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Augmented reality cues and elderly driver hazard perception

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AUGMENTED REALITY CUES AND ELDERLY DRIVER HAZARD PERCEPTION

by

Mark Christopher Schall, Jr.

A thesis submitted in partial fulfillment
of the requirements for the
Master of Science degree in Industrial Engineering
in the Graduate College of
The University of Iowa

December 2011

Thesis Supervisors: Associate Professor Geb Thomas
Professor Matthew Rizzo

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Mark Christopher Schall, Jr.

has been approved by the Examining Committee
for the thesis requirement for the Master of
Science degree in Industrial Engineering at the December 2011
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ABSTRACT

Perceptually challenging driving environments pose a particular threat of motor vehicle crashes to elderly drivers. Augmented reality (AR) cueing is a promising technology to mitigate risk by directing a driver's attention to roadway hazards. The objective of this study was to evaluate the effectiveness of AR cues in improving driver safety in older drivers who are at increased risk for a crash due to age-related cognitive impairment.

Twenty elderly (Mean= 73 years, SD= 5), licensed drivers with a range of cognitive abilities measured by a speed of processing (SOP) composite participated in a 36-mile (1 hour) drive in an interactive, fixed-base driving simulator. Each participant received AR cues to potential roadside hazards in three of six, straight, 6-mile-long-rural roadway segments. AR cueing was evaluated using response time and response rate for detecting potentially hazardous events (e.g. pedestrian alongside road), detection accuracy for non-target objects (e.g. recreational sign), and ability to maintain a consistent distance behind a lead vehicle.

AR cueing aided the detection of pedestrians and warning signs, but not vehicles. Response times decreased for AR-cued warning signs. AR cues did not impair perception of non-target objects or the ability to maintain consistent distance behind a lead vehicle, including for drivers with lower SOP capacity.

AR cues show promise for improving older driver safety by increasing hazard detection likelihood without interfering with secondary task performance.

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LIST OF ACRONYMS

Acronym	Definition
AR	Augmented Reality
FA	False Alarm
Pegs	Grooved Pegboard Test
SIREN	Simulator for Interdisciplinary Research in Ergonomics and Neuroscience
SOP	Speed of Processing
TMT-A	Trail Making Test Part A
TTT	Time to Target
UFOV	Useful Field of View

PREFACE

This Master's thesis presents the results of a study conducted at the Simulator for Interdisciplinary Research in Neuroscience and Ergonomics (SIREN), Department of Neurology, University of Iowa. The thesis is presented as it was prepared for submission to the journal *Human Factors: the Journal of the Human Factors and Ergonomics Society*. The article was submitted for peer review on September 28, 2011.

CHAPTER I

INTRODUCTION

Elderly drivers are at particular risk for motor vehicle crashes in challenging driving environments and tasks such as left turns (Chandraratna & Stamatiadis, 2003; Cerelli, 1995) due to age-related visual, cognitive, and physical impairments (Ball, Owsley, Sloane, Roenker, et al., 1993; Ball, Owsley, Stalvey, Roenker, et al., 1998). Functional impairments that affect older driver safety can be measured with neuropsychological tests (Dawson, Anderson, Uc, Dastrup, et al., 2009; Dawson, Uc, Anderson, Johnson, et al., 2010; Uc, Rizzo, Anderson, Shi, et al., 2005; Uc, Rizzo, Johnson, Dastrup, et al., 2010). Speed of processing (SOP) is one of the best indicators of cognitive aging (Salthouse, 1996). A recent confirmatory factor analysis of 345 older drivers evaluated several neuropsychological tests chosen for their relevance to driving performance, such as Block Design, Complex Figure Test, and the Useful Field of View (UFOV) task (Anderson, Aksan, Dawson, Uc, et al., in press). The results showed that it was possible to isolate a SOP latent factor, based on the Trail Making Test Part A (TMT-A), Grooved Pegboard Test (Pegs), and UFOV task — which has been shown to be sensitive to crash involvement (Ball & Owsley, 1993; Ball, Edwards, & Ross, 2007; Ball, Horswill, Marrington, McCullough, et al., 2008; Owsley, Ball, McGwin, Sloane, et al., 1998). The current study used this SOP factor to characterize driving relevant cognitive function in elderly drivers using prototype assistance technologies.

