

Directing driver attention with augmented reality cues

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ABSTRACT

This simulator study evaluated the effects of augmented reality (AR) cues designed to direct the attention of experienced drivers to roadside hazards. Twenty-seven healthy middle-aged licensed drivers with a range of attention capacity participated in a 54 mile (1.5 h) drive in an interactive fixed-base driving simulator. Each participant received AR cues to potential roadside hazards in six simulated straight (9 mile long) rural roadway segments. Drivers were evaluated on response time for detecting a potentially hazardous event, detection accuracy for target (hazard) and non-target objects, and headway with respect to the hazards. Results showed no negative outcomes associated with interference. AR cues did not impair perception of non-target objects, including for drivers with lower attentional capacity. Results showed near significant response time benefits for AR cued hazards. AR cueing increased response rate for detecting pedestrians and warning signs but not vehicles. AR system false alarms and misses did not impair driver responses to potential hazards.

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1. Introduction

Safe automobile driving requires drivers to process large amounts of dynamic information under time pressure. However, drivers can attend to only a small percentage of visual stimuli at once. Some objects are easily noticed (i.e., conspicuous) whereas others require more time and effort. Failure to notice less conspicuous objects could result in a serious injury or fatality. Highlighting cues may provide a promising countermeasure to reduce such adverse events. Jonides (1980) found a “dynamic blinking” cue used for highlighting to be effective at attracting attention. Fisher and Tan (1989) found that subjects located a target faster in highlighted displays than in displays with no highlighting. Yeh and Wickens (2001) showed

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that cueing aided target detection in an aviation visual search task. They found target detection accuracy was enhanced when the object cued was not conspicuous.

Head-up display (HUD) technology has the potential to increase attention to cued elements without adversely affecting attentional resources and reducing the ability to respond to environmental information outside the focus of attention. This advantage may relate to a greater degree of conformal symbology in HUD displays. Conformal symbology links elements of the display image to elements in the far domain and relates to the extent that the display serves as a virtual analog of the far domain elements (Naish, 1964). Lauber, Bray, Harrison, Hemingway, and Scott (1982) and Wickens and Long (1995) found that HUD advantages were enhanced when symbology was conformal. Conformal displays may reduce the tendency to neglect information in the world while attending to the HUD (Caird, Horrey, & Edwards, 2001; Tufano, 1997).

One strategy that emphasizes using HUD technology to present conformal information is augmented reality (AR). AR refers to the combining of real and artificial stimuli, with the aim to improve human performance (Azuma, 1997; Azuma et al., 2001). This typically involves overlaying computer-generated graphics so that they appear to be embedded in the real world (Kearney, Rizzo, & Severson, 2007). The augmentation may highlight important objects or regions. A limitation of HUD technology is the potential for clutter that may interfere with other items in the panorama (Ververs & Wickens, 1998). Attentional mechanisms may cause HUD images to interfere with attending to objects that would have otherwise been detected. A pilot study showed that static visual cues increased response times (RTs) for detecting hazards due to obstruction (Schall, Rusch, Lee, Vecera, & Rizzo, 2010), possibly due to the non-conformal nature of the static cue, and to the low complexity and cognitive demands of the driving scenarios.

AR technology may serve as a safety countermeasure for drivers with visual attention impairments. Vision is important to driving and driver safety worsens with visual attentional decline. Attentional decline due to advancing age can reduce the useful field of view (UFOV), construed as the portion of the visual field in which information can be acquired during a single glimpse without head or eye movements. UFOV decline increases driver visual search time (Underwood, Crundall, & Chapman, 2002), vehicle stopping distances, and crashes (Myers, Ball, Kalina, Roth, & Goode, 2000; Owsley et al., 1998; Rogé & Pébayle, 2009).

On-board driver assist applications may improve the ability to perceive and react to roadway hazards in drivers with age related visual information processing impairments (Ho, Reed, & Spence, 2007; Scott & Gray, 2008). By directing driver attention, these systems may produce safety benefits such as reduced RT to hazardous situations (Ho & Spence, 2005; Scott & Gray, 2008) and reduced collision involvement (Kramer, Cassavaugh, Horrey, Becic, & Mayhugh, 2007; Lee, McGehee, Brown, & Reyes, 2002).

The effectiveness of in-car alerts in directing driver attention to a potential hazard depends on how sensory cues and other salient information capture attention at a particular object or location and context. Some research suggests that a highly salient item (e.g., a red item in a field of green items) will capture attention even when this salient item is never a potential target and, therefore, irrelevant to the task at hand (Theeuwes, 1991; Theeuwes, 1992; see Theeuwes, 2010, for a review). Other findings, however, indicate that such attentional capture only occurs for items that are task relevant; attentional capture is contingent on observer goals (Folk, Remington, & Johnston, 1992). Further, attentional capture is reduced under dual-task situations (Boot, Brockmole, & Simons, 2005) and in visually complex displays (Cosman & Vecera, 2009; Cosman & Vecera, 2010), two results that suggest that in-car alerts might do little to summon drivers' attention because driving involves multitasking and searching complex visual scenes.

The primary goal of this study was to determine the costs and benefits of dynamic conformal AR cues to alert experienced drivers to potential roadway hazards. We predicted that these AR cues would not interfere with the perception of non-target objects or with driver performance, including in drivers with reduced attentional abilities. We hypothesized that alerts would help to direct attention to potential hazards. Further, we expected that these benefits should be greatest for those with a higher degree of attentional impairment, as defined by UFOV scores.

