Effective cues for accelerating young drivers' time to transfer control following a period of conditional automation

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Abstract

Objective: During conditional automated driving, a transition from the automated driving suite to manual control requires the driver to take over control at a moment's notice. Thus, it is critical that a driver be made situationally aware as quickly as possible in those conditions where he or she may not be paying full attention. Recent research suggests that specific cues about upcoming hazards (e.g., "crosswalk ahead") can increase the drivers' situation awareness during these safety-critical take-over situations when compared with a general cue ("take over control"). The current study examines whether this increased situation awareness which occurs as a result of more specific cues translates into improved hazard mitigation performance within the same limited time window.

Method: Fifty-seven drivers were randomly assigned to one of five between-subjects conditions (one control condition and four experimental auditory cue conditions) that varied in the specificity of information provided about an upcoming hazard. The four experimental conditions included a period of conditional automated driving where the driver was engaged in a driving-irrelevant task and looked away from the forward roadway prior to a take-over request. Drivers in the fifth condition had no cue and drove manually throughout. The same six simulator scenarios were used in all five conditions to evaluate how well the driver mitigated a hazard. The average velocity, standard deviation of velocity, and average absolute acceleration were recorded along with the glance behaviors of drivers.

Results: In general, during the 4s prior to a latent hazard (following the alerting cues in the automated driving conditions), the more likely a driver was to glance towards a latent hazard the more likely the driver was to reduce his or her speed. Moreover, analyses focusing solely on hazard mitigation behavior revealed patterns that mirrored the glance behavior results. Specifically, drivers that were presented with cues that described the environments in which hazards were likely to occur were more likely to demonstrate vehicle behaviors that were consistent with speed reductions (lower velocity, higher speed variability, and higher absolute acceleration) than were drivers who were presented general cues or cues about the identity of the upcoming hazards.

Conclusion: Even in as little as 4s prior to a potential hazard, cues that inform the driver of the environment in which the hazard is likely to occur increase the likelihood that the driver mitigates the crash compared with drivers who are provided general information or threat identity information.

Keywords: conditional automation; transfer of control; auditory alerts; information cues

1. Introduction

Automation is viewed as a solution to provide safe transportation for drivers that are prone to error either as a result of inexperience or aging, fatigue, distraction, or a combination of these factors. Unfortunately, technology has not advanced (and may not ever) to the point in which the driver is obsolete in automated driving situations (e.g., Reimer, 2014). For example, automation may fail or road conditions may require that the driver resume manual control of the vehicle following an extended period of automation. These situations in which the driver must resume control are likely to be particularly problematic with the changes in workload and situational awareness that are associated with higher levels of automation (e.g., Level 2 and Level 3; SAE International, 2014). That is, the decreased workload demands of the driving task often leads to increased engagement in driving-unrelated secondary tasks and less situational awareness in critical driving situations (see de Winter, Happee, Martens, & Stanton, 2014 for review). With reduced awareness of the driving task and the forward roadway, it remains a challenge to quickly and effectively alert drivers of potential unexpected situations whereby they have sufficient time to resume manual control of the vehicle, and complete the appropriate driving action.

The reduced situation awareness during these take-over situations is especially problematic for younger drivers who require more time following a general take-over alert than experienced drivers to resume manual control of vehicle following a period of conditional automation (Wright, Samuel, Borowsky, Zilberstein & Fisher, 2016). Due to their lack of experience and knowledge, younger drivers will scan most anywhere for hazards while driving (Pradhan et al., 2005). Specifically, experienced drivers are six times more likely to scan for a latent hazard at a location such as a marked midblock crosswalk than are younger drivers. The marked midblock crosswalk for the older drivers serves as the stimulus for scanning for pedestrians. Without specific mention of this stimulus (hazard environment), the younger drivers are clueless, thus a general cue for alerting younger drivers—one with no specific hazard information (e.g., Wright et al., 2016) --may not be the most efficient and effective alert for these drivers in take-over situations.

Wright and colleagues (2017) examined a method for quickly and effectively alerting younger drivers in these transfer of control situations. In addition to general cues that simply instruct drivers that a transfer of control (or a take-over of control) is required (e.g., Agrawal et al., 2017; Erikkson & Stanton, 2017; Gold, Damböck, Lorenz, & Bengler, 2013; Merat, Jamson, Lai, Daly, & Carsten, 2014; Samuel, Borowsky, Zilberstein & Fisher, 2016; Wright et al., 2016,), the authors provided groups of drivers informative audio cues 4s prior to a latent hazard that either described the upcoming environment (e.g., "crosswalk ahead") in which the hazard was likely to materialize *(environment cue*), the identity (e.g., "scan for pedestrians") of the potential hazard (*threat cue*), or a combination of both hazard environment and threat ("crosswalk ahead scan for pedestrians") cue types (*combination cue*). (See Table 1 for a description of the cues used in Wright et al., 2017). Analyses of eye data showed that among those younger drivers who had to take-over control from the Level 3 automation (*conditional automation*), those who were given environment or combination cures anticipated approximately 40% more latent hazards than those who were given no hazard specific information (general cue). Moreover, the levels of hazard anticipation observed with these informative cues that were presented 4s in advance were comparable to non-informative cues that needed at least double the time (8s; Samuel et al., 2016).