In-vehicle driver assistance technologies such as augmented reality (AR) may increase the speed and accuracy of performance in impaired older drivers (Ho, Reed, & Spence, 2007; Ho & Spence, 2005; Scott & Gray, 2008), direct driver attention to roadway hazards (Ho & Spence, 2005; Scott & Gray, 2008), improve target detection (Yeh & Wickens, 2001), and reduce collision involvement (Kramer, Cassavaugh, Horrey, Becic, et al., 2007; Lee, McGehee, Brown, & Reyes, 2002). AR combines natural and artificial stimuli by projecting computer graphics on a transparent plane (Azuma, 1997; Azuma, Baillot, Behringer, Feiner, et al., 2001). The graphical augmentation can highlight important roadway objects or regions, or provide informative annotations. However, adding these graphical cues may also interfere with driver perception, decreasing driver accuracy and response time for detecting roadway hazards (Schall, Rusch, Lee, Vecera, et al., 2010) due to masking, crowding, interposition, and divided attention. A semi-transparent AR cue may mitigate these interference effects (Rusch, Schall, Gavin, Lee, et al., submitted).

This study assessed the utility of semi-transparent AR cues in alerting older drivers with age-related cognitive impairments to potential roadside hazards. The question was whether cognitively impaired drivers benefited from, or were distracted by additional information intended to alert or warn them. We tested whether AR cues improve or degrade driver response rates and response times to potential hazards.

CHAPTER II

METHODS

Participants

Twenty older drivers (Mean= 73 years, SD= 5; males= 13, females= 7) participated in this study. Telephone screening prior to enrollment excluded drivers with existing medical conditions (e.g., neurodegenerative disease, anxiety, depression, etc.) or taking specific medications (e.g., stimulants, antidepressants, narcotics, hypnotics, etc.) that could influence performance. Consent was obtained in accord with institutional guidelines. All participants possessed a valid US driver's license and had normal to corrected normal vision (determined through near and far visual acuity and contrast sensitivity).

Participants self-reported their driving history and frequencies using the Mobility Questionnaire (Stalvey, Owsley, Sloane, & Ball, 1999). They reported an average of 56 years (SD=6) of driving experience. Weekly mileage was 1-50 miles (20 %), 51-100 miles (40 %), 101-150 miles (10 %), and over 150 miles per week (30%). Twenty percent drove 2-4 days per week, 25 percent drove 5-6 days per week, and 55 percent drove 7 days a week.

Experimental design

A factorial design assessed the effect of cueing (with AR) as a within-subject variable. The experiment consisted of two practice blocks and six experimental blocks. Three blocks of cued scenarios and three blocks of uncued scenarios were alternated during the experimental session for a total of six blocks. Blocks comprised one of three instances (1, 2, or 3) in the following order: Uncued Instance 1, Cued Instance 1, Uncued

Instance 2, Cued Instance 2, Uncued Instance 3, Cued Instance 3. Uncued scenarios were always presented before cued scenarios (in blocks 1, 3, and 5) and were not counterbalanced to test for carry over benefits. The cued conditions included three levels of accuracy: 1) 0% false alarms (FAs) and 0% misses (no cue), 2) 15% FAs, 0% misses, or 3) 15% misses, 0% FAs. The three levels of accuracy were counterbalanced to avoid potential order effects. The road geometry (i.e., landscape, road width, etc.) was similar for all blocks.

Cognitive Assessment

All participants were tested using a set of standardized neuropsychological procedures administered by a trained technician during a single session (Table 1). Speed of processing (SOP) relevant tests included the Useful Field of View (UFOV), Trail Making Test - Part A (TMT-A), and Grooved Pegboard (Pegs).

Drivers were screened for UFOV impairments using Visual Attention Analyzer Model 3000 (Vision Resources, Chicago, IL; Ball & Owsley, 1993; Edwards, Vance, Wadley, Cissell, et al., 2005). Scores on subtests 3 (350 and above) and 4 (500) were used to classify drivers with UFOV impairment as in previous studies (e.g., Dawson et al., 2009; 2010; Anderson et al., in press). These cut-offs had a sensitivity of 89% and specificity of 81% for predicting crash involvement (Ball & Owsley, 1993; Edwards, et al., 2005).

Table 1. Neuropsychological tests

Exam	Resource	Description
Useful Field of View (UFOV)	Ball & Owsley, 1993; Edwards et al., 2005	UFOV is a test of speed of processing for visual attention that relies on subtests of processing speed, divided attention, and selective attention.
Trail Making Test Part A (TMT-A)	Reitan, 1955 & 1958	A visual search and visuomotor speed task that requires a subject to 'connect-the-dots' of 25 consecutive targets on a sheet of paper. In version A, the targets are all numbers (1, 2, 3, etc.). The subject's goal is to finish the test as quickly as possible, and the time taken to complete the test is used as the primary performance metric.
Grooved Pegboard (Pegs)	Matthews & Klove, 1964	A visuomotor coordination task. This task consists of placing 25 pegs into 25 randomly oriented slots on a board. The pegs, which have a key along one side, must be rotated to match the hole before they can be inserted.