2. Method

2.1. Participants

Twenty-seven healthy middle-aged drivers (Mean = 45 years, SD = 6; males = 13, females = 14) participated in the study. All participants possessed a valid US driver's license and were without neurological disease. UFOV scores were gathered through a computerized test that was administered on a touchscreen PC (Edwards et al., 2005) with four tests: (1) processing speed, (2) divided attention, (3) selective attention, and (4) selective attention with a simultaneous same/different discrimination at fixation. A total UFOV score was calculated from addition of the four UFOV subtests. UFOV scores on each subtest represent the threshold in milliseconds at which the individual correctly responds to 75% of the trials (Ball & Owsley, 1992). All participants had normal or corrected to normal vision (determined through near and far visual acuity and contrast sensitivity tests).

On average, participants had 29.1 years (SD = 6.3) of driving experience. Fifteen percent reported that they drove 1–50 miles per week, 19% reported 51–100 miles per week, 33% reported 101–150 miles per week, and 33% reported over 150 miles per week. Concerning the number of days driven per week, 7% reported that they typically drove 2–3 days per week, 19 reported 4–5 days per week, and 74 reported 6–7 days a week. The average UFOV score was 323.9 (SD = 132.8,

min = 142, max = 638), from the normal to mildly impaired range, as would be expected in a group of healthy middle-aged drivers.

2.2. Experimental design

The experiment followed a two-way factorial design with cueing as a within-subject independent variable. Subjects participated in three pairs of driving scenarios. Each pair consisted of an uncued scenario followed by a cued scenario (Fig. 1). We refer to these pairs as instances (1, 2, or 3; the second independent variable) from this point forward.

The three cued scenarios had different levels of cue accuracy, either: (1) 0% false alarms (FAs) and 0% misses (no cue), (2) 15% FAs, 0% misses, or (3) 15% misses, 0% FAs. The presentation order of cued conditions was between participants. The uncued conditions were not counterbalanced to allow assessment of effects of increasing cue-related training. The road geometry (i.e., landscape, road width, etc.) was similar for all conditions.

To distinguish between cueing and acclimation effects, we analyzed cueing, instance, and the interaction between these factors. A main effect of instance would suggest acclimation whereas main and interaction effects with cueing would indicate costs and benefits of the cues. Of note, trust of in-vehicle technology is linked to warning system reliability and sensitivity settings (Lee & See, 2004). High FA rates associated with high sensitivity can reduce driver trust in the alerting system and annoy the driver, leading to failure to benefit from the warnings and overall increase in driver errors (Ben-Yaacov, Maltz, & Shinar, 2002; Bliss & Acton, 2003; Dingus et al., 1997; Maltz & Shinar, 2004; Wilson, 1996). Reliability of 70% may be a critical crossover point for performance; no automation may be better than automation that is less than 70% reliable (Wickens & Dixon, 2007). This study included false positive AR cues and misses, and system reliability was never less than 85%.

2.3. Apparatus

This study was conducted using the Simulator for Interdisciplinary Research in Ergonomics and Neuroscience (SIREN). This simulator has a four-channel, 150° forward view, and 50° rear view (Lees, Cosman, Fricke, Lee, & Rizzo, 2010). An Intel® Pentium® D processor-based PC was used to run the task software. The screen was located in front of a 1994 GM Saturn simulator cab. Two Monsoon flat panel speakers (8.5 × 4.5 in.), mounted on the far left and right of the vehicle dashboard, were used to present instructions from the researchers. Instructions and scenario questions were presented from the speakers at 83 dBA.

2.4. Driving task and display

The primary task involved driving while responding to various targets presented alongside six straight rural roadways (Table 1). Drivers were instructed to respond to potential hazards (pedestrians, vehicles, and warning signs) by flashing their high beams. Targets were not presented as sudden hazards and were never obscured (e.g., by objects in the foreground) unless the driver was “tailgating” behind a lead vehicle. Tailgating and obstruction were minimized through a speed control mechanism (described later). Cue presence and reliability (no cues, reliable cues, cues that missed targets, cues with FAs) varied across scenarios. The FAs only occurred when no target or secondary object was displayed and mimicked activity of an oversensitive sensor (e.g., that detects minor debris blowing across the road). Participants occasionally encountered secondary objects presented on the roadside opposite to the primary targets: commercial, recreational, or associated with construction (Table 1). These secondary objects were not classified as hazardous and were not cued.

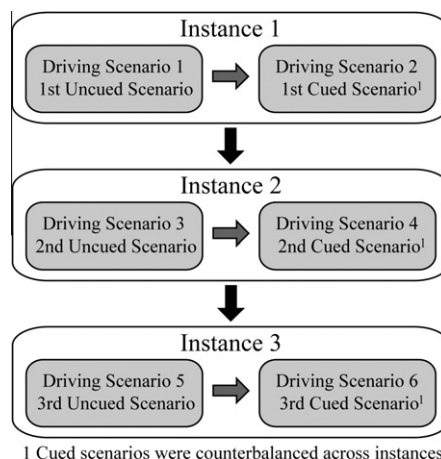
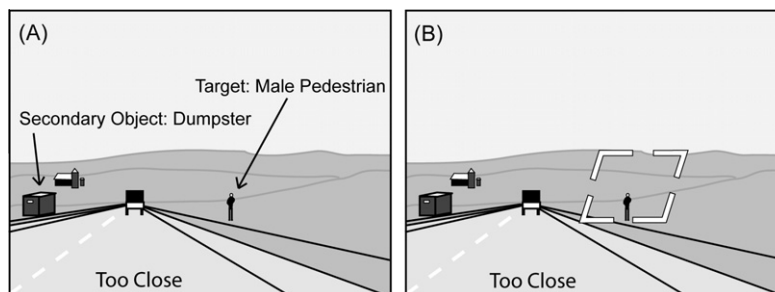


Fig. 1. Illustrates the presentation order of driving scenarios and how they map onto instances.