While the levels of hazard anticipation observed in Wright et al. (2017) were promising, for younger drivers for an alert that occurred so close in time to the potential hazard, it is unclear whether the brief 4s window will allow younger drivers enough time to successfully mitigate a hazard. Previous work has shown that driving speed and speed variability are critical vehicle performance metrics related to hazard mitigation and determining risk for crashes (see Aarts & Schnagen, 2006 for review). The current study examined whether the increased situation awareness from environment cues translates to improved hazard mitigation performance within the same limited time window. It is hypothesized that: 1) increases in latent hazard anticipation (glances on potential hazard locations) will be associated with increases in hazard mitigation behavior (lower velocity, higher speed variability, higher absolute acceleration, and 2) informative audio cues that provide drivers information about the environment (environment or combination cues) will show the best hazard mitigation performance among drivers taking over manual control from Level 3 automation.

2. Method

The participants drove a total of six scenarios in one of five different conditions, four with an auditory cue which indicated information about the upcoming hazard and one in which no cue was provided. Vehicle and eye behaviors were recorded. More information is available in Wright et al. (2017).

2.1 Participants

Sixty licensed younger drivers (18-26 years of age) completed an hour-long driving simulator study and were compensated $25 for their time. The study had complete approval from the University of Massachusetts Amherst Institutional Review Board and all participants were recruited from the town of Amherst and surrounding areas. Each of these drivers were randomly assigned to one of five between-subjects conditions (a manual driving and four alert cue conditions). Three participants were not included in analyses as a result of a technical failure (*N*

= 1) and drop outs due to simulator sickness during the practice/familiarization drive (*N* = 2). Since these incidents of simulator sickness occurred prior to any of the experimental drives, no partial data are available. See Table 1 for statistics describing the sample.

Table 1. Participant and auditory cue information. (Standard deviations are in parentheses.)

Cue Condition	**Years of Age (SD)**	**Years of Driving Experience (SD)**	**Example Auditory Cue**
Manual Driving (*N* = 12)	22.31 (3.42)	4.53 (2.21)	-
General Cue (*N* = 12)	20.58 (1.44)	3.26 (1.88)	"Take-over control"
Environment Cue (*N* = 11)	20.64 (1.21)	3.79 (1.51)	"[Hazard location] ahead"
Threat Cue (*N* = 12)	20.75 (2.05)	2.17 (1.58)	"Scan for [hazard]"
Combination Cue (*N* = 10)	21.60 (2.12)	3.73 (1.86)	"[Environment cue] + [threat cue]"

2.2 Apparatus

A driving simulator, an eye tracker, and an iPad were used in the current experiment for studying driver behavior and to measure driver performance.

A Realtime Technologies Inc. (RTI) full cab, fixed-base driving simulator was used in the current study. The simulator has three screens subtending 150 degrees of horizontal field of view. The images are projected using projectors and appropriate environment sounds, and doppler is produced using a Dolby surround sound system. The controls of the simulator are similar to that found in an on-road vehicle, and participants are instructed to operate the controls of the simulator cab just as they would, a normal vehicle. While in the simulator, drivers' eye movements were recorded with an Applied Science Laboratories (ASL) Mobile Eye portable eye-tracker. The driving simulator was equipped with an automation software package that allowed for the appropriate engagement and disengagement of an automated driving suite

(ADS). The viper toggle was programmed to be the trigger for both, engaging and disengaging the automation.

The eye tracker is monocular and has two cameras, including a scene camera and an infrared eye camera. Moreover, the tracker produces a crosshair through the superimposition of images obtained from the scene and eye cameras that is representative of where the participants are fixating, with an accuracy of approximately 0.5 degrees of visual angle.

In the current study, drivers were instructed to perform a secondary task (reading from an iPad) while the ADS was engaged. Participants were provided a chapter from the drivers' manual for the reading task and were provided some practice with the secondary task, including the use of the iPad displaying this text, during the practice simulator session. Participants were specifically instructed to not engage in the reading task when actively controlling the simulator vehicle (manual driving).

2.3 Scenarios

The scenarios used to evaluate latent hazard anticipation are listed below in Table 2. As an example, consider the first scenario (Blind Drive). The driver is traveling on a two-lane road (one-travel lane in each direction), heading down a hill. A blind drive is ahead and on the right-hand side of the road. The nose of a car is just visible and serves as a latent hazard upon which the driver should glance.

Table 2. Scenarios used to evaluate hazard anticipation.