Apparatus

The simulator used in this study, SIREN, has a four-channel display, 150° forward view, and 50° rear view (Lees, Cosman, Fricke, Lee, et al., 2010). The screen was located in front of a 1994 GM Saturn simulator cab. Two Monsoon flat panel speakers (8.5 x 4.5 inches) mounted on the far left and right of the vehicle dashboard were used to present verbal instructions from the researchers. Instructions and scenario questions were presented from the speakers at 83 dBA. All participants were instructed on how to drive the simulator and allowed to make seat, steering wheel, and mirror adjustments to accommodate individual comfort preferences.

Augmented Reality Cue

The AR cue comprised broken yellow lines that gradually elongated and converged to form a complete rhombus (Figure 1). This rhombus was not filled in order to convey information to the driver without obstructing the target (pedestrian, vehicle, warning sign). The size, length, and direction of tilt of the rhombus elements signaled the position and distance of the target. The converging lines conveyed motion mapped to the relative speed of the driver's vehicle. Motion was included in the cue design as motion attracts attention to an object (Abrams & Christ, 2003). The yellow color was chosen to convey a warning rather than an immediate threat (Chapanis, 1994; Gelasca, Tomasic, & Ebrahimi, 2005). The enlarging rhombus subtended 0.7 degrees of visual angle at onset and 16.7 degrees when the vehicle passed. The AR cue was always centered on the target with the base positioned at the same height as the target.

For cued conditions, the rhombus appeared when the driver was within 350 meters of the primary target and it was visible between 11 to 13 seconds while the driver approached at between 60 and 70 mph. The AR cue was upgraded every 43.7 meters (8 times) to enclose the primary target as the participant approached it.

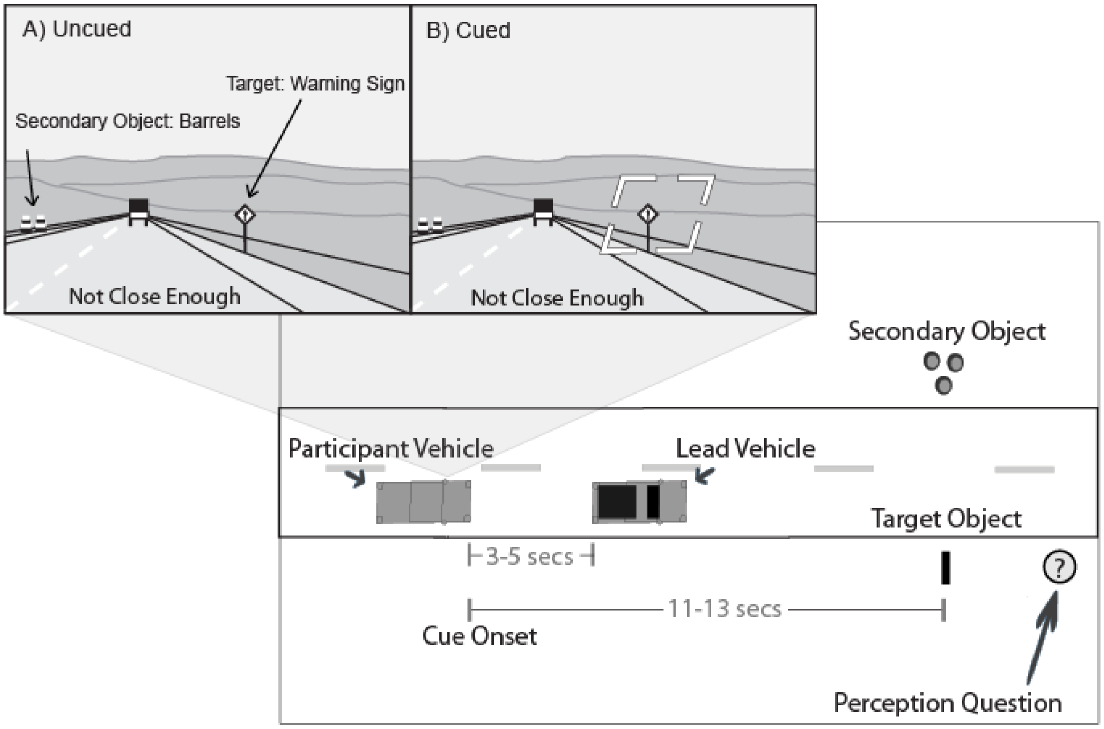

Figure1. Illustration of the driving task and AR cue

Procedure

Participants drove through six, straight, 6-mile-long-rural roadway segments. During each of the six drives, participants approached common objects, some of which were hazardous (e.g., pedestrian), defined as target objects, while others were non-hazardous (e.g., phone booth), defined as secondary objects. Each driver was shown the targets and secondary objects prior to the experiment to familiarize themselves with the classification of targets. Table 2 lists all objects and their classifications. Participants were asked to discriminate between the target and secondary objects by flashing the high beams for only target objects and only when they could identify the specification type of the object (e.g., gender of pedestrian, type of vehicle, type of warning sign). The participants were also instructed that they would be queried about the specification type of both target and secondary objects. Once the participants responded by flashing the vehicle high beams, a white box occluded both target and secondary objects to prevent drivers from "cheating" by glancing back at the objects. There were twelve events in each of the six drives. Each event included a single target object. Nine of the twelve events also included a secondary object. The presence of a secondary object was randomized to prevent anticipation.