Table 1

Description of targets/secondary objects and 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

**Fig. 2.** Illustrates: (A) an uncued scenario and (B) a cued scenario (with tilted and broken lines).

The cue was presented as a rhombus shape of broken lines that gradually connected to form a closed rhombus (Fig. 2). The size, length, and direction of tilt associated with the rhombus elements signaled the position and distance of the primary target. This cue design provided information to the driver without obstructing the target. The converging broken lines conveyed motion. The yellow color communicated a warning rather than an immediate threat. The cue's visual angle range was the same for all targets: 0.7° at the onset of the cue to 16.73° at the point at which the vehicle passed the cue. The cue was always centered on the target with the base positioned at the same height as the target.

For cued conditions, the target was highlighted when the driver was within 350 m of the primary target. The cue was visible between 11 and 13 s while the driver was traveling between 96.6 and 112.7 km per hour (60 and 70 mph). The cue was graded over eight levels (every 43.75 m), becoming more opaque and a more fully enclosed rhombus as the participant approached the target. The grading was designed to direct the participant's attention to the target at every level with increasing opacity and to generate abrupt onsets associated with motion.

2.5. Procedure

Each participant received an explanation of the purpose of the study and provided consent. Prior to the drive, participants received instructions on how to operate the vehicle and were allowed to adjust the seat, steering wheel, and mirrors for comfort. Each driver participated in one uncued practice session and one cued practice session prior to starting formal testing scenarios.

In both cued and uncued conditions, participants were instructed to flash their high beams as soon as they could recognize the gender of the pedestrian, if a vehicle was a car or truck, or if a warning was a pedestrian or deer crossing warning sign. Before the first scenario, the participants reviewed a set of images to familiarize themselves with the objects and vocabulary used to label each.

Immediately after the driver flashed the high beams, the target was hidden behind a white box to prevent the driver from identifying the object too soon. As the participant passed by the target, the target and secondary objects disappeared and a recorded question was asked about the presence or absence of a target or secondary object.

A lead vehicle following task made the experience more representative of typical driving situations and engaged drivers so that the targets would be more difficult to perceive, accentuating the potential benefits of cueing. This required drivers to maintain a 3–5 s headway from a lead vehicle whose speed fluctuated between 96.6 and 112.7 km per hour. The velocity settings were randomized and changed approximately every half mile. If the driver got too close, a message appeared at the bottom of the screen that read, "Too Close" (Fig. 2). If the driver got too far behind, a message appeared that read "Not Close Enough" and a following vehicle honked.

The six sections of rural two-lane highway were each approximately 9 miles in length (approximately nine minutes in driving time). These were presented with variations on the cue's reliability. Participants completed the sections in an alternating fashion (back and forth between uncued and cued sections; Fig. 1).

Target and secondary objects were always positioned immediately alongside the road (Fig. 2). Approximate time to complete each trial depended on velocity and target type. On average, there was 0.5 mile (30 s) between each trial. Each object type was counterbalanced to be included on the left or right with an equal distribution on each side. Table 1 lists and defines all the objects. There were 18 events where each event included a target and secondary object question. Of the 18 events, 12 included a secondary object along with the target. The presence of a secondary object was randomized to make it unpredictable.

2.6. Independent and dependent variables

Independent variables included age, gender, UFOV score, condition, and instance. Driving performance was evaluated with the following dependent measures:

2.6.1. Outcomes associated with interference

We predicted that AR cues would not interfere with the perception of non-target objects or with driver performance. Interference was measured through two outcome measures including: question accuracy and headway variation.

1. *Accuracy of responses to questions*: The number of times (frequency) a participant correctly identified target and secondary objects in response to questions presented during each scenario.
2. *Headway variation*: A summed frequency of the number of times a participant's headway was less than two or greater than 4 s while the target distance was less than 400 m.

Attentional ability was examined within each outcome category by investigating main and interaction effects between individual measures and continuous UFOV scores for all drivers. We evaluated the possibility AR cuing might cause more interference for drivers with lower UFOV scores. This would be reflected by lower scores for secondary object questions in the AR cued hazard perception trials relative to uncued trials.

Data on change in lane position and acceleration variation were also collected. No major significant effects were realized and are not presented in this paper. This finding was most likely due to the straight roadway (i.e., no curves).

2.6.2. Outcomes associated with directing attention (through cueing)

We hypothesized that alerts would help to direct attention to potential hazards. Directing attention was measured through two outcome measures: response rate and reaction time.

3. *Response rate measured by count*: The frequency in which a participant accurately used the high beams when identifying target objects.
4. *Reaction time measured by time to target (TTT)*: The time (s) from the target when the participant activated the high beams.

