditions of high workload and high temporal uncertainty may contribute to cognitive capture.

Fadden, Ververs, and Wickens (12) recently conducted a meta-analysis of HUD studies. They found that the benefits of HUDs are often affected by the format in which they are presented (i.e., conformal or non-conformal), along with user expectancy about the frequency of certain traffic events. The meta-analysis showed that detection is enhanced when HUD users expect the appearance of targets. The meta-analysis also demonstrated benefits of conformal imagery for tracking and detection. However, this particular analysis was entirely based on aviation studies. It did not include any driving studies as none of the driving studies used conformal imagery as a variable. Thus, there is a need for experimental research in the driving domain with conformal HUDs.

Summary of VES Research

Research on VES is reviewed in depth in Caird et al. (13). Responses to some targets within the VES improved as drivers were given more exposure in both laboratory (e.g., perception-response time (PRT) decreases for unexpected events) (14) and field (e.g., earlier detection) (15) experiments. These are expected benefits of VES suggesting that earlier perception of hazards will result in earlier responses to the hazards, possibly avoiding late detection errors. While responses to events in the VES improved, perceived mental effort and demand (16), and frustration (14) increased when using a VES. Outside the narrow visual range of a VES, responses to targets in the periphery degraded (17). Speed and lane deviation measurements with VES, however, revealed non-convergent results. Although driving speed rose with increased exposure to a VES in the laboratory (14), it decreased with exposure in field tests (16). Gish et al. (18) found older drivers reported that they were often uncomfortable looking down at a VES display, whereas the younger participants were much more receptive to using the technology. Given the methodological concerns with previous VES studies and the questioned fidelity of infrared test systems, coming to consensus on the effects of specific dependent measures is difficult.

A major limitation of both the reviewed simulator and field testing of VES is the fidelity of the system and the external features it detects. The potential advantage of a VES is in the detection and response to human and animal hazards deemed critical to the primary task of safe driving. The purpose of a VES is not to enhance a central field of view to the driver. The purpose instead is to enhance only particular objects (e.g., pedestrians, other vehicles) within that range. This would, theoretically, enable the driver earlier detection and recognition, as a result of reduced search time. If, instead, a VES were to fully enhance a section of the central view (i.e., 15° x 10°), then the task to the driver would be to not only detect and recognize critical objects through the entire windshield, but also within the enhanced image representation. This would result in the increased likelihood of captured attention in the enhanced section of the windshield and missed signals outside the enhanced central view (10).

Present Study

The essential issue of VES is the degree to which drivers—especially those who are older with declining visual capabilities—are able to detect and use system information to control their vehicles safely. While these systems are touted to aid drivers during adverse (i.e., nighttime, fog, inclement weather) driving conditions, convergent and reliable experimental results are as yet unavailable. It is not known, for example, whether or not drivers will adopt higher speeds at night (a negative behavior compensation) because they can see further ahead. What and why a portion of the traffic environment should be enhanced should guide the selection and application of VES technology. Convergent empirical evidence for the safety and performance of these systems under a variety of simulated and real-world contexts is needed (19). The purpose of this research project is to focus on which real-world objects should be enhanced and how these enhancements affect older and younger driver performance in important traffic contexts.

METHODS

Participants

Forty-eight participants completed the study; half were younger drivers (aged 18 to 32, M = 23.5) and half were older drivers (ages 67 to 86, M = 71.9). Each age group had 24 participants, equally balanced between men and women. All had valid driver's licenses and drove, on average, 17,500 km per year (10,900 miles). Older participants drove an average of 3,000 km per year more (1,800 miles) than their younger counterparts. Younger drivers were recruited using posters on the campus of the University of Minnesota. Seventeen younger drivers had corrective vision lenses. The average corrected visual acuity for this group was 20/20. All younger participants had normal contrast sensitivity. Older drivers volunteered from a number of community programs in the Twin Cities (e.g., the Elder Learning Institute and the Elder Hostel Programs). Twenty older drivers had corrective vision lenses. The average corrected visual acuity for this group was 20/24 and all participants displayed acceptable levels of contrast sensitivity. Participants were required to score in the normal range for the Stereo Optics™ Sine Wave Contrast Test for no fewer than 3 of the 5 spatial frequency functions. All participants were paid $20 US for participating in the study.

Materials

Simulator Hardware

This study was conducted using the flat-screen driving simulator at the Human Factors Research Laboratory at the University of Minnesota. Participants were seated in a 1989 Honda Accord LX situated in front of a 2.96 m wide by 2.2 m high Draper™ white screen. A NEC MultiSync™ MT 830+ data projector with a resolution of 800 x 600 pixels was used to project the driving simulation images. A 250 MHz Silicon Graphics Indigo™ 2 computer with 128 MB of RAM ran the simulation.

Software and Modeled Environment Overview

Driving environments were created using Medit™ Version 2.1m (Open GL) 3D graphics software and LynX™ Version 3.2 development software. Driving scenarios were developed for the study, each approximately 700 m to 1000 m long. In these scenarios, the road layout consisted of straight, bi-directional roads in city urban areas with one lane in each direction. Buildings, trees, open areas, and other vehicles were randomized across the scenarios. Six trials were developed to obtain baseline measures. Nine trials in day conditions with VES were developed, as were 10 with varying levels of visibility in fog. Each of the scenarios or experimental trials is described in the Procedure section.