Table 2. Description of targets and secondary objects and their categorical definitions

Object	**Type**	**Target Object**	**Secondary Object**
Pedestrian	Male	X	
Pedestrian	Female	X	
Vehicle	Car	X	
Vehicle	Truck	X	
Warning Sign	Pedestrian	X	
Warning Sign	Deer	X	
Commercial	Phone Booth		X
Commercial	Dumpster		X
Construction	Construction Trailer		X
Construction	Barrel		X
Recreational Sign	Rest Area		X
Recreational Sign	Recreational Activity		X

A car following task was added to make the drives more representative of actual road demands where assistive cues might provide a benefit (Schall et al., 2010). The lead vehicle's speed fluctuated between 60 and 70 mph. Drivers were instructed to maintain a three to five second headway from the lead vehicle at all times. A message appeared at the bottom of the screen (Figure 1) that read "Too Close" if the driver adopted a headway of three seconds or less. A message appeared that read "Not Close Enough" and a tailing vehicle honked if the driver fell more than five seconds behind.

Three of the six drives received AR cues and three did not. Target and secondary objects were always visible from a distance and never obscured (e.g., by objects in the foreground). Targets were cued except when the cueing system "failed" at a rate of 15% during the unreliable condition. Because secondary objects were classified as non-hazardous they were never cued.

Dependent/ Independent Variables

To evaluate the effectiveness of AR cueing, two outcome measures were used to assess benefits (i.e., directed attention) and two outcome measures were used to assess potential costs (i.e., interference). Table 3 defines each outcome measure associated with benefits and costs.

Table 3. Outcome measures to assess effectiveness of AR cues

Outcome Measure	Definition
Benefits: Directed Attention	
Response Rate (Count)	The number of times a participant accurately used the high beams to identify target objects.
Response Time to Target (TTT)	The time (sec) needed to reach the target at which the participant activated the high beams. Larger TTT values indicate sooner (faster) responses.
Costs: Interference	
Response Accuracy	The number of times a participant correctly identified target and secondary objects in response to questions during the drive.
Headway Variation	The variance in a participant's headway from the lead vehicle in those segments of the drive when s/he was within 400 meters of a primary target.

Differences in the outcome measures described in Table 3 were examined as a function of the following independent variables: cueing (cued, uncued), instance (order of scenario presentation), age, gender, and SOP composite.

Analysis

Linear mixed models were fit to the data using likelihood-based methods. These models included the main effects of age (continuous), gender, SOP composite (continuous), cueing (cued vs. uncued), instance (instance 1 through 3), and cueing reliability (0% FA & 0% misses; 15% FA & 0% misses; 15% misses & 0% FA). However, because the cueing reliability factor showed no effects on outcome measures in a preliminary analysis, this factor was dropped. All higher order factors (i.e., three-way interactions) were tested and dropped because results were insignificant and the models did not show a better fit (e.g., AIC) in comparison to models that included only two-way interactions.

The following two-way interactions were tested: a) cueing by instance, b) instance by SOP, and c) cueing by SOP. Collectively, these systematic effects allowed us to distinguish between cueing and general learning effects. A main effect of instance would suggest a general learning effect whereas main and interaction effects of cueing would suggest AR cue effects.

When interactions between covariates (e.g., SOP) and factors were significant, slopes and standard errors were estimated. Predicted estimates for the lowest quartile (<=-1.35) and highest quartile (>=1.17) SOP indices were plotted to illustrate two-way interactions between SOP and cueing levels for headway variation.

CHAPTER III

RESULTS

Neuropsychological Test Summary Statistics

A principal component analysis of UFOV, TMT-A, and Pegs scores showed only one eigenvalue greater than one (1.98) and it explained 66% of the variability. The first principal component was used as the SOP composite in all analyses. Table 4 shows the means and standard deviations of all three tests as well as the SOP composites for those who were UFOV impaired and unimpaired.

Table 4. Means and standard deviations of neuropsychological test scores[1]

	UFOV	**PEGS**	**TMT-A**	**SOP**
UFOV Unimpaired (N=13)	547.46 (162.73)	85.23 (15.55)	29.16 (9.86)	-0.74 (1.07)
UFOV Impaired (N=7)	978.57 (300.07)	111.86 (25.93)	39.58 (5.38)	1.43 (1.29)

1 Higher scores and composites correspond with the poorest abilities

Outcomes Associated with Directing Attention with AR cueing

Response rate (Count). Table 5 shows the effect of AR cueing on response rates (counts). Figure 2 presents Least Square Means (LSM) and standard errors of each cueing condition. A main effect of cueing was observed for pedestrian and warning sign targets. Participants responded to approximately 0.82 more pedestrians and 0.53 more warning signs when cued.