We hypothesized that the AR visual cues would increase response rates and TTTs. Larger TTTs indicated a participant responded to the target object sooner. We expected that these benefits should be greatest for those with a higher degree of attentional impairment, as defined by UFOV scores.

3. Results

3.1. Analysis

Likelihood-based methods were used to fit linear mixed models to the data. These models tested for differences between cueing, instance (order of presentation), an interaction between instance and cueing, age (continuous), gender, UFOV score (continuous), and for interactions between UFOV score with cueing and instance. Follow up Bonferroni-adjusted pair-wise tests were conducted among the three groups for the instance variable.

Preliminary analysis showed that cueing accuracy (i.e., FA/miss rate) had no effect as there were no differences among cued conditions. Therefore, cueing was analyzed in general terms with two levels (uncued or cued). Instance was also analyzed in general terms where *instance 1* consisted of the first set of uncued and cued scenarios, *instance 2* consisted of the second set of uncued and cued scenarios, and *instance 3* consisted of the third set of uncued and cued scenarios.

Slopes and standard errors were estimated for covariates (e.g., UFOV), along with linear combinations of slopes when an interaction between covariates and factors was significant. Predicted estimates for the lowest (≤ 209) and highest (≥ 384) UFOV scores were plotted to illustrate two-way interactions between UFOV and instance.

We fit our models using SAS Proc Mixed, assuming a compound symmetry correlation structure, which is a type of spherical correlation pattern. This assumption implies that within-subject correlations are unaffected by the elapsed time

between observations. Since the time frame for each subject was a single visit, we anticipated that this was a reasonable approximation. As a sensitivity analysis, we double-checked our significant results under the Toeplitz (banded) correlations structure, which allows the correlations to change as a function of the time elapsed. Since the results were very similar, we present only the compound symmetry results, except when indicated otherwise.

3.2. Outcomes associated with interference

There was no main effect of cueing ($F(1, 117) = 0.10$, $p > 0.05$; uncued 95% CI [16.87, 17.44], cued 95% CI [17.07, 17.64]; $d = -1.401$) nor was there an interaction effect between cueing and instance for question accuracy (all $p > 0.05$). On average, participants answered 17.26 (0.14) questions correctly for both uncued and cued scenarios. The 95% confidence interval (CI) for the main effect of cueing on the question accuracy outcome (uncued minus cued) was -0.47 to 0.08 . These findings suggest that there was no interference associated with the cue's presence (i.e., clutter). Thus there were no negative outcomes (costs) on the perception of non-target objects external to targets.

There was a nearly significant effect showing that participants with the poorest UFOV scores tended to answer fewer questions correctly ($F(1, 22) = 3.89$, $p = 0.06$; slope = -0.002 , SE = 0.001). There was a -0.38 to 0.01 confidence interval for a 100 unit increase in UFOV. These findings were even stronger in the interaction between UFOV and instance, where a negative relationship was found for the first uncued/cued scenarios ($F(2, 117) = 4.66$, $p = 0.01$; Table 2 and Fig. 3A). The negative relationship found for these first uncued/cued scenarios was stronger than that found in the second and third uncued/cued scenarios. There was no interaction of cueing and UFOV that would have suggested interference with the perception of non-target objects associated with reduced attentional abilities.

Table 3 presents the results from a linear mixed model comparing headway variation for the three target categories. For age (Table 3), headway variation was poorest for the oldest participants in all target categories: pedestrians (slope = 0.003 , SE = 0.001 , 95% CI [0.000, 0.005]), vehicles (slope = 0.003 , SE = 0.001 , 95% CI [0.001, 0.006]), and warning signs (slope = 0.005 , SE = 0.002 , 95% CI [0.001, 0.009]).

A borderline significant main effect of instance was found for headway variation while approaching a target vehicle ($p = 0.05$); however, the analysis based on the Toeplitz correlation structure was not significant ($p = 0.07$). A significant interaction between instance and cueing was found for headway variation while approaching vehicles ($p < 0.01$) and warning signs ($p = 0.04$). While approaching vehicles participants failed to maintain 3–5 s headway more frequently in the first instance of the uncued scenario (Mean = 0.19 , SE = 0.01 , 95% CI [0.166, 0.224]) than all other scenarios (Mean = 0.01 , SE = 0.02 , 95% CI [0.009, 0.040], $d = 14.632$; $p < 0.05$). There were no significant differences between the first cued scenario and all later scenarios that would suggest interference with driver performance associated with headway variation while approaching pedestrians or vehicles. For warning signs, drivers failed to maintain 3–5 s headway more frequently in the first instance of the uncued scenario (Mean = 0.11 , SE = 0.02 , 95% CI [0.075, 0.137]) than all other scenarios (Mean = 0.02 , SE = 0.02 , 95% CI [-0.002 , 0.043], $d = 6.253$; $p < 0.05$) except the first cued scenario (Mean = 0.06 , SE = 0.02 , 95% CI [0.025, 0.089], $d = 3.073$).

3.3. Outcomes associated with directing attention

3.3.1. Response rate (count)

Cueing provided a benefit that diminished with exposure for pedestrian count (uncued instance one 95% CI [4.750, 5.217], all later uncued/cued instances 95% CI [5.707, 5.934], $d = -9.064$; $p = 0.03$) and warning signs (uncued instance one 95% CI [5.348, 5.630], all later uncued/cued instances 95% CI [5.889, 6.028], $d = -8.412$; $p < 0.01$) (Table 4). Fig. 4 presents means and standard errors of each condition. In characterizing these findings by age, pedestrian count was smaller for older participants than for younger participants ($F(1, 23) = 12.79$, $p < 0.01$; slope = -0.034 , SE = 0.009 , 95% CI [-0.053 , -0.014]).

