THE EFFECTS OF ALERT CUE SPECIFICITY ON SITUATION AWARENESS IN TRANSFER OF CONTROL IN LEVEL 3 AUTOMATION

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ABSTRACT

Typically, drivers in a Level 3 automation environment need at least 8s following a manual take-over request to achieve appropriate levels of situation awareness. Studies that have derived this time estimate use general audio alerts that suggest a transfer of control from the automation to the driver might be required. The current experiment examined if improvements in younger drivers' situation awareness might be observed in as little as 4s prior to when a latent hazard might materialize and a transfer of control occurs if more specific audio alerts are used. Younger drivers were randomly assigned to 1 of 4 between-subjects cue conditions: 1) a general cue condition, 2) a condition that described the risky feature(s) of the roadway and the location of those features, 3) a condition that contained information regarding the actual identity of the threat and the required behavior, 4) a combination cue condition (both environment and threat cue). Eye-movements were recorded as drivers completed six scenarios in a simulated automated driving experiment. The results showed that audio cues that contained information regarding risky roadway features increased the detection of latent hazards by almost 40% compared to when a general cue or a threat cue was used. Performance with the combined cue was no better than performance with the environment cue. The environment cue gives drivers the critical seconds needed to mitigate a potential crash. Results are informative regarding which types of alerts to use to inform drivers of upcoming hazards.

Keywords: automated vehicles, transfer of control, situation awareness, hazard anticipation

1. INTRODUCTION

Automation is often conceptualized as varying in levels, with increasing levels associated with more components of a task automated [*1*]. As automation increases, the situation awareness of the operator tends to decrease [*2*]. In automated tasks such as driving, this often leads the operator to be out of the information processing loop, as they engage in irrelevant secondary tasks [*3*]. This is particularly problematic for the driver at intermediate levels of automation (e.g., Level 2 and 3). At Level 2, the driver is always expected to be monitoring the progress of the vehicle, but this is difficult to guarantee. The recent crash of a Tesla is telling in this regard [*4*]. At Level 3, the driver is still expected to jump back into the driving task in a matter of seconds when the automation fails or reaches a boundary condition. A critical human factors challenge is to efficiently reengage the driver's attention in the driving task, so he or she can achieve situation awareness and safely resume control of the vehicle in these transfer of control situations.

Samuel and colleagues (2016) found that drivers in a simulated Level 3 environment engaged in an in-vehicle task the entire time need 8s following a request to take-over control to achieve the same level of situation awareness as drivers gazing continuously at the forward roadway [*5*]. Specifically, drivers glancing inside a vehicle equipped with Level 3 automation require a take-over request 8s in advance (referred to as *transfer of control alerting time*; TOCAT) of a potential hazard in order to anticipate the hazard with the same likelihood that they do when glancing continuously at the forward roadway [*5*]. This 8s TOCAT was derived from a non-informative auditory cue (e.g., "take-over control"). Other work has uncovered similar TOCATS using general cues [*6*]. In studies like these, drivers had no information regarding the potential threat or the features of the roadway environment that made a potential threat likely. The drivers knew only that they had to take-over control.

There is evidence to suggest that more detailed information than just an auditory alert may reduce the TOCAT for younger drivers. Specifically, experienced drivers who are known to better anticipate hazards than younger drivers [*7*] required less time to achieve situation awareness in a Level 3 environment than inexperienced drivers [*8*]. It follows that a more specific, informative auditory cue may allow younger, less experienced drivers of a semi-autonomous system to achieve situation awareness faster. In fact, similar informative auditory cues that identify the category of a participant's target have improved the efficiency of visual search in simple displays of basic laboratory paradigms [*9*, *10*, *11*]. If these effects of semantic cues were observed even for the search of simple displays, it is likely that we may find still larger effects in more complex and dynamic environments such as those in simulated driving scenes. It follows that the 8s TOCAT observed by Samuel et al. (2016) may be reduced when these more informative cues are utilized, and therefore precious time saved.

However, there is also evidence that suggests more information could delay situation awareness. Due to the processing limits of the human operator [*12*], providing drivers with too much information in a brief time frame may yield no benefit or even impair drivers' ability to safely take-over control of the vehicle. Similar information overload effects have been observed in the decision-making literature, where more information does not always translate to improved performance on decision-making tasks. In fact, more information can often have no benefit or even negatively impact performance [*13*, *14*]. This is especially likely for individuals who are multitasking or for decisions that are time pressured [*15*].

In summary, the complexity of the driving task and the limited ability to provide advance warnings to drivers in a Level 2 and Level 3 automation environment when something unexpected by the driver occurs suggests that the best hazard cues may be those that efficiently convey only the information absolutely necessary to resume manual control of the vehicle.