Hazard	Description (latent hazard in italics)	Cues	Image
Blind Drive	The driver is on a two-lane road. The driver passes a downhill that contains a blind drive. There is a *vehicle* parked outside a house on the blind drive (right side of the road). The vehicle acts as a latent hazard and never materializes.	E: “Blind drive ahead” T: “Scan for vehicle” C: “Blind drive ahead; scan for vehicle”	
Railroad Crossing	The driver is on the two lane suburban road. The driver passes a traffic sign (cue) indicating there is a railroad crossing ahead. The railroad crossing is densely crowded with trees and houses, and, therefore, the driver needs to carefully scan for an approaching *train* due to the low visibility under the assumption that signals do not always work.	E: “Railroad crossing ahead” T: “Scan for train” C: “Railroad crossing ahead; scan for train”	
Rotary	This particular scenario requires the driver to navigate the rotary. The rotary is densely crowded with trees and vegetation and therefore visibility of the rotary is restricted to essentially 75 feet in advance of the rotary. Thus, careful scanning is required to avoid other *vehicles* that have the right of way in the rotary.	E: “Rotary ahead” T: “Scan for vehicle” C: “Rotary Ahead; Scan for vehicle”	
Work Zone	There is a work zone on the right side of an emergency lane on a two lane highway. This work zone contains construction trucks, barrels and other roadside objects and includes two construction workers. As the driver navigates this scenario, we are interested in observing the drivers’ ability to detect a potential *worker* in front of the work zone hidden by the equipment.	E: “Work Zone Ahead” T: “Scan for worker” C: “Work zone ahead; scan for worker”	

Midblock Crosswalk	This classic scenario represents a midblock crosswalk on a four-lane city road (with two travel lanes in either direction). As the participant approaches the crosswalk, a truck is stopped in the left of two lanes for a potential *pedestrian* who may traverse the crosswalk. The driver needs to scan for a potential *pedestrian*.	E:“Crosswalk ahead” T: “Scan for pedestrian” C:“Crosswalk ahead; scan for pedestrian”	
Hiker	In this scenario, the participant is traveling straight on a two-lane rural road and passes a hiker sign (cue) There is a lead vehicle in front of the participant that brakes and slows for a *hiker* on the right side of the road who might potentially cross over to the left side. The crossing never materializes, but still the driver should have scanned for the hiker.	E:“Hiking trail ahead” T: “Scan for hiker” C:“Hiking trail ahead; scan for hiker”	

*E = Environment Cue, T = Threat Cue, C = Combination Cue

2.3 Auditory Cues

There were four different auditory cues that provided information about the upcoming latent hazard: 1) a *general cue* (“take-over control”), 2) a cue that described the risky feature(s) of the roadway and the location of those features (*environment cue*), 3) a cue that contained information regarding the actual identity of the threat and the required behavior (*threat cue*), and 4) a cue that contained information about the environment and the threat (a *combined cue*). In the general cue condition, a simple “take-over control” message occurred prior to each of the six hazards. The environment, threat and combination cues for the six scenarios are listed below in Table 2. For example, for the Blind Drive scenario, the environmental cue was: “Blind drive ahead.” The threat cue was: “Scan for vehicle.” And the combination cue was: “Blind drive ahead; scan for vehicle.”

2.4 Procedure & Experimental Design

After providing written informed consent, participants were outfitted with an eye-tracker. Then, each of the participants completed a practice drive with the goal of familiarizing the participants with the simulator controls as well as the automation (for those participants in the cue groups). The participants in the cue groups were also given one or more opportunities (as many required for the driver to feel comfortable) to activate and deactivate the automation (including engaging and disengaging from the iPad reading task). On average, the practice drive lasted approximately 5 minutes. As soon as the participant felt comfortable with the procedure (including transferring and taking-over control for those participants in the cue groups), the driver navigated the six experimental drives, each with one scenario containing a latent hazard. To control for systematic practice effects, the order of these six drives were counterbalanced between participants for each experimental group. These latent hazard scenarios required the driver to scan for (anticipate) and mitigate hazards that could potentially materialize. However, in all six (blind drive, midblock crosswalk, railroad crossing, rotary, and hiking trail) scenarios, no hazards actually did materialize. That is, latent hazards were used to ensure that fixations on potential hazards were indicative of driver's top-down anticipatory processes and not fixations indicative of reflexive eye movements to materialized hazards' unique bottom-up stimulus properties (e.g., looked at the hazard but did not anticipate it; e.g., Pradhan, Pollatsek, Knodler, & Fisher, 2009). For the six experimental drives, all participants were instructed to drive as they normally would in the right lane at the posted speed limit of 45mph. Those participants in the cue groups were told to activate the automation as soon as the drive began and stay engaged in the iPad reading task while the automation was engaged. In each of the six scenarios, the vehicle continued to travel at a constant speed of 45 mph while in automated mode. Finally, participants in the cue groups were instructed to take-over manual control of the vehicle when they heard an audio alert that either provided no information concerning the upcoming hazard (general cue) or identified the location (environment cue), identity (threat cue), or both (combination cue) of the upcoming hazard. (See Table 1 and Table 2.) These cues always appeared 4s prior to the location of the latent hazard. Following the completion of the scenarios, participants filled out a post-study questionnaire involving a few basic demographic and driving history related questions. The entire session was approximately 1-hour in duration.