There was a main effect of instance for detecting pedestrian targets. Participants responded more frequently to pedestrians as the instance number increased (Table 6). There was also a main effect of gender; male participants (LSM=3.99, SE=0.05) responded to more warning signs than females (LSM=3.76, SE=0.07, *p*=0.02). The youngest participants responded most often to vehicles (slope = -0.041, SE = 0.016). Participants with the poorest SOP composites responded to the fewest warning signs (slope = -0.086, SE = 0.039).

Table 5. AR effects on pedestrian count, vehicle count, warning sign count

Effect	NDF	DDF	**Pedestrian Count**		**Vehicle Count**		**Warning Sign Count**	
			F	*p*	F	*p*	F	*p*
Cueing	1	89	21.77	<0.01	0.86	0.36	25.64	<0.01
Instance	2	89	9.73	<0.01	0.90	0.41	0.91	0.40
Cueing*Instance	2	89	1.42	0.25	0.15	0.86	1.59	0.21
Age	1	15	1.72	0.21	6.52	0.02	1.89	0.19
Gender	1	15	0.32	0.58	0.15	0.71	6.98	0.02
SOP[1]	1	15	1.59	0.23	1.40	0.25	4.85	0.04
SOP*Cueing	1	89	0.92	0.34	0.73	0.40	1.03	0.31
SOP*Instance	2	89	1.37	0.26	0.46	0.63	1.58	0.21

1 The confidence interval for SOP on overall count was 95% CI [-0.55, 0.42]

Table 6. Least square means (LSM) for the instance main effect

Instance Number	**Pedestrian Response Rate**		**Pedestrian TTT**		**Warning Sign TTT**	
	LSM	*p*[1]	LSM	*p*[1]	LSM	*p*[1]
Instance 1	2.82 (0.16)	<0.01	2.60 (0.22)	<0.01	3.98 (0.23)	<0.01
Instance 2	3.14 (0.16)	<0.01	2.15 (0.22)	<0.01	3.54 (0.23)	<0.01
Instance 3	3.76 (0.17)	<0.01	2.77 (0.22)	<0.01	3.44 (0.23)	<0.01
Instance 2 - Instance 1	0.32	0.14	-0.45	0.08	-0.44	0.02
Instance 3 - Instance 1	0.94	<0.01	0.17	0.50	-0.54	<0.01
Instance 3 - Instance 2	0.62	0.01	0.62	0.02	-0.10	0.58