2. METHOD

The goal of the current experiment was to examine whether specificity of alerts influences drivers' ability to anticipate hazards in a Level 3 transfer of control situation (the applicability to Level 2 we describe later in the Discussion). In order to achieve this goal, we conducted a driving simulator experiment that contained four between-subject conditions: an environment cue group, threat cue group, combination cue group, and a general cue group. All four conditions require the driver to take over control from the automated driving suite (ADS) when alerted to do so. The alerting time in the transfer condition was set to be 4s, with the expectation that environment cue groups and threat cue groups will anticipate more hazards than the other groups. Moreover, it was expected that the combination cue group would anticipate fewer hazards than the other groups. During all conditions the drivers were engaged in an in vehicle reading task on an iPad while ADS was in control.

2.1 Hypotheses

There are two main hypotheses in this study:

- **H1** (Effect of specificity of alerts on latent hazard anticipation): Drivers with limited specific information (environment cues or a threat cues) about upcoming hazards will be able to anticipate hazards more precisely than drivers with general alerts; and
  H2 (Effect of information overload on latent hazard anticipation): Drivers with too much information (combination cue) about upcoming hazards in the brief timeframe will anticipate hazards more poorly than drivers with the limited specific information.

2.2 Participants

47 subjects aged 18-26 were recruited from the University of Massachusetts Amherst and surrounding areas for this study and were paid 25 dollars for their participation. Data from 1 subject were dropped due to a technical failure and 1 subject was dropped due to simulator sickness. Table 1 includes sample statistics including sample size, drivers' age and driving experience for each experimental condition.

TABLE 1 Participants' demographic information (Standard deviations are in parentheses).

Cue Condition	Age (years)	Driving Experience (years)
General Cue (N = 12)	20.58 (1.44)	3.26 (1.88)
Environment cue (N = 11)	20.64 (1.21)	3.79 (1.51)
Threat Cue (N = 12)	20.75 (2.05)	2.17 (1.58)
Combination Cue (N = 10)	21.60 (2.12)	3.73 (1.86)

2.3 Apparatus

The current experiment utilized a driving simulator, an eye tracker and an autonomous driving suite package that mimicked Level 2 functionality (lateral and longitudinal control).

2.3.1 Driving Simulator

A Realtime Technologies Inc. (RTI) Simulator was used to conduct this experiment. The RTI simulator is a full cab, fixed base driving simulator. The cab in the simulator is a fully equipped 1995 Saturn sedan placed in front of three screens with overhead projectors. The visual environment encompasses 135 degrees horizontally and 180 degrees vertically at a resolution of 1240 x 768 pixels per screen and a frequency of 60 Hz. The participants are instructed to control the car, just as they would in a normal car. The vehicle dynamics, physics, graphics, and audio (Dolby surround system consisting of side speakers and two sub woofers located under the hood of the car) provide a realistic experience for the participants. The current sound setup mimics the effect of wind, road and other vehicle noises with appropriate direction, intensity and Doppler shift.

2.3.2 Eye Tracker

An Applied Science Laboratories (ASL) Mobile Eye was used to monitor fixations of the driver. The ASL Eye tracker provides visual angle range of 50 degrees in the horizontal direction and 40 degrees in the vertical direction with an accuracy of 0.5 degrees of visual angle. The ASL eye tracker is a portable head mounted eye tracker system.

2.3.3 Automation Control Suite

The RTI driving simulator is equipped with a Level 3 automation package 'SimDriver'. SimDriver allows for the engagement and disengagement of automation by the windshield wiper toggle stick on the right side of the steering wheel. When transferred to automated mode, the automation completely took control of the car and performed all the steering, braking and acceleration tasks for the car. During the time that the automation was engaged, the speed of the car is set to a default value of 45 mph. There was no haptic feedback for the driver when the automation was engaged.

2.3.4 Scenarios

The participants each navigated through six drives with each drive containing one scenario lasting approximately two minutes. All six scenarios contained one latent hazard. Out of six latent hazards, two were pedestrians, two were vehicles and one a hiker and one a train. All the scenarios are briefly described along with their perspective views for illustrations in Table 2.

TABLE 2 Scenarios used to evaluate hazard anticipation.

Hazard	Description (latent hazard in italics)	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.	
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.	
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.	
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.	

Mullins Center	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*.	
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.	

2.3.5 Experiment Design

The experiment utilized a between-subjects design. Drivers navigated through six virtual scenarios and were alerted to take-over control of the vehicle with one of the four between-subjects categories of alerts (environment cue, threat cue, combination cue, or general cue). The environment cue group received alerting messages with a description of the upcoming hazard environment (e.g., crosswalk ahead), and the threat cue group received alerting messages that informed them of the appropriate threats to scan for (e.g., scan for pedestrian). The combination cue group was alerted with a message that combined the two categories of alerts (e.g., crosswalk ahead; scan for pedestrian). See Table 3 for the six alert messages for each experimental cue condition. In the general cue condition, a simple "take-over control" message occurred prior to each of the six hazards.