2.5 Outcome Measures

2.5.1 Hazard Anticipation

As calculated and presented in Wright and colleagues (2017), a driver's latent hazard anticipation for each scenario was scored as either a 0 (miss) if the driver failed to glance towards the target zone area in which the hazard may materialize or a 1 (hit) if the driver successfully glanced towards the target zone area within the 4s prior to the hazard (the launch zone). Specifically, a target zone was defined as that area of the forward roadway where a potential or actual threat may materialize while the launch zone was defined as that area of the roadway in which the driver should glance towards the target zone in order to be able to successfully detect and mitigate the latent hazard (see Samuel & Fisher, 2015). The launch zone began 4s prior to the location of a latent hazard and ended approximately 2s before the location of a latent hazard. This 2s was based on the amount of time drivers would likely need to successfully mitigate a latent hazard. These binary scores across the six scenarios were averaged to calculate the proportion of glances on latent hazards for each participant.

2.5.2 Hazard Mitigation

Of interest to the current study was whether drivers' improved latent hazard anticipation translated to their ability to successfully mitigate hazards. The average velocity, standard deviation of velocity, and average absolute acceleration were used to assess the extent to which the driver was prepared to successfully mitigate latent hazards across the six scenarios. These variables were computed for just the 4s prior to a latent hazard (immediately following the introduction of the audio alert in the automated conditions). That is, the 4s period that was examined started when the audio alert began (or corresponding period in manual driving condition). In this way, the 4s period marks the same physical location for every driver.

4.Results

Table 3 presents the drivers' hazard anticipation (proportion of glances on latent hazards from Wright et al., 2017) and mitigation (average velocity, standard deviation of velocity, and average absolute acceleration) results from the 4s prior to a latent hazard. These results are discussed individually below.

4.1 Hazard Anticipation

In Wright et al. (2017), analyses of the proportion of glances on latent hazards revealed a significant main effect of cue type. Those results are presented below (Table 3) and have been discussed above. Here we want to look at the association between glance behavior and vehicle behavior.

Consistent with the hypotheses for the current study, the proportion of glances on latent hazards was positively related to drivers' absolute acceleration during the 4s prior to a latent hazard, $r(55) = .31$, $p = .02$, and negatively related to drivers' average velocity during this same time period, $r(55) = -.38$. While the drivers' proportion of glances on latent hazards was not significantly related to their standard deviation of velocity, $r(55) = .10$, $p = .45$, when only the automated driving conditions were included, a relationship between this hazard anticipation and mitigation outcome was revealed, $r(43) = .37$, $p = .01$. Including only the automated driving conditions also increased the size of the other previously reported correlations (absolute acceleration: $r(43) = .38$, $p < .01$; average velocity, $r(43) = -.51$, $p < .001$). In sum, when drivers anticipated a latent hazard, they also tended to slow down, particularly in the environment and combination cue conditions (see Table 3).

Table 3. Hazard anticipation and mitigation results. (Standard deviations are in parentheses.) [Bivariate correlations between the latent hazard anticipation and hazard mitigation measures are in brackets.]

Cue Condition	***% of Glances on Latent Hazards (from Wright et al., 2017)***	***Average Velocity (m/s)***	***Standard Deviation of Velocity (m/s)***	***Average Absolute Acceleration (m/s^2)***
Manual Driving (N = 12)	*.93 (.11)*	*34.43 (3.43) [-.34]*	*5.65 (.85) [-.41]*	*.54 (.10) [-.41]*
General Cue (N = 12)	*.49 (.25)*	*36.58 (2.74) [-.49]*	*5.63 (1.11) [.04]*	*.43 (.16) [.04]*
Environment Cue (N = 11)	*.69 (.18)*	*32.82 (3.52) [-.67*]*	*7.63 (1.88) [.31]*	*.67 (.26) [.19]*
Threat Cue (N = 12)	*.50 (.19)*	*34.72 (2.40) [-.14]*	*6.28 (1.11) [-.02]*	*.40 (.12) [.22]*
Combination Cue (N = 10)	*.66 (.17)*	*32.25 (5.08) [-.45]*	*7.41 (2.29) [.56]*	*.56 (.20) [.62]*