[1] *p-values* were derived from follow-up Tukey Pair-wise comparisons

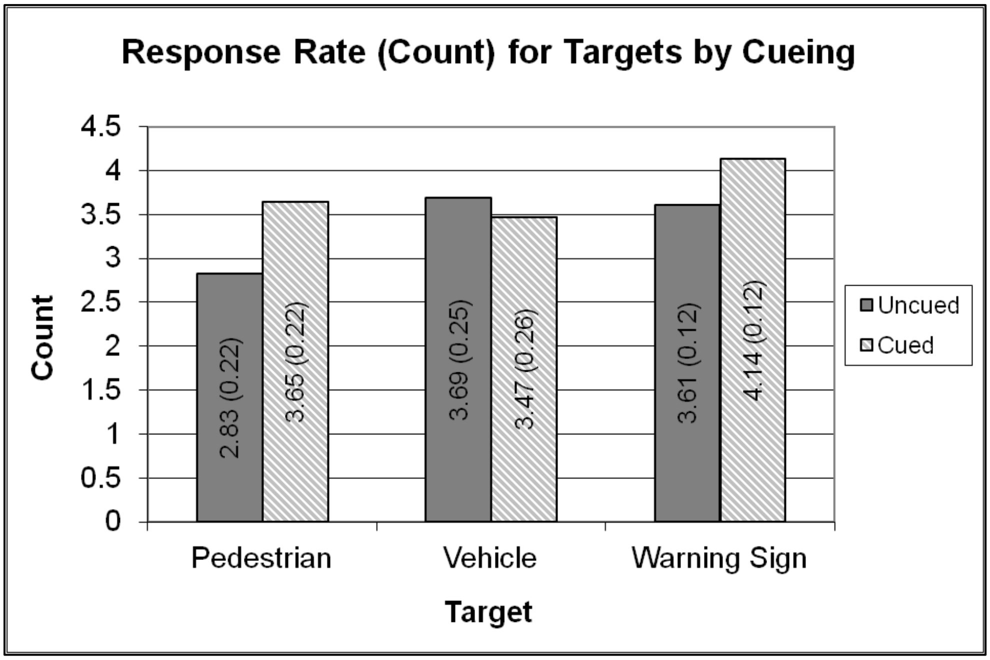

Figure 2. Response rate (count) for targets

Response time (Time to Target). Table 7 shows the effect of AR cueing on time to target (TTT). Figure 3A presents LSM and standard errors of each condition of cueing. There was a main effect of cueing for warning sign TTT. Participants responded 0.35 seconds sooner in cued conditions than in uncued conditions (*p*=0.02). There was a main effect of instance for both pedestrian and warning sign TTT. Participants responded to pedestrians fastest during the final instance (Table 6). In contrast, for warning signs, participants responded faster in earlier instances (Table 6).

There was a main effect of gender for all target categories. Figure 3B presents LSM and standard errors of each target category for differences in gender. On average, females responded 1.37 seconds faster than males (*p*<0.01). There was a main effect of SOP for both pedestrian TTT (slope = -0.381, SE = 0.185) and warning sign TTT (slope = -0.451, SE = 0.202). Overall, participants with the poorest SOP composites responded most slowly.

Table 7. AR effects on pedestrian TTT, vehicle TTT, warning sign TTT

			Pedestrian TTT		**Vehicle TTT**		**Warning TTT**	
Effect	**NDF**	**DDF**	F	*p*	F	*p*	F	*p*
Cueing	1	90	2.70	0.10	2.61	0.11	5.24	0.02
Instance	2	90	3.28	0.04	0.32	0.73	4.90	<0.01
Cueing*Instance	2	90	0.11	0.90	1.14	0.32	0.30	0.74
Age	1	16	0.07	0.79	0.00	0.95	0.30	0.59
Gender	1	16	9.92	<0.01	6.73	0.02	6.47	0.02
SOP[1]	1	16	4.35	0.05	2.66	0.12	6.77	0.02
SOP*Cueing	1	90	0.41	0.52	0.52	0.47	0.00	0.99
SOP*Instance	2	90	1.01	0.37	0.29	0.75	0.15	0.86