For pedestrian count, participants with the poorest UFOV scores detected fewer pedestrians in the first instance of scenarios (Table 4 and Fig. 3B). The negative relationship for the first scenario was stronger than in the later scenarios (Table 2).

Table 2

Estimated slopes, slope comparisons, standard errors and comparison results for UFOV \times Instance^a for question accuracy, pedestrian count, and pedestrian TTT.

	Question accuracy			Pedestrian count			Pedestrian TTT		
	Slope(SE)	95% CI	P	Slope(SE)	95% CI	P	Slope(SE)	95% CI	P
Instance 1	<i>-.004(.001)</i>	<i>-0.647, -0.162</i>	<i>.002</i>	<i>-.002(.001)</i>	<i>-0.375, -0.108</i>	<i>.001</i>	<i>.001(.002)</i>	<i>-0.294, 0.457</i>	<i>.662</i>
Instance 2	<i>-.001(.001)</i>	<i>-0.380, 0.106</i>	<i>.262</i>	<i>-.000(.001)</i>	<i>-0.153, 0.115</i>	<i>.777</i>	<i>-.003(.002)</i>	<i>-0.660, 0.093</i>	<i>.134</i>
Instance 3	<i>-.000(.001)</i>	<i>-0.269, 0.217</i>	<i>.832</i>	<i>.000(.001)</i>	<i>-0.093, 0.175</i>	<i>.544</i>	<i>-.001(.002)</i>	<i>-0.493, 0.260</i>	<i>.532</i>
Instance 1–Instance 2	<i>-.003(.001)</i>	<i>-0.520, -0.015</i>	<i>.038</i>	<i>-.002(.001)</i>	<i>-0.411, -0.034</i>	<i>.021</i>	<i>.004(.001)</i>	<i>0.109, 0.621</i>	<i>.006</i>
Instance 1–Instance 3	<i>-.004(.001)</i>	<i>-0.631, -0.126</i>	<i>.004</i>	<i>-.003(.001)</i>	<i>-0.471, -0.094</i>	<i>.004</i>	<i>.002(.001)</i>	<i>-0.058, 0.454</i>	<i>.129</i>
Instance 2–Instance 3	<i>-.001(.001)</i>	<i>-0.365, 0.142</i>	<i>.385</i>	<i>-.001(.001)</i>	<i>-0.249, 0.128</i>	<i>.527</i>	<i>-.002(.001)</i>	<i>-0.423, 0.089</i>	<i>.199</i>

Italicized values reflect those findings where $P > 0.05$.

^a Effects of UFOV, stratified by instance, with pairwise comparisons of slopes across instance. Confidence intervals are based upon a 100 unit increase in UFOV.