Vision Enhancement Systems

Two types of VES were developed; one conformal and one non-conformal. Figure 1 A and C show conformal displays in daylight and fog, respectively. Figure 1 B and D show non-conformal displays. Both systems enhanced moving and parked vehicles and, in the intersection scenario, the traffic light.

Conformal vision enhancement of moving and parked vehicles consisted of a horizontal blue bar superimposed on the front and rear bumpers. As the vehicles approached, the blue bar increased in size (corresponding to the increasing size of the bumper). In the fog trials, the horizontal bar was seen at a greater distance than the vehicle itself.

Non-conformal vision enhancement of moving and parked vehicles consisted of an expanding blue bar placed at 1.2° below the line of sight, directly in front of the driver. The expansion was coupled with the approach of the vehicle such that the size of the bar corresponded to size increases of the vehicle's bumper. The bar alerted the driver as to the approach of a vehicle but offered no visual cues as to the location of this vehicle, that is, whether parked on the right, left, or oncoming. To use the non-conformal information, participants had to scan the environment for a corresponding object.

In two scenarios, one for day and one for fog, the traffic light at the intersection was highlighted by the conformal and non-conformal VES. For the conformal condition, a blue bar was placed behind the traffic light such that it surrounded the light. For the non-conformal display, an expanding blue bar was placed on the road which was identical to the bars placed on the vehicles in the conformal condition. The traffic light, however, was superimposed on the bar thus denoting the approach to an intersection. The colour of the traffic light was not represented on the approaching bar (see Figure 1 D).

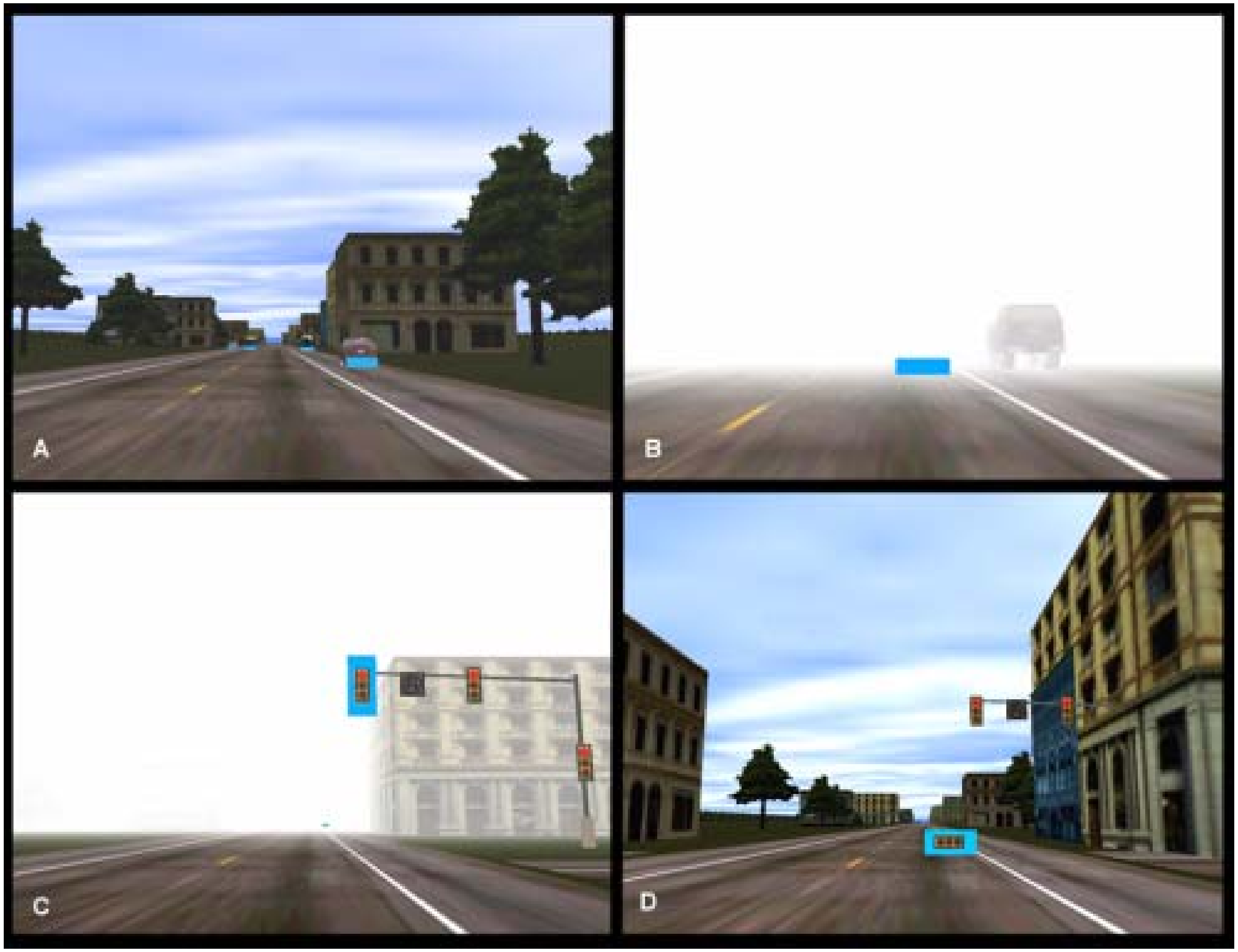

FIGURE 1 Conformal and non-conformal VES displays.