1 The confidence interval for SOP on overall TTT was 95% CI [-0.94, -0.03]

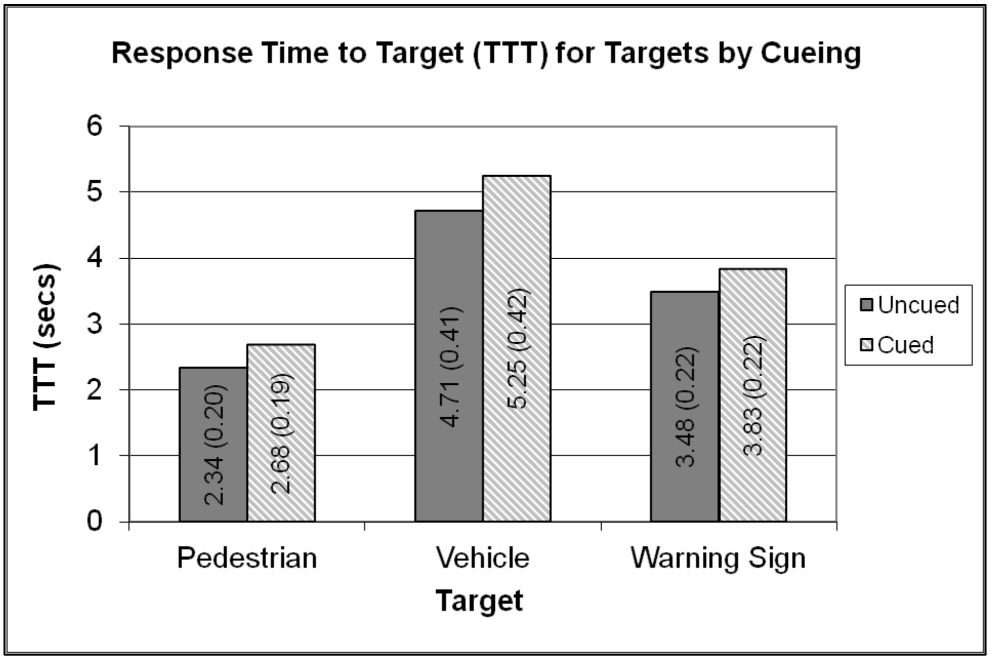

Figure 3. Response time to target (TTT) for targets

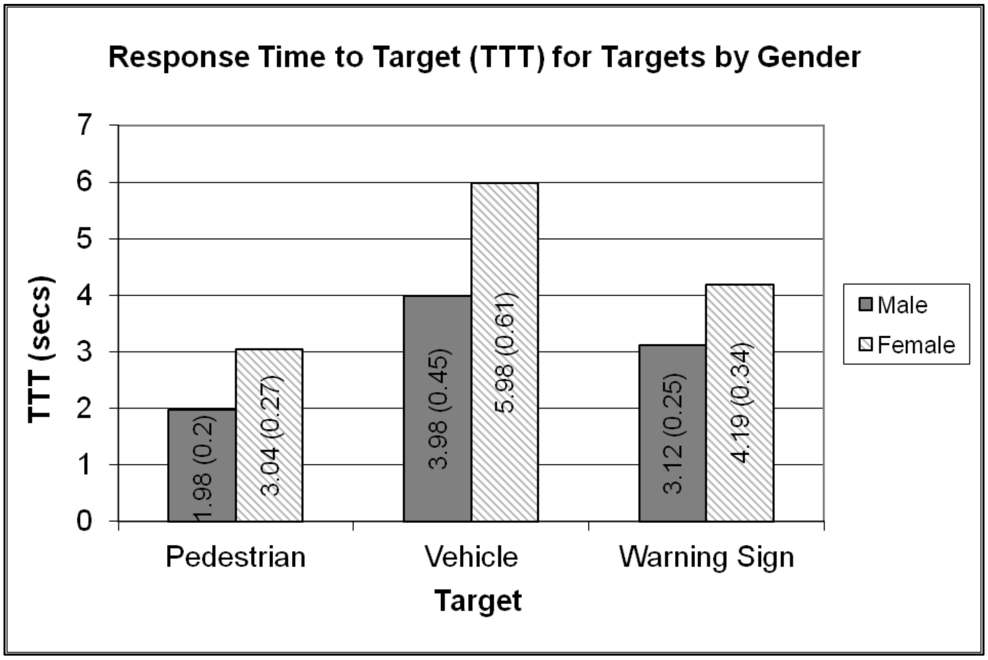

Figure 4. Response time to target (TTT) for gender across all target categories

Outcomes Associated with Interference

Accuracy of responses to questions. Table 8 shows the effect of AR cueing on accuracy in identifying targets and secondary objects. There was no main effect of cueing, small confidence intervals, and similar mean values (F(1,90) = 0.01, $p>0.05$, uncued 95% CI [10.20, 10.88], cued 95% CI [10.18, 10.86]). A main effect of instance was observed as participants responded more accurately with greater exposure to the targets (Instance 1 Mean=9.55, SE=0.18; Instance 2 Mean=10.75, SE=0.18; Instance 3 Mean=11.29, SE=0.18). A main effect of gender was also observed as male participants (LSM=10.83, SE=0.17) responded more accurately to objects (LSM=10.24, SE=0.23; $p=0.05$) than females. The oldest participants (slope = -0.098, SE = 0.035) and those with the poorest SOP composites (slope = -0.262, SE = 0.123) were the least accurate in identifying objects correctly.

Table 8. AR effects on accuracy in identifying targets and secondary objects

Effect	**Numerator Degrees of Freedom**	**Denominator Degrees of Freedom**	**Question Accuracy**	
			F	*p*
Cueing	1	90	0.01	0.92
Instance	2	91	31.58	<0.01
Cueing*Instance	2	90	0.24	0.78
Age	1	16	7.95	0.01
Gender	1	16	4.33	0.05
SOP	1	16	4.53	0.05
SOP*Cueing	1	90	0.00	0.99
SOP*Instance	2	91	1.69	0.19

Headway Variation. Table 9 shows the effects of AR cueing on headway variation. There was no main effect of cueing (F(1,90)=0.91, *p*>0.05, uncued 95% CI [0.04, 0.10], cued 95% CI [0.05, 0.11]). A main effect of instance was observed while drivers approached pedestrian targets, such that participants improved their ability to maintain headway distance better in all later instances (Instance 1 Mean=0.10, SE=0.16; Instance 2 Mean=0.06, SE=0.16; Instance 3 Mean=0.04, SE=0.17). There was a main effect of SOP while drivers approached pedestrians (slope = 0.018, SE =0.014) such that drivers with the poorest SOP scores improved their ability to maintain headway distance. There was also an interaction between SOP and cueing for headway variation while approaching vehicles. Table 10 presents estimated slopes, slope comparisons, standard errors, and selected comparisons for this interaction. Participants with the poorest SOP composites had more difficulty maintaining headway in the uncued scenarios (while approaching vehicles) relative to cued scenarios.