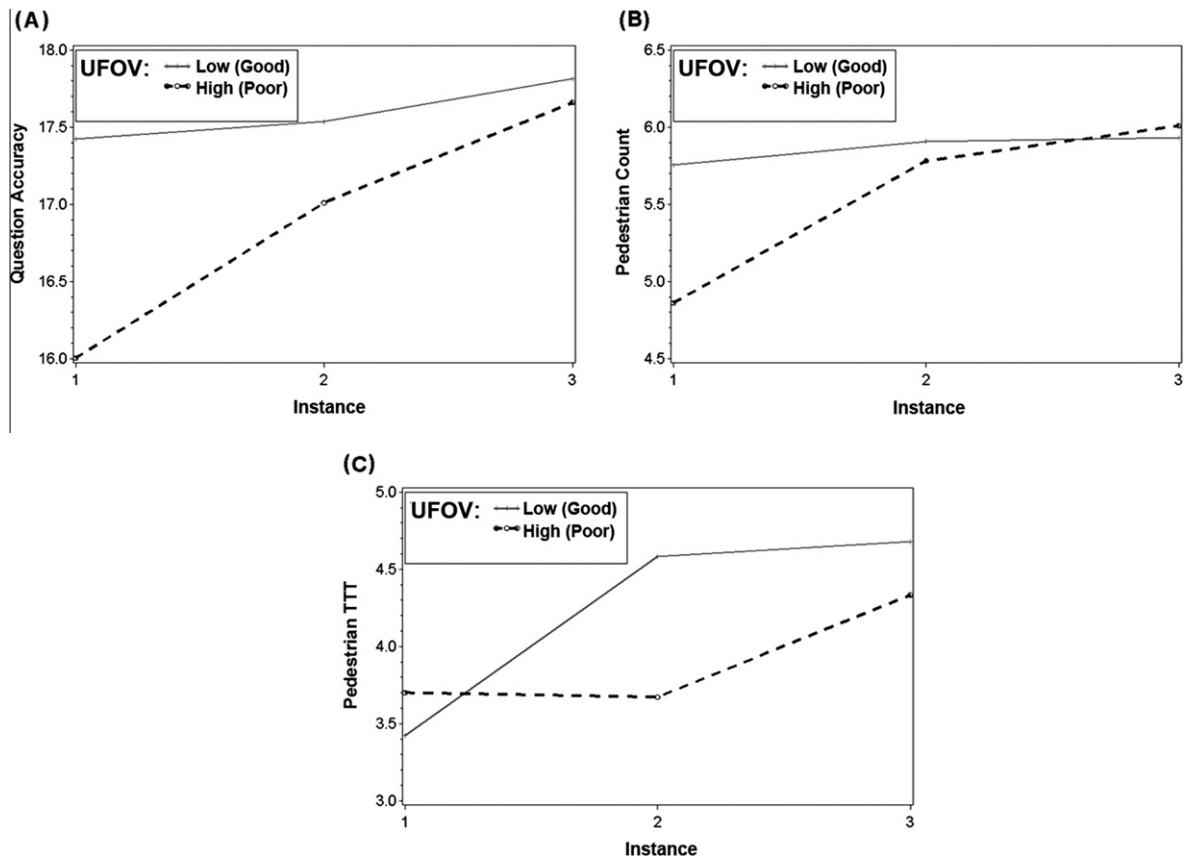


Fig. 3. Predicted UFOV estimates for: (A) question accuracy, (B) pedestrian count, and (C) pedestrian time to target (TTT).

Table 3

Mixed effects for pedestrian Headway Variation (HV), vehicle HV, warning sign HV.

Effect	Numerator degrees of freedom	Denominator degrees of freedom	Pedestrian HV		Vehicle HV		Warning sign HV	
			<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>
Cueing	1	116	0.04	0.85	1.32	0.25	0.45	0.50
Instance	2	116	0.22	0.80	3.11	0.05	2.22	0.11
Cueing*Instance	2	117	0.41	0.66	14.90	<0.01	3.19	0.04
Age	1	23	4.62	0.04	6.69	0.02	6.47	0.02
Gender	1	22	0.15	0.71	3.15	0.09	0.03	0.87
UFOV	1	22	0.04	0.84	0.22	0.65	0.09	0.77
UFOV*Cueing	1	116	0.02	0.89	0.09	0.77	0.15	0.69
UFOV*Instance	2	116	0.36	0.70	0.66	0.52	0.06	0.94

Italicized values reflect those findings where $P > 0.05$.

Table 4

Mixed effects for response rate: pedestrian count, vehicle count, warning sign count.

Effect	Numerator degrees of freedom	Denominator degrees of freedom	Pedestrian count		Vehicle count		Warning sign count	
			<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>
Cueing	1	116	0.00	0.95	0.16	0.69	0.10	0.75
Instance	2	116	0.57	0.57	0.72	0.49	0.08	0.92
Cueing*Instance	2	117	3.75	0.03	1.73	0.18	5.20	<0.01
Age	1	23	12.79	<0.01	0.15	0.70	2.25	0.15
Gender	1	23	0.87	0.36	0.49	0.49	1.56	0.22
UFOV	1	23	3.46	0.08	2.44	0.13	0.22	0.65
UFOV*Cueing	1	116	1.82	0.18	0.29	0.59	2.01	0.16
UFOV*Instance	2	116	4.90	<0.01	0.48	0.62	0.80	0.45

Italicized values reflect those findings where $P > 0.05$.

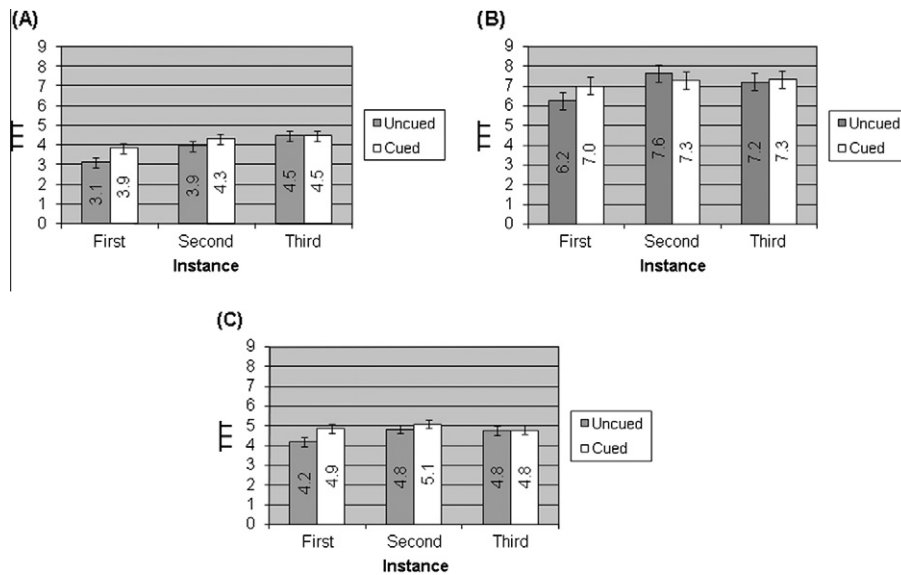


Fig. 4. Shows a comparison of (A) pedestrian count, (B) vehicle count, and (C) warning sign count in cued versus uncued scenarios across all instances.

Table 5

Mixed effects for pedestrian TTT, vehicle TTT, warning sign TTT.