Procedure

At the beginning of the 90-minute session, participants completed an informed consent form, a driving experience questionnaire, and tests for visual acuity and contrast sensitivity. Participants were given a short verbal overview of the study followed by two practice trials in the driving simulator. Participants were randomly assigned to either the conformal or non-conformal condition. Participants were instructed to drive as they normally would and to obey traffic rules. The participants were not told how to respond to traffic lights, other vehicles, or pedestrians.

The baseline block was completed first, followed by the day and fog block of trials. Participants could take a short break after each block if they desired. All the scenarios within the three blocks were counterbalanced. The baseline scenarios were performed in daytime conditions and did not include any VES imagery. Five baseline scenarios were completed: four intersections (two light changes and two no light changes), and one everyday driving scenario. During these trials, baseline measures of lane position, perception-response time (PRT), and response types (e.g., brake and / or steer) for the various events were recorded. PRT is defined as the time for drivers to detect and identify an event (e.g., pedestrian, light change), decide on an appropriate course of action, and to initiate the response (i.e., press the brake, steer away from the hazard) (20). Following the baseline session, participants were given several practice trials with either the conformal or non-conformal VES in day conditions.

After the practice trials, participants completed a series of experimental trials; three were intersections (two light change and one no light change), one pedestrian, and one everyday driving scenario. In the fog session, participants were given similar sequences of driving scenarios.

Everyday Driving

Each of the scenarios is illustrated in Figure 2. Everyday driving is shown in panel C. Participants first drove past five vehicles parked on the right-hand side (at varying distances apart) followed by five approaching vehicles in the oncoming lane. Vehicles were in similar locations during the fog session but visibility was reduced to 40 m. The reduced visibility was intended to mask the lane markings (i.e., center and shoulder line) thus making lane tracking more difficult.

Intersection

Four intersection scenarios were developed (see Figure 2 B). The intersection stoplight was green as each participant approached. In two of the scenarios, the light did not change. In the other two scenarios, the light changed from green to yellow to red. The timing of the light allowed drivers to brake safely or, if they chose, to proceed through the intersection during a red light. The timing constraints of the present scenario made stopping for the lights at the intersection challenging. In one of the light change scenarios another vehicle approached the intersection at the same time as the participant’s car. The purpose of adding the other vehicle was to increase the visual workload of the situation. In the other light-change scenario, there was no oncoming vehicle at the intersection. In the fog conditions, the visibility of the intersection was reduced to 155 m. At this level, the light change to yellow could be perceived at a distance of 68 m to the intersection (see, e.g., Figure 1 C and 2 B).

Pedestrian

The surprise appearance of a pedestrian was presented to measure a participant’s ability to respond to an unexpected event (see Figure 2 D). When the pedestrian appeared, drivers had 35 m or approximately 2.3 s in which to respond (i.e., steer and/or brake). For the fog session, visibility was reduced to 60 m. Although the pedestrian was slightly masked by the fog, he was clearly visible (see Figure 2 D).

FIGURE 2 Traffic scenarios used in the study.

Failure Trials

At the conclusion of all experimental trials, participants were presented with a VES failure scenario. Visibility in the fog was set at 80 m for both the conformal and non-conformal failure trials. In the conformal VES failure trial, participants approached an intersection with a green light as an oncoming vehicle approached simultaneously. The VES bar, however, was misaligned. Instead of appearing superimposed on the bumper of the approaching vehicle, the VES bar appeared in the lane directly in front of the participant's car. The misaligned bar was visible from a great distance, but it was not clear which lane it was in until it was closer. The misaligned bar was not consistent with previous experiences, but may be indicative of the technical difficulties of aligning sensor and real-world information at the eye of the driver. In the non-conformal failure instead of the normal expansion of the bar as the vehicle approached, an oscillating figure-8 pattern appeared. An oscillating bar may represent a general sensor or cross-talk failure of the VES.

Participants then completed a short questionnaire that addressed the utility and preference for the VES as well as the realism and effects of the simulation. They were then debriefed on the nature of the study, and remunerated for their participation.

RESULTS

Experimental Design

The experimental design was a 2 (Age: Younger, Older) x 2 (VES Type: Conformal, Non-conformal) x 2 (Condition: Day, Fog). Each participant experienced baseline, day, and fog conditions. Half of the participants were in the conformal VES group and the other half were in the non-conformal VES group. Age and VES Type were between-subjects variables and Condition was a within-subjects variable. Each of the scenarios was analyzed separately (i.e., Everyday, Pedestrian, Intersection, and VES Failure).

Everyday Driving

During this scenario, participants drove a section of roadway which varied in oncoming and parked vehicles. The dependent variable collected was lateral separation distance between the participant's vehicle and parked and oncoming vehicles. In both the conformal or non-conformal displays increased separation distance was of interest. The greatest separation distance was assumed to be at the point of passing a parked or oncoming vehicle (see, e.g., 21, 22).

For parked vehicles, a MANOVA for Gender (male, female), Condition (baseline, day, & fog), Age (young, old), and VES Type (conformal, non-conformal) found a significant Condition main effect ($\underline{F}(2, 92) = 3.29$, $\underline{p} < 0.041$). Age, VES Type, and Gender were not significant nor were there any interactions. Post hoc comparisons found differences between baseline and day ($\underline{p} < 0.025$), and day and fog ($\underline{p} < 0.037$). Day separation was less ($\underline{M} = 1.51$ m) compared to baseline ($\underline{M} = 1.61$ m), and fog ($\underline{M} = 1.61$ m).