TABLE 3 Auditory cues presented in experiment examining how cue specificity influences the transfer-control alerting time for drivers in a vehicle with Level 3 automation.

Scenario	Environment cue	Threat Cue	Combination
Blind Drive	"Blind drive ahead"	"Scan for vehicle"	"Blind drive ahead; scan for vehicle"
Railroad Crossing	"Railroad crossing ahead"	"Scan for train"	"Railroad crossing ahead; scan for train"
Rotary	"Rotary ahead"	"Scan for vehicle"	"Rotary Ahead; Scan for vehicle"
Work Zone	"Work Zone Ahead"	"Scan for worker"	"Work zone ahead; scan for worker"
Mullins Center	"Crosswalk ahead"	"Scan for pedestrian"	"Crosswalk ahead; scan for pedestrian"

Hiker	"Hiking trail ahead"	"Scan for hiker"	"Hiking trail ahead; scan for hiker"

The order of the drives was counterbalanced across participants within each group. Drivers were in autonomous mode for at least two minutes on average prior to the transfer of control from the ADS to the driver. While in autonomous mode, drivers were required to engage (keep their eyes) on a secondary iPad reading task.

2.4 Procedure

Participants first completed an informed consent form to provide written consent to participate in this study. After obtaining informed consent, participants were outfitted with an eye tracker and asked to navigate a practice drive with the goal of familiarizing the participants with the simulator controls as well as the automation. Next, the driver navigated the six experimental drives. Subsequent instructions were provided to participants at the onset of each drive. Specifically, drivers were asked to maintain the current speed limit when they were in control of the car and were asked to engage in the reading task on the iPad only when car was in autonomous mode. Following the completion of the scenarios, participants filled out a post-study questionnaire involving few basic demographic and driving history related question. The entire session was approximately 1-hour long.

2.5 Dependent variable

The dependent variable for each scenario was whether or not the driver anticipated the latent hazard (the italicized words in Table 2). The value of dependent variable for each scenario is determined by the glance location of the driver as he or she approaches the latent hazard. 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. A driver's latent hazard detection performance for each scenario is scored as either a 0 (miss) if the driver fails to glance towards the target zone in the launch zone or a 1 (hit) if the driver does glance towards the target zone in the launch zone. The launch zone and target zone used in this experiment were previously utilized in other experiments for the evaluation of latent hazards anticipation [*16*].

3. RESULTS

Gaze data were analyzed using a logistic regression model within the framework of Generalized Estimating Equations (GEE). The model included participants as a random effect and treatment (4 experimental conditions) as a between-subjects factor. A significant main effect of treatment was observed, Wald $X_3^2 = 9.72$; $p = .02$. As evident in Figure 1, the main effect was consistent with our hypotheses. Replicating Samuel and colleagues (2016), when drivers were given a general cue to take-over control, they anticipated less than half of the latent hazards (M = 49%, SD = 25%). This level of hazard anticipation was equivalent to the threat cue condition (M = 50%, SD = 19%), t (22) = .09, p = .93. However, drivers were able to anticipate approximately 40% more hazards than these two cue conditions (general cue: t (21) = 2.12, p = .046; threat cue: t (21) = 2.45, p = .02) when they were given a environment cue that described the location and roadway features of the upcoming latent hazard (M = 69%, SD = 18%)—a level of hazard anticipation that is similar to the 6s and 8s alerting conditions and nominally higher than experienced drivers in the same 4s condition in previous work [*1*, *3*]. More information did not always translate to better hazard anticipation, though, as the combination cue resulted in drivers anticipating 66% (SD = 17%) of the latent hazards. This level of hazard anticipation in the combination cue condition was not statistically greater than any of the other cue conditions (all p's > .05).