Effect	Numerator degrees of freedom	Denominator degrees of freedom	Pedestrian TTT		Vehicle TTT		Warning sign TTT	
			<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>
Cueing	1	116	0.06	0.80	0.23	0.63	2.96	0.09
Instance	2	116	9.88	<0.01	2.25	0.11	5.57	<0.01
Cueing*Instance	2	117	2.31	0.10	2.61	0.08	2.74	0.07
Age	1	23	0.84	0.37	2.07	0.16	2.78	0.11
Gender	1	23	1.58	0.22	2.43	0.13	1.19	0.29
UFOV	1	23	0.40	0.53	0.37	0.55	0.16	0.70
UFOV*Cueing	1	116	0.70	0.41	0.02	0.88	0.47	0.49
UFOV*Instance	2	116	4.00	0.02	1.08	0.34	2.92	0.06

Italicized values reflect those findings where $P > 0.05$.

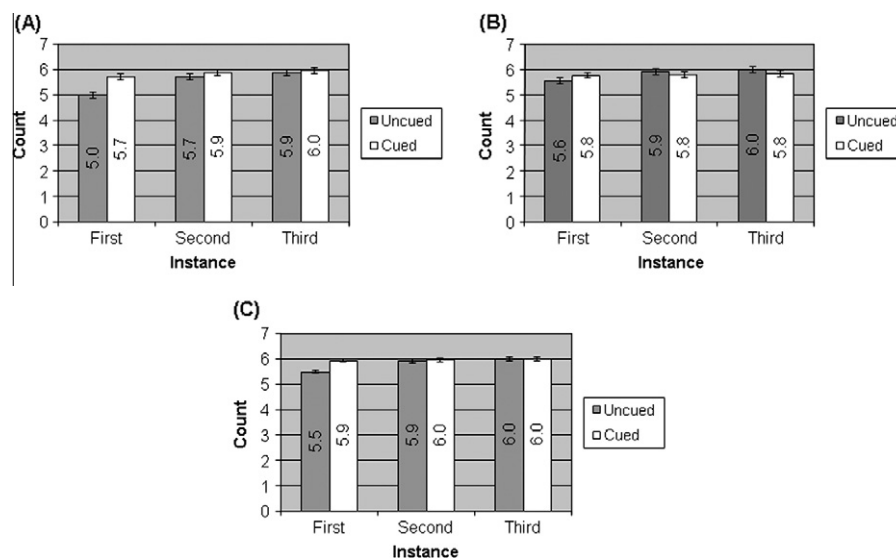


Fig. 5. Shows a comparison of (A) pedestrian TTT, (B) vehicle TTT, and (C) warning sign TTT in cued versus uncued scenarios across all instances.

3.3.2. Reaction time (time to target)

Table 5 presents the results from a linear mixed model comparing time to target (TTTs) for the three target categories. Pedestrian TTT for the first instance of scenarios (Mean = 3.48, SE = 0.23, 95% CI [2.994, 3.947]) was less than the TTT for all later instances (Mean = 4.30, SE = 0.23, 95% CI [3.835, 4.742], $d = -3.599$; $p < 0.05$). Warning sign TTT for the first instance of scenarios (Mean = 4.51, SE = 0.21, 95% CI [4.094, 4.935]) was less than the TTT for the second instance of scenarios (Mean = 4.94, SE = 0.21, 95% CI [4.514, 5.365], $d = -2.046$; $p < 0.01$). There were consistent near significant interaction effects of cueing and instance on all TTT responses ($F(2, 117) = 2.95$, $p = 0.06$), which occurred for all specific targets in pedestrian, vehicle, and warning sign TTTs (all $p \leq 0.10$) (Table 5). Fig. 5 presents means and standard errors of each condition.

There was a main effect of instance on the overall average of TTT ($F(2, 116) = 7.94$, $p < 0.01$) and a nearly significant interaction between instance and UFOV ($F(2, 116) = 2.94$, $p = 0.06$; see Table 2 for CIs in all categories). Pedestrian TTT was smallest for participants with the poorest UFOV scores for the first instance of scenarios (slope = -0.004 , SE = 0.001, $p = .006$). Further, there were a number of negative relationships with UFOV scores where the effects on the first instance were stronger than those found with the second and third instances. These results show that adaptation was slower for participants with lower UFOV scores. The effect of UFOV on pedestrian TTT (Table 5 and Fig. 3C) was more negative for the first instance of scenarios than for the second instance of scenarios.

4. Discussion

This study investigated potential costs and benefits of using dynamic conformal AR cues to direct the attention of healthy middle-aged drivers to potential roadway hazards. The results revealed no costs associated with interference. AR cues improved response rate and showed near significant effects that suggest improvement in response times relative to uncued conditions, as predicted. A secondary objective was to investigate the effects of AR cues with respect to attentional abilities (measured by UFOV). AR cues did not cause interference for drivers with lower attentional capacity. There was no indication that the cues would result in any added benefits for these drivers relative to individuals with high attentional abilities.

4.1. Costs associated with interference

There were no significant effects associated with cueing for question accuracy, regarding perception of secondary objects, which suggests that cueing was not causing interference. Because the mean difference and the confidence interval were small we think there is a good argument that the data support this argument. Based on the confidence interval, the largest likely positive effect of cueing was less than half a point (0.47) on an 18-point scale. Further, on average, headway variation was better for all later scenarios that followed the first uncued scenario. Because these findings involved an interaction with cueing it is hard to rule out that cue-related training might have helped participants to offload some of the cognitive demands associated with detecting targets. Further, subsequent to collecting data for the current study, we replicated the same overall pattern of findings in another study that investigated older driver performance (Schall et al., *in preparation*), suggesting that this pattern is unlikely to be an artifact of the small sample size.