Oncoming vehicle separation from the participant's vehicle was tested with a MANOVA with the same between and within variables as parked. The VES Type by Condition interaction was significant, $\underline{F}(2, 90) = 4.39$, $\underline{p} < 0.015$. Age and gender were not significant. Figure 3 shows the means of baseline, day, and fog conditions for conformal and non-conformal displays.

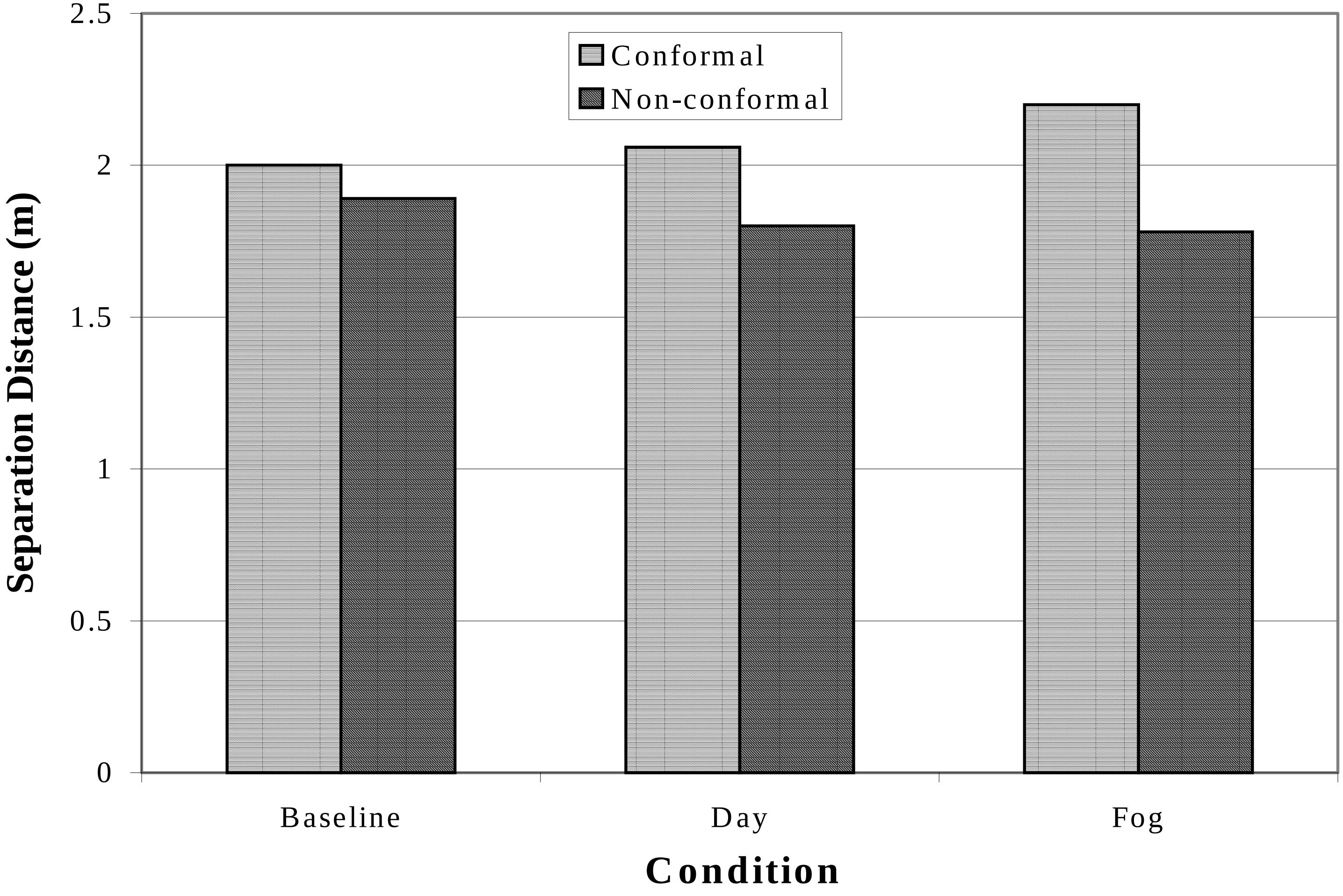

FIGURE 3 Separation distance to oncoming vehicles across baseline, day, and fog conditions for conformal and non-conformal VES displays.

Those who used the conformal display kept a greater separation distance in day and fog conditions than those who used the non-conformal display.

Pedestrian Sudden Appearance

The sudden appearance of a pedestrian from between parked cars occurred twice; once in day and once in fog. The most effective response was to brake and steer to avoid striking the pedestrian (see Figure 2 D). Response type and PRT were analyzed.

When the first pedestrian appeared during the day, 18 of 43 participants struck him. Seventeen of the 18 participants braked and one steered. Of those who did not strike the pedestrian, 17 steered and braked, and 8 steered only. Fewer participants struck the pedestrian in the fog (13) and again these drivers braked, but too late. Thirty-five avoided the pedestrian distributed across brake (16), steer (3), and brake and steer (16).