*Indicates bivariate correlation is significant at $p < .05$

4.2 Hazard Mitigation

To examine drivers' ability to mitigate hazards in each of the cue and manual driving conditions, the average velocity, standard deviation of velocity, and average absolute acceleration data were entered into separate one-way ANOVAs, each with cue condition (none, general, environment, threat, combination) as a between-subjects factor. No correction for Type I error was made for a priori planned pairwise comparisons. The one-way ANOVA with average velocity as a dependent variable revealed a significant main effect, F (4, 52) = 2.69, p =.04, η^2 = .17. As evident in Figure 1, drivers who were given a cue with information about the location of the upcoming hazard (either through the environment or combination cue) drove the slowest on average during the 4s prior the hazard. A priori planned pairwise comparisons were examined with independent samples t-tests. These revealed that the average velocity observed in the environment and combination cue conditions was significantly slower than the velocity of drivers who were given a general cue with no information about the upcoming hazard, t (21) = 2.88, p < .01, d = 1.19 and t (20) = 2.55, p = .02, d = 1.06, respectively. No other significant differences were revealed through follow-up contrasts (all p's > .05).

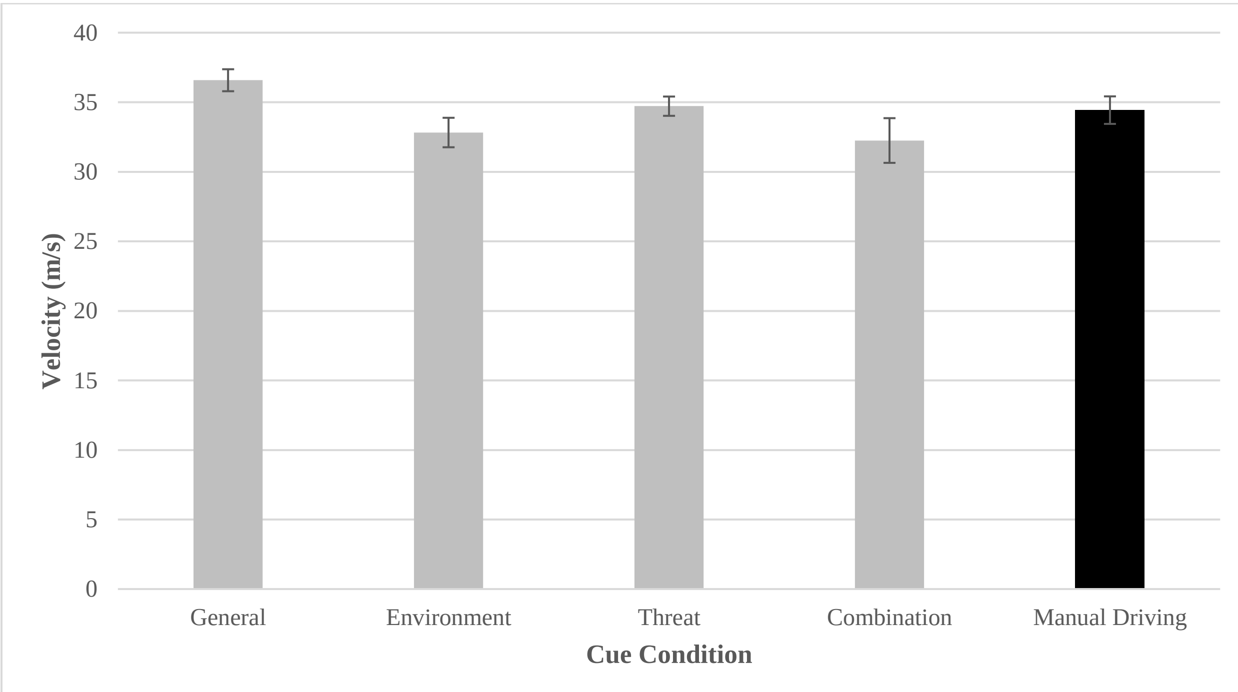

Figure 1. Average velocity during the 4s prior to a latent hazard in each of the alerting cue and manual driving conditions. Error bars represent standard error of the mean.

Next, variability in speed was examined to confirm which cues are best in alerting younger drivers to take-over manual control following a period of conditional automation. As evident from Figure 2, the average velocities during the 4s prior to a latent hazard were all below 45mph. Considering that the automation was set at a continuous speed at 45mph and manual driving participant were instructed to drive at this same speed, it follows that any variability in speed that is observed during the same 4s time period are indicative of speed reductions.