Table 9. AR effects on headway variation
to pedestrians, vehicles, and warning signs

Effect	**NDF**	**DDF**	**Pedestrian HV**		**Vehicle HV**		**Warning HV**	
			F	*p*	F	*p*	F	*p*
Cueing	1	90	0.17	0.68	0.04	0.84	3.11	0.08
Instance	2	90	4.67	0.01	1.63	0.20	1.10	0.34
Cueing*Instance	2	90	0.02	0.98	1.03	0.36	1.09	0.34
Age	1	16	0.01	0.91	0.00	0.95	0.09	0.77
Gender	1	16	2.50	0.13	2.13	0.16	1.75	0.20
SOP[1]	1	16	5.99	0.03	1.69	0.21	3.04	0.10
SOP*Cueing	1	90	0.06	0.81	7.94	<0.01	0.02	0.89
SOP*Instance	2	90	0.45	0.64	2.22	0.11	0.52	0.59

Table 10. Estimated slopes, slope comparisons, standard errors and comparison results for SOP by Cueing[1] interaction for vehicle headway variation

	Vehicle HV		
	Slope	SE	*p*
SOP	0.017	.013	.212
SOP*Cueing (Cued)	0.002	.014	.867
SOP*Cueing (Uncued)	0.031	.014	.036
SOP*Cueing (Cued-Uncued)	-0.029	.010	.006

1 Effects of SOP, stratified by cueing, with pairwise comparisons of slopes across condition

CHAPTER IV

DISCUSSION

This study investigated the potential costs and benefits of using AR cues to alert older drivers with diminished SOP capacity to potential roadside hazards. AR cues improved driver response rates and response times relative to uncued conditions, as predicted. Importantly, the results showed no evidence that AR cues caused interference for drivers, including those with lower SOP capacity.

Benefits Associated with Directing Attention with AR cueing

In this study, pedestrian and warning sign targets were more difficult to identify than vehicles, which were generally visible from a greater distance. A response rate benefit of cueing was observed for pedestrian and warning sign targets in which participants responded to 21% more pedestrians and 12% more warning signs in cued conditions than in uncued conditions. This result is consistent with past findings such as Yeh and Wickens (2001) and Rusch et al. (submitted) in which the benefits of cueing were greatest for objects of low salience. In addition, AR cues improved driver response time (TTT) to critical roadside hazards of low salience. For example, participants responded to warning signs 0.35 seconds faster in cued conditions than in uncued conditions. This result is important as early warnings have been observed to help drivers react more quickly, particularly compared to when no warning is given (Lee et al., 2002). A response that is initiated 0.35 seconds sooner could have a substantial effect on total braking time, especially since age-related decrements to braking performance have been attributed to longer response times rather than poor response execution (Martin, Audet, Corriveau, Hamel, et al., 2010).

The observed benefits of AR cueing are also consistent with findings of Kramer et al. (2007). They showed that collision avoidance systems can effectively alert older drivers even when driving difficulty is increased by the addition of wind gusts or a non-driving related secondary task such as a digit number reading task. Similarly, benefits of AR cueing in this current work were evident with more ecologically valid secondary task assignments such as car following and secondary object identification.

Costs Associated with Interference

Interference caused by added information is a potential adverse outcome of AR cueing (Schall et al., 2010). However, this study did not show such adverse effects, consistent with Rusch et al. (submitted). There was no evidence suggesting that AR cues impaired driver perception of target and non-target objects for drivers with and without diminished SOP capacity.

Driving performance decrements such as increased headway variation is another potential adverse outcome of AR cueing. However, participants' headway maintenance was not degraded by the inclusion of AR cueing. In fact, participants with the poorest SOP composites displayed superior headway maintenance in the cued scenarios relative to the uncued scenarios. These effects suggest that AR cueing did not burden drivers, but rather that AR cueing seemed to aid impaired elderly drivers maintain a safer headway distance. These findings would suggest that effects of AR cueing are distinct from in-vehicle displays which have been shown to impair driver performance in closing headway situations (Lamble, Laakso, & Summala, 1999).

Limitations, Implications, and Future Research

Our findings did not suggest that AR cueing was particularly beneficial for drivers with low SOP abilities compared to drivers with high SOP abilities. In three out of four outcome measures, the interaction effect between SOP and cueing was not significant. It is unlikely negative findings reflect a limited range on SOP abilities in this sample. However, it is possible our sample size was too small to detect such interaction effects. Another possibility is that differential benefits of AR cues for impaired older drivers are specific to a subset of performance measures. AR cues differentially benefitted drivers with low SOP scores in maintaining headway distance.

AR cueing may also be beneficial for improving hazard perception abilities of less experienced drivers. Experienced drivers have been observed to be more sensitive to unexpected hazards than young-inexperienced drivers (Borowsky, Shinar, and Oron-Gilad, 2010). AR cues may assist inexperienced drivers by helping them “expect the unexpected on the road.” Future research needs to test costs and benefits of AR cues in driving scenarios involving both expected and unexpected hazards. In addition, AR cues may also prove useful in negotiating the demands of challenging driving tasks such as left-turns. Overall, the findings show that AR cueing merits further investigation.

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