PRTs to the pedestrian, as indicated by either the first movement of the brake or steering wheel deflection, was faster when using the conformal display in day (M = 1.33 s, SD = 0.16) and fog (M = 1.51 s, SD = 0.31) than those that used the non-conformal display during the day (M = 1.48 s, SD = 0.18) or in fog (M = 1.73 s, SD = 0.62). A MANOVA for Age (young, old), Gender (male, female), VES Type (conformal, non-conformal), and Condition (day, fog) with velocity at the time the pedestrian first appeared as the covariate, found a significant effect for condition ($F(1, 41) = 9.98$, $p < 0.003$) and VES Type ($F(1, 41) = 11.22$, $p < 0.002$). Figure 4 illustrates these main effects. Age, gender, and interactions were not significant. PRTs in fog conditions were slower than during the day. PRTs to the pedestrian were faster with the conformal display than with the non-conformal display.

Intersection Scenario

Approximately two-thirds of the participants ran the stoplight on the first and second baseline trials. During the day trials about half stopped and half ran the stoplight. In the fog,

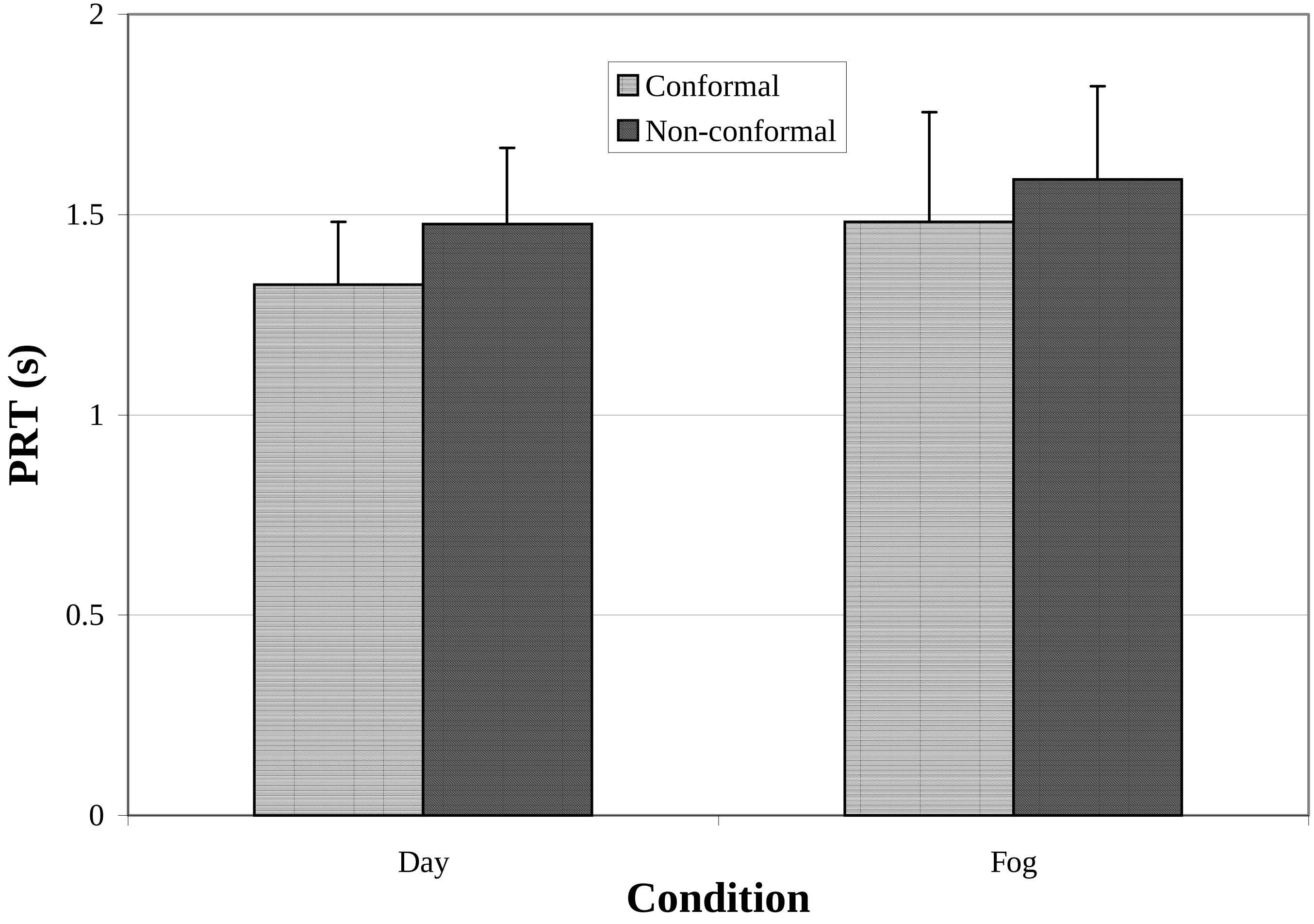

FIGURE 4 PRT to the sudden appearance of a pedestrian by condition for conformal and non-conformal VES displays. Error bars are one standard deviation.

about two-thirds stopped for the light. Initial velocity at the green to yellow and yellow to red changes were slower in fog. Within the stop or run the light responses, a number of trends are evident. More older drivers ran the stoplight in day (13) and fog (10) than younger drivers in day (8) and fog (6). This may be due, in part, to slower response capabilities by the older sample. Those with the conformal display tended to run the light less often in day (8) and fog (5) than those who used a non-conformal display (day, 13; fog, 11). Additional scan time to determine what the non-conformal display was coupled to in the environment may account for having less time to stop for the traffic light and thus, more instances of running it. Finally, enhancement of the stoplight, either conformally or non-conformally, tended to benefit drivers in this condition. Because the stoplight appeared in the non-conformal display, search was minimized.