A pilot test study showed that static visual cues can increase drivers' RTs for detecting hazards by obstructing objects (Schall et al., 2010). Static cues involved enclosed non-changing opaque rhombus shapes. These features made it complicated to discriminate information about the targets in which they highlighted. In contrast, dynamic cues (comparable to the cues used in this study) which were tested in comparison to the static cues did not appear to produce any negative masking effects. A shortcoming of the Schall et al. study was the lack of complexity of the driving scenarios. The low complexity of the scenarios produced a ceiling effect, inasmuch as the hazards were easily perceived and the alerts were superfluous for the driver. The current study examined added complexity that was more representative of actual roadways. Simulators must place drivers in situations which represent enough complexity as would be found in the real-world to accurately assess whether cueing would have a benefit. Based on drivers' limited attentional capacity, cueing is likely to provide a benefit when drivers must perform more than one driving-related task. If cueing were to interfere with attention to the roadway we might have observed poorer performance in headway variation in cued scenarios relative to uncued scenarios.

4.2. Benefits associated with directing attention

Cueing, instance, and an interaction of the two factors were analyzed to differentiate between effects due to cue-related training versus acclimation. Differences found with a main effect on instance were suggestive of acclimation and differences found with an interaction between cueing and instance were suggestive of effects related to the cueing. Differences in response rate showed that drivers tended to respond to one to two more targets in all scenarios that followed the first uncued scenario. Further, the TTT provided evidence that the AR cues may reduce drivers' response time. A near significant effect for overall TTT suggests drivers responded 800 ms more quickly in all scenarios that followed the first uncued scenario. These findings provide support for potential benefits and show that changes in performance occurred as a result of cue-related training that carried over to later uncued conditions.

4.3. Limitations

A limitation on findings associated with question accuracy (perception of secondary objects) was that secondary objects were always positioned in a fixed position immediately alongside the road. Given a design that included objects in a variety of positions across a wider field of view, there may have been more variability. Another limiting factor on question accuracy was the chosen rural environment. In a study of driver distraction Lee, Caven, Haake, and Brown (2001) found impairment (increased RT) depended on scene complexity. While no greater benefit was observed for those with UFOV impairment in this study, such a benefit might be seen with more complex driving scenes. Likewise, more complex HUD imagery might interfere with attention to the road.

In cases where response rate benefits were only found for pedestrians and warning signs we identified two limiting factors in detecting targets. First, consistent with Yeh and Wickens (2001), cue salience played a role in the ability of a participant to detect targets. In comparison to vehicles, pedestrians and warning signs were more difficult to see (because of less color contrast) and thus easier to miss. The cue helped to ensure that drivers perceived targets. Second, target visibility played a role in the ability of a participant to perceive targets. Most vehicles were visible before the cue appeared. In some cases participants responded to them even before the cue appeared. This level of visibility caused vehicles to be more conspicuous than pedestrians and warning signs and thus unlikely that they would be missed. Thus we conclude that cues were not as beneficial at drawing attention to them relative to pedestrians and warning signs.

Cueing was found to provide a benefit early (i.e., immediately after the first uncued scenario), but not later (i.e., after all other scenarios). Whether this is due to cue-related training or simply acclimation to the scenario that would have happened without cueing is an argument that merits discussion. Differences were found for the main effect of instance for pedestrian and warning sign TTT. These results may suggest acclimation. Results associated with cue-related training and TTT may have been limited because targets were frequent and not unexpected (i.e., vigilance effects). Borowsky, Shinar, and Oron-Gilad (2010) found differences in drivers' ability to detect unseen hazards in critical contexts such as a child that might enter the street from between parked cars versus hazards that were less imminent. If the targets in this study had been presented in a way that would have made them more difficult to perceive (e.g., a pedestrian hidden by a vehicle) we may have realized a greater benefit for the AR cueing.

The population tested in this study involved healthy middle-aged drivers who rarely exhibit major UFOV loss. UFOV decrements increase with age. The drivers in this study had a range of attentional abilities, although none could be characterized as highly "at risk" based on their UFOV scores. Notwithstanding, we found that individuals with poorer UFOV responded less frequently to targets and less accurately to questions than those individuals with better UFOV scores. These influences were present in relationship to instance, but not for cueing. There was no indication that the cues would be any more beneficial as a countermeasure for individuals with low attentional abilities relative to individuals with high attentional abilities. Given a wider range of UFOV scores, we might have observed more significant differences to support the benefits of such a countermeasure.

4.4. Conclusions

AR cues may offer a promising means to improve driver safety, potentially reducing response time and increasing hazard detection likelihood. We found no evidence that the AR cues interfered with the perception of non-target cues in the periphery or with driver performance. We did not find any significant negative costs related to the cue's presence (e.g., interference) in general or associated with individuals with UFOV impairment.

These findings suggest that AR cueing merits further investigation. Future studies would benefit from larger sample sizes, as our somewhat modest sample raised the possibility that some of the factors that were non-significant may have had some effects that we were unable to detect. Future studies might also apply a between-subject study design (i.e., one group receiving all both cued and uncued scenarios and one group receiving only uncued scenarios) that would provide stronger support for distinguishing benefits from cue-related training versus acclimation.

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