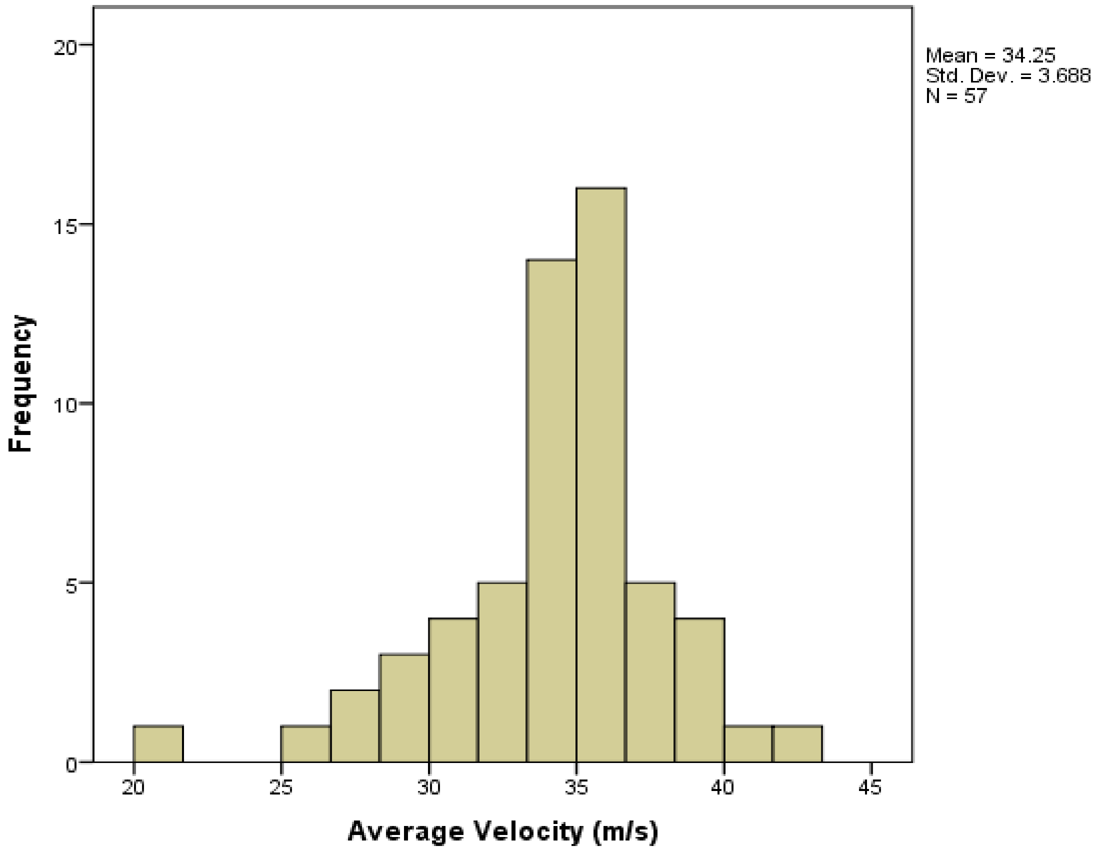

Figure 2. Histogram illustrating distributions of average velocities during the 4s prior to a latent hazard.

The one-way ANOVA with standard deviation of velocity as a dependent variable also revealed a significant main effect, F (4, 52) = 4.49, $p < .01$, $\eta^2 = .26$. Once again, no correction for Type I error was made for a priori planned pairwise comparisons. From Figure 3, the pattern is clear, and independent samples t-test confirm that drivers who received an environment cue that described the location and roadway features of the upcoming latent hazard varied their speed to a greater extent than drivers who received a general cue, t (21) = 3.14, p = .02, d = 1.30, or a threat cue, t (21) = 2.12, $p < .05$, d = 0.87. This suggests that drivers who received an