Qualitative Analyses

Six open-ended questions which addressed positive and negative perceptions of the conformal and non-conformal VES were analyzed in depth. Self reports of the fidelity and realism of the fog seems to support that the fog used in the primary experiment was adequate. When asked whether the VES helped them to notice hazards, both younger and older drivers responded that both types of VES systems made them more aware of other vehicles, but not necessarily to unexpected hazards such as pedestrians. In general, older drivers appeared to be somewhat more skeptical of the utility of VES than younger participants. When asked whether VES interfered with their ability to respond to hazards, participants mentioned that the pedestrian may not have been noticed as quickly because attention was focused on the enhancements. For those who experienced the non-conformal VES, a number wrote that the display obscured a portion of the roadway. Focus on the enhancements may reduce the use of perceptual cues such as the outline of vehicles. A reduction in scene scanning was also mentioned.

Participants were asked what they liked and disliked about the VES. Positive comments included: assistance in fog; felt safer (conformal); highlighted the traffic light; and helped to know where other vehicles were. Negative comments or dislikes included: distracting when many vehicles were present (conformal); makes a driver only look out for cars; did not show pedestrians; did not show where vehicles were (non-conformal); and too much effort to match bars to cars (non-conformal).

The final pair of questions asked which traffic situations would benefit from enhancements and which would not. When environmental conditions restricted visibility, such as night, snow, fog, and rain, VES was thought to be advantageous. Locations where it may benefit included: intersections, railway crossings, parked vehicles that were running, and during rural driving. Extremely heavy traffic and cluttered environments were thought to be poor situations for the application of VES. Daytime driving, which was a phase of the testing regimen, was also thought to be a place where VES may decrease driving performance.

DISCUSSION AND CONCLUSIONS

Experimental Results

The reported research study tested conformal and non-conformal VES displays during the day and in fog with younger and older drivers. Separation distance to oncoming vehicles was greater in the conformal condition than the non-conformal condition. This increased separation is a positive benefit in fog because it allows for a larger safety gap between the driver's vehicle and other road users thereby allowing them more room to maneuver in the event of an emergency. In the day and fog conditions, responses to the sudden appearance of the pedestrian were faster for the conformal display than the non-conformal display. The presence of the non-conformal bar in a central location may have inadvertently made the task of detecting the pedestrian more difficult. The pedestrian appears in close proximity to the non-conformal VES bar. The bar may have therefore visually masked the pedestrian. Highlighting the stoplight reduced the need to scan the environment for the link between the display information and environment information. If highlighting information is not attached to intended objects, certain types of technical problems such as the reliability of conformal systems may cause drivers to stop when they need not.

Subjective impressions of the conformal and non-conformal systems, once experienced, were quite interesting. The perceived benefits of VES systems are in situations where visibility is limited by either weather, time of day light levels, or roadway geometry. VES devices may distract, especially when unexpected events occur. Less than one-quarter of participants said they would use a VES with regularity if it were installed in their vehicle. Although separation distance increased when oncoming vehicles were highlighted with a conformal bar, enhancement of parked and oncoming vehicles was thought to be of questionable usefulness.

Overall, conformal displays can clutter the traffic environment with blue bars which may distract drivers. Non-conformal displays require the driver to scan the environment for the link between displayed and environmental objects. In settings where boredom may prevail, this may increase vigilance. However, in congested heavy traffic, the highlighting information may add to the visual workload. Conformal displays provide enhancements in the spatial location where needed. Non-conformal displays heighten awareness of approaching objects.

With the exception of the intersection scenario, differences between younger and older drivers were not found in the quantitative analyses. Older drivers are known to have difficulties with intersections (23) and tend to have higher accident involvement (24). The absence of statistical differences between age groups should be interpreted as a positive result. The sample of older drivers in the primary study were active physically and mentally. Of course, increasing the number of participants over the age of 75 could reveal a number of age differences that were not indicated in the present study. Although the studies did not address night driving, future studies that do may want to include a larger sample of older drivers that do not drive at night. Only 2 of 24 older drivers in the study agreed or strongly agreed with the statement that they do not drive at night.

Experimental design trade-offs limited specific comparisons that could be made. In particular, the set ordering of baseline, day, and fog may have introduced order or learning effects. A fog baseline condition against which to compare fog performance would have been beneficial. The decision to not have a fog baseline was made because participants would have had to come back for a second session. Unfortunately, this was not logistically or economically feasible. Allowing participants to drive as they would ordinarily made data reduction, classification of behaviors, and analysis problematic. Analysis of the car following and intersection scenarios was limited as a result. The use of scenarios for testing performance in specific contexts was relatively effective (35) and achieved a greater degree of ecological validity. However, constraints to a scenario where fewer choices are available would significantly increase the statistical power of certain comparisons. In the future, scenarios should be constrained so that quantifiable behaviors can be extracted.

Simulation of nighttime and snow conditions is exceedingly difficult to achieve in a driving simulator due to luminance limitations of projection systems and the computational burdens of snow. Simulation of differential wheel traction is also computationally intensive. Fog is relatively easy to model graphically.