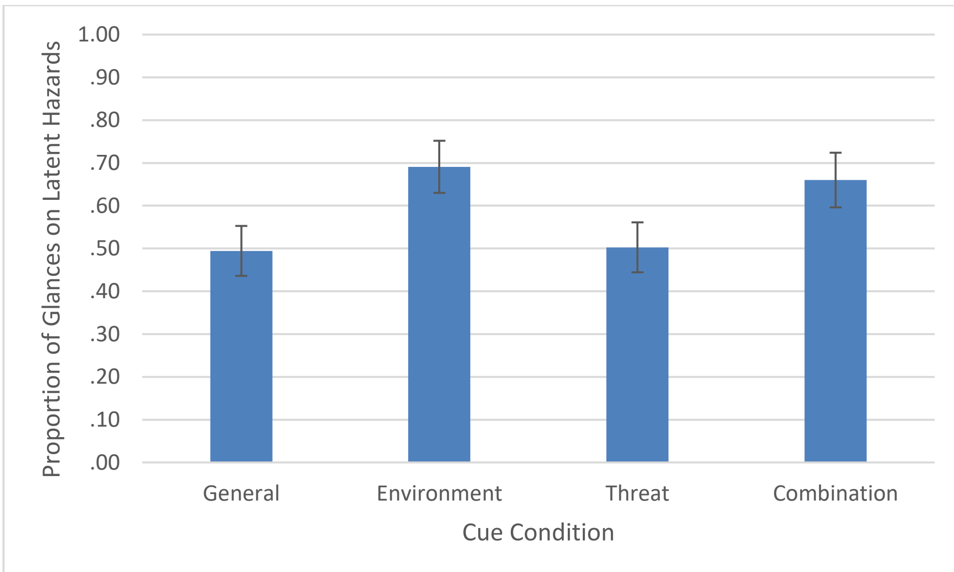

FIGURE 1 Latent hazard anticipation as a function of cue condition.

4. DISCUSSION

Typically, inexperienced drivers need at least 8s to achieve an appropriate level of hazard anticipation following a period of not looking at the forward roadway while driving under Level 3 automation. An appropriate level of hazard anticipation is defined as one that is consistent with those driving without automation who are continuously attending to the forward roadway. In fact, those drivers that have engaged the ADS and are performing an in-vehicle task anticipate less than half of the latent hazards when they are only given a general warning 4s in advance of when a potential hazard could materialize. The current experiment replicated this result in the general 4s alerting condition.

A novel finding in this experiment, consistent with Hypothesis 1, is that when drivers were given more specific information about the location of the upcoming hazard, they anticipated approximately 40% more latent hazards—close to the performance of the 6s or 8s condition in previous work examining appropriate alerting times for younger, less experienced drivers [*5*] and a nominally greater level of hazard anticipation than experienced drivers within the same timeframe [*8*]. In driving, fractions of a second are the difference between life and death and it would appear that environment cues could give drivers life-saving additional seconds in which to mitigate a potential crash.

Somewhat surprisingly, performance in the threat cue condition was no better than performance in the general cue condition. There are two possible reasons for this. First, we had expected that by identifying the threat we would much more quickly help the driver determine for what to scan. To see what the problem might have been with this line of reasoning, consider the blind drive scenario. Here the environment cue was "Blind drive ahead". The threat cue was "Scan for vehicle ahead." Although the environment cue does not specifically tell the driver for what he or she should be scanning, it does tell the driver what features of the environment are creating a risk and, by inference, what to look for (a car) and where to look for it (in whatever driveway is obscured). The threat cue does not tell the driver what features of the environment are creating the risk. Therefore the driver does not know where to focus the scan for the threat. In fact, if anything the threat cue would seem to be distracting. A driver who knew to look for vehicles in a blind drive might reason if given a threat cue, "Scan for vehicle ahead", that there was a second, threat vehicle and look away from the blind drive for an unexpected vehicle.

Second, the environment cue focused the driver immediately on the features of the roadway that were creating the risky situation. The threat cue focused first on the instruction to scan and then only on the identity of the latent threat. This would only have delayed the relevant information by a second or two, but given that the alerting time was 4s, this might have been sufficient to neutralize any advantages a threat cue might have had had the threat been presented first.

Interestingly, consistent with Hypothesis 2, the second explanation above could provide a reason for why the combination cue group's performance was worse than the performance of the best forming group (environment cue). The additional time taken to process the information in the combined cue could actually distract the driver from the task at hand which is to scan for a latent threat. The difference between the environment cue and combined cue groups was not statistically significant, but it was in a direction consistent with the above line of reasoning.

The results of the current study are not only informative of what alerts to use in Level 3 automation scenarios, but also what alerts might be useful to alert drivers as they inappropriately use lower levels of automation and lose situation awareness. The brief time frame that was the focus of this study is consistent with the time frame that drivers may be out of the loop as a result of inappropriate glances away from the forward roadway while Level 2 automation is engaged. Future work should not only confirm results on an open road, but also continue to find effective ways of precisely conveying information in a way that can improve drivers' hazard anticipation ability in a limited time frame. Specifically, the visual modality or a combination of the audio and visual modalities may be a more efficient means of conveying information regarding *how* to take-over manual control when a transfer of control is required.

Finally, this study was conducted to inform a larger project that aims to develop a model that provides the driver the right cues at the right time automatically (based on available time and driver state). This system is designed to issue the best cues to maximize the success of a transfer of control, but is also prepared for situations in which the driver fails to take over control, in which case the car stops either in its lane or safely on the side of the road. A future study will test the effectiveness of issuing variable time-dependent and context-dependent cues based on the remaining time as well as driver state. The model proposes issuing one cue (the most effective one) when time is limited, but more cues can be issued when there is more time or when the driver seems to be in a state that can benefit from other cues (based on eye tracking or other methods) [*17*].

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