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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 4 s 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 4 s 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.

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

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driving task often leads to increased engagement in driving-unrelated secondary tasks and less situational awareness in critical driving scenarios (see de Winter et al., 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 scenarios 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 after a period of conditional automation (Wright et al., 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 et al. (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; Eriksson and Stanton, 2017; Gold et al