Conclusions

Ideally, a VES forewarns the driver of changes in road geometry and the presence of potential hazards such as pedestrians and animals on or near the road. Once illustrated using salient visual cues, a driver reacts appropriately and proceeds safely. Pragmatically, these goals are not so easily achieved (25, 26). Coupling or overlaying of visual cues onto the roadway or pedestrians is limited by technical and driver constraints. When a visual cue is placed over an environmental cue to increase the contrast and salience of that cue, the environmental cue may then be obscured. In addition, a highlighted cue is then increased in relative importance over others. Highlighting may be insufficient to allow a driver to identify an object and react appropriately. The additional processing necessary to achieve recognition may exceed the additional detection time had the object not been highlighted. Basic human limitations constrain performance with each type of enhancement. Response time increases and decreases are possible depending on signal detection, signal confusion, distraction, and response selection. If additional clarification of a signal is required by a driver to identify a hazard, response time may not be optimal. If presentation of visual enhancements is consistent for a long period of time, response selection with each becomes more efficient.

Enhancing the salience of certain visual cues, such as oncoming and parked vehicles, may re-order and restrict the prioritization and search for more important cues (27). Perceptual and response experience with a system is necessary before the highlighting of new cues achieves an appropriate level of performance. If VES systems are operated only at night or in limited visibility conditions, acquiring sufficient experience may be an issue (33). Specific highlighting of one object over others, implies that the object is of recognized importance by traffic safety experts. Treatment of the environment with retroreflective material indicates the importance of edgelines, centerlines, stoplines, signs, and pedestrian clothing to vehicle control, hazard detection, and traffic control adherence (28). VES may provide information that is redundant, replaces, enhances, or is non-essential. The placement of the information within the vehicle, in the environment, or both logically follows. Each kind of enhancement has advantages and disadvantages and the relative effectiveness of each to increase mobility and safety is rarely known.

Future Research

Like many human factors research endeavors, long-term use of a technology was limited in this study (29). Long-term adaptation to a VES display would, hypothetically, allow older drivers to perceptually learn the salience of visual enhancements. Similarly, when to use the system could be learned. If VES devices were installed in a driver's own vehicle for a prolonged period of time, strategic uses could be observed (30). Increases in driver speed above previous levels on routine routes could be determined (i.e., to determine behavioral adaptation) (31, 32). The use of VES to achieve ends is not in the best safety interests of the driver (34).

A number of the conformal enhancements made in the present study are not technically possible at this time. What should be enhanced is a crucial question. How can highlighted information be coupled to existing responses without interference? Is detection less likely, in the presence of enhancements, when unexpected events occur? These are critical questions that must be addressed in the design of VES. Specification of enhancement that is meaningful to the driver, can be integrated into a repertoire of actions, and is technically feasible should determine the direction of research and development as opposed to brute technology infusion into the driver's cockpit.

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REFERENCES

1. Kyle, R. NightSight family of products. *Paper presented at the 3rd Annual Automotive Enhanced Driving/Night Vision Conference.* Sept., 1997. Detroit, MI.
2. Parkes, A.M., Ward, N.J., & Bossi, L.L.M. The potential of vision enhancement systems to improve driver safety. *Le Travail Humain,* Vol. 58, No. 2, 1995, pp. 151-169.
3. Flannagan, M.J., & Harrison, A.K. *The effects of automobile head-up display location for younger and older drivers.* Rep. No. UMTRI-94-22. Ann Arbor: University of Michigan Transportation Research Institute, 1994.
4. Gish, K.W., & Staplin, L. *Human factors aspects of using head-up displays in automobiles: A review of the literature*. Interim Rep. DOT HS 808 320. Washington, D.C.: National Highway Traffic Safety Administration, 1995.
5. Wickens, C.D., & Long, J. Object versus space-based models of visual attention: Implications for the design of head-up displays. *Journal of Experimental Psychology: Applied,* Vol. 1, No. 3, 1995, pp. 179-193.
6. Tufano, D.R. Automotive HUDs: The overlooked safety issues. *Human Factors,* Vol 39, No. 2, 1997, pp. 303-311.
7. Okabayashi, S., Sakata, M., Fukano, J., Daidoji, S., Hashimoto, C., & Ishikawa, T. *Development of practical heads-up display for production vehicle application*. SAE Technical Paper No. 890559. New York: Society of Automotive Engineers, 1989.
8. Sojourner, R.J., & Antin, J.F. The effects of a simulated head-up display speedometer on perceptual task performance. *Human Factors,* Vol 32, No. 3, 1990, pp. 329-339.
9. Kiefer, R. *Effect of a head-up versus head-down digital speedometer on visual sampling behaviour and speed control performance during daytime automobile driving.* SAE Technical Report Paper No. 910111. New York: Society of Automotive Engineers, 1991.

10. Ward, N.J. & Parkes, A. Head-up displays and their automotive application: An overview of human factors issues affecting safety. *Accident Analysis and Prevention*, Vol 26, No. 6, 1994, pp. 703-717.

11. Chugh, J. S., & Caird, J. K. In-vehicle train warnings (ITW): The effect of reliability and failure type on driver perception response time and trust. *Proceedings of the 43rd Annual Meeting of the Human Factors and Ergonomics Society Meeting*. Santa Monica, CA: Human Factors and Ergonomics Society, 1999, pp. 1012-1016.

12. Fadden, S., Ververs, P.M., & Wickens, C.D. Costs and benefits of head-up display use: A meta-analytic approach. *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*. Santa Monica, CA: Human Factors and Ergonomics Society, 1998, pp. 16-20.