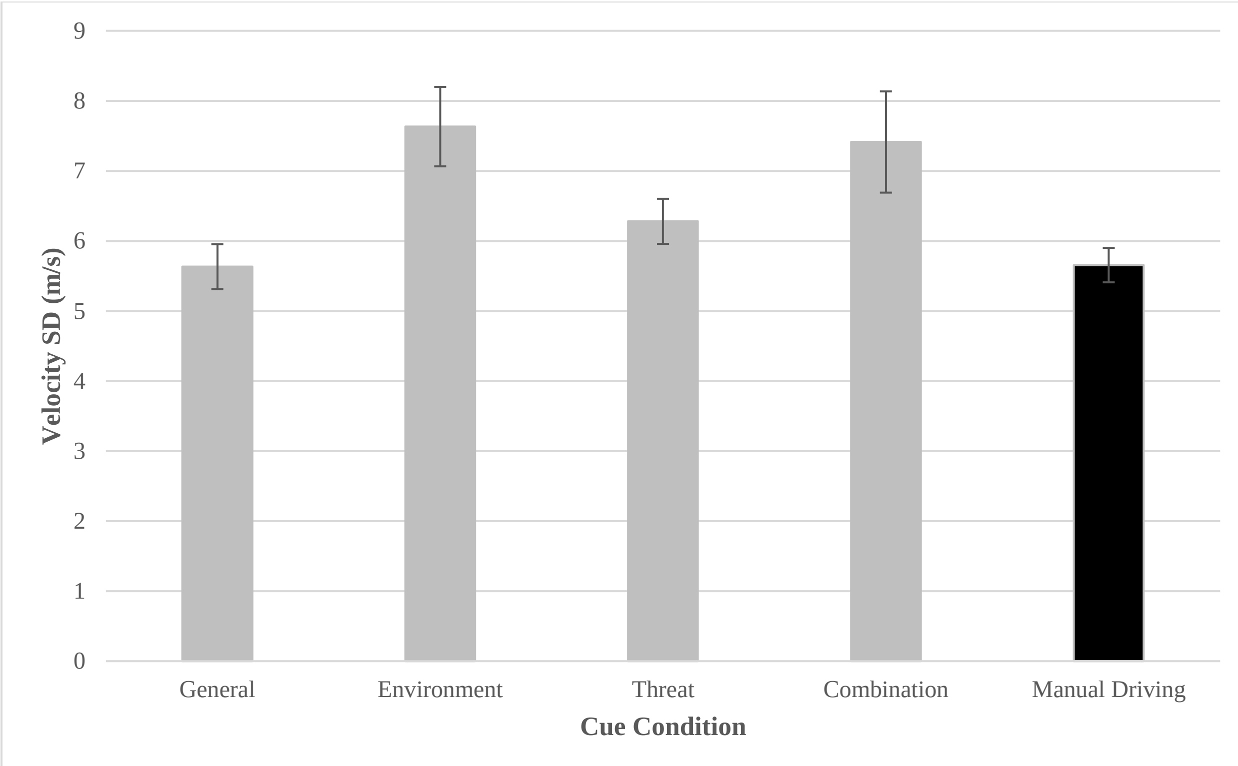

Figure 3. Standard deviation of velocity during the 4s prior to a latent hazard in each of the alerting cue and manual driving conditions. Error bars represent standard error of the mean.

environment cue were more likely to slow down than those drivers who received the other individual cue types. The specific hazard information from the threat cue and combination cues were less effective in warning drivers of upcoming hazards than the environment cue. That is, results of independent samples t-tests show that when drivers received the threat cue, they were no more likely to successfully mitigate a hazard than when they received a general or combination cue (all *p*'s > .05). Independent samples t-tests also show that while the combination cue did produce a benefit compared to the general cue, t (20) = 2.25, p = .04, d = 0.99, it did not result in significantly better performance compared to the other cue conditions (all *p*'s > .05).

Finally, the one-way ANOVA with average absolute acceleration as a dependent variable also revealed a significant effect, F (4, 52) = 4.50, p < .01, η^2 = .26. As above, no correction for

Type I error was made for a priori planned pairwise comparisons. Figure 4 shows these data. Consistent with previous results, independent samples t-test show that drivers who received the environment cue had greater absolute acceleration than drivers who received the threat cue that identified the hazard, t (21) = 3.28, p < .01, d = 1.33, and drivers who received the general cue with no specific information about the hazard, t (21) = 2.76, p = .01, d = 1.11. This again suggests that drivers are slowing down (decelerating) upon hearing the auditory cue with information concerning the environment of the upcoming hazard. All other follow-up contrasts revealed no significant differences (all p's > .05).

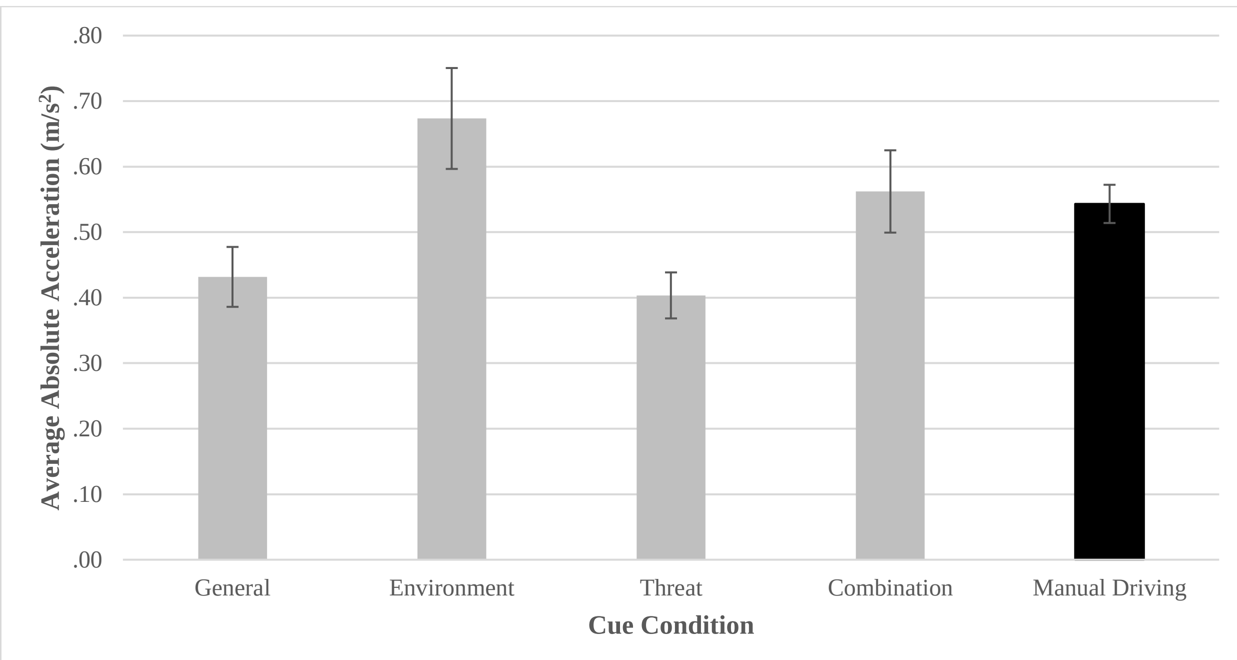

Figure 4. Average absolute acceleration during the 4s prior to a latent hazard in each of the alerting cue and manual driving conditions. Error bars represent standard error of the mean.

5. Discussion

Wright and colleagues (2017) showed that an audio cue describing the location and roadways features of the upcoming latent hazard can increase the drivers' ability to anticipate hazards in as little as 4s prior to when the hazard could potentially materialize. The current study extends these findings by showing that this improved hazard anticipation also leads to significant improvements in the drivers' mitigation of the potential hazards. Glances in areas where a hazard could materialize were associated with decreased speed and increased absolute acceleration during the 4s prior to a hazard. Moreover, in the environment cue condition, and to some extent the combination cue condition, multiple vehicle measures suggest that audio cues that inform drivers of the location of upcoming hazards not only result in drivers better anticipating these hazards (Wright et al., 2017), but also slowing down thereby preparing them to safely mitigate these hazards as well.

Interestingly, drivers in the manual driving control group anticipated the greatest proportion of hazards across scenarios (Wright et al., 2017), but there was no evidence that they were better prepared to mitigate these hazards. The manual driving control group was not significantly slower or more likely to decelerate during the 4s prior to a latent hazard than were the drivers in the other conditions. Moreover, when the manual driving group was not included, the relationship between the latent hazard anticipation and mitigation indices was stronger. It is likely the hazard relevant information presented in the audio cue for the drivers in the environment cue group, and to some extent the combination cue group, influenced their expectations that a hazard might materialize at the highlighted location. This resulted in the drivers in these cue conditions not only looking but also slowing down more for a potential hazard. Future work should examine whether the presence of a cue for manual drivers may increase their expectations that a hazard might materialize, and as a result, influence their hazard mitigation performance as well.

Both the above dissociation between the hazard anticipation and mitigation performance for drivers in the manual driving control group, and the lack of benefit observed from the cue that described the identity of the upcoming hazard (threat cue) could be due to the young drivers' minimal experience—a factor already shown to influence both hazard anticipation generally (Pradhan et al., 2005) and specifically hazard anticipation following transfers of control from automation to the human (Wright et al., 2016). This lack of knowledge regarding where to scan for hazards may make the threat cue non-beneficial for this age group. For example, in hearing "scan for vehicle," younger drivers may look up and immediately see no vehicle, so neglect to scan the blind drive. Alternatively, in hearing "blind drive ahead," younger drivers look at the blind drive and decelerate to prepare for a vehicle they infer could materialize. When drivers hear no cue, but are already looking up at the forward roadway (as in the manual driving condition), even though they may scan for the potential hazard, they either expect that the hazard is unlikely to materialize or fail to assess the risk of not slowing down for such a hazard. This would suggest the development of hazard mitigation skills with driving experience takes longer than hazard anticipation. That is, younger drivers may learn where to look before learning what to do with the information obtained from scanning (Muttart, 2015). Future work should further examine this potential dissociation between hazard anticipation and mitigation, as well as whether the benefits from the cues used in this study are exclusive to younger, inexperienced drivers.

It is important to note that the current results were obtained in a driving simulator without any actual risk to the participant. Future work should confirm the benefits of hazard cues on the open road. Also, future work should examine other modalities to present the most informative and beneficial cues to drivers within a minimal timeframe. The current study showed that the cues with the most information (combination cues) were not the most beneficial, but the current study also looked at a very brief timeframe for the driver. It is possible that with more time, more information could be useful, or with a combination of visual/auditory modalities that drivers could benefit from more information in the limited timeframe.

Acknowledgements

This research was supported in part by a National Science Foundation (NSF) Grant No. 1405550 to Shlomo Zilberstein, and by a grant from the U S Department of Transportation (USDOT), Tier 1 University Transportation Center (UTC) to Umit Ozguner (PI) & Donald Fisher (Co-PI).

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