13. Caird, J.K., Horrey, W.J., Chugh, J.S., & Edwards, C.J. *The effects of conformal and non-conformal vision enhancement systems on older driver performance.* Rep. No. TP 13422E. Montreal, Canada: Transportation Development Centre, Transport Canada, 2000.

14. Nilsson, L., & Ålm H. Effects of a vision enhancement system on drivers' ability to drive safely in fog. In A. G. Gale et al. (Eds.), *Vision in Vehicles V* Amsterdam: North-Holland. Elsevier Science, 1996, pp. 9-18.

15. Ståhl, A., Oxley, P., Berntman, M., & Lind, L. The use of vision enhancements to assist elderly drivers. *Proceedings of the First World Congress on Foundations of Transport Telematics and Intelligent Vehicle-Highway Systems*, Vol 4, 1994, pp. 1999-2007.

16. Ward, N.J., Stapleton, L., & Parkes, A.M. Behavioural and cognitive impact of nighttime driving with HUD contact analogue infrared imaging. Paper presented at the *14th International Technical Conference on the Enhanced Safety of Vehicles.* Munich, Germany, 1994, Paper No. 94-S2-0-04.

17. Bossi, L.L., Ward, N.J., Parkes, A.M., & Howarth, P.A. The effect of vision enhancement systems on driver peripheral visual performance. In I. Noy (Ed.), *Ergonomics and Safety of Intelligent Driver Interfaces.* Mahwah, NJ: Erlbaum, 1997, pp. 239-260.

18. Gish, K.W., Staplin, L., Stewart, J., & Perel, M. Sensory and cognitive factors affecting automotive head-up display effectiveness. *Preprint papers from the 78th Annual Meeting Transportation Research Board* [CD-ROM]. Washington, D.C.: Transportation Research Board, 1999.

19. Caird, J.K., Chugh, J.S., Wilcox, S., & Dewar, R.E. *A design guideline and evaluation framework to determine the relative safety of in-vehicle intelligent transportation systems for older drivers.* Rep. No. TP 13349E. Montreal, Canada: Transportation Development Centre, Transport Canada, 1998.

20. Olson, P.L. *Forensic aspects of driver perception and response*. Lawyers and Judges Publishing, Tuscon, AZ, 1996.

21. Summala, H. Driver/vehicle steering response latencies. *Human Factors,* Vol. 23, 1981, pp. 683-692.

22. Summala, H. Drivers' steering reaction to a light stimulus on a dark road. *Ergonomics,* Vol. 24, No. 2, 1981, pp. 125-131.

23. Caird, J.K., & Hancock, P.A. Left turn and gap acceptance accidents. In R.E. Dewar & R. Olson (Eds.), *Human factors in traffic safety*. Tucson, AZ: Lawyers & Judges Publishing, in press.

24. Massie, D. L., Cambell, K.L., & Williams, A.F. Traffic accident involvement rates by driver age and gender. *Accident Analysis and Prevention,* Vol. 27, No. 1, 1995, pp. 73-87.

25. Barham, P., Oxley, P., & Ayala, B. Evaluation of the human factors implications of Jaguar’s first prototype near infrared night vision system. In A.G. Gale (Eds.), *Vision and Vehicles VI.* Amsterdam: Elsevier, 1998, pp. 203-212.

26. Wierwille, W.W. Visual and manual demands of in-car controls and displays. In B. Peacock & W. Karwowski (Eds.), *Automotive Ergonomics.* Washington, D. C.: Taylor & Francis, 1993, pp. 299-320.
27. Nieber, E., & Koch, C. Computational architectures for attention. In R. Parasuraman (Ed.), *The Attentive Brain.* Cambridge, MA: MIT Press, 1998, pp. 163-186.
28. Triggs, T.J., & Fildes, B.N. Roadway delineation at night. In A. G. Gale et al. (Eds.), *Vision in Vehicles.* Amsterdam: North-Holland. Elsevier Science, 1986, pp. 375-384.
29. Chapanis, A. Some generalizations about generalization. *Human Factors,* Vol. 30, No. 3, 1988, pp. 253-267.
30. Francher, P.S., Ervin, R., Sayer, J., Hagan, M., Bogard, S., Bareket, Z., Mefford, M., & Haugen, J. *Intelligent cruise control field operational test.* Rep. DOT HS 808 849. Washington, D.C.: National Highway Traffic Safety Administration, 1998.
31. Caird, J.K. Intelligent transportation systems (ITS) and older drivers' safety and mobility. *Transportation in an aging society: A decade of experience.* Washington, D.C.: National Academy of Sciences, Transportation Research Board, in press.
32. OECD. *Behavioural adaptations to changes in the Road Transport System* Paris: Organisation for Economic Co-operation and Development, Road Research Group, 1990.
33. Snowden, R.J., Stimpson, N., & Ruddle, R.A. Speed perception fogs up as visibility drops. *Nature*, Vol. 392, 450, 1998.
34. Moray, N. Driving us mad: A reply. [Letter to the editor]. *Perception,* Vol 5, 1976, pp. 371-372.
35. Schiff, W., & Arnone, W. Perceiving and driving: Where parallel roads meet. In P. A. Hancock, J. M. Flach, J. K., Caird, and K. J. Vicente (Eds.), *Local applications to the ecology of human-machine systems.* Hillsdale, NJ: Erlbaum, 1995, pp.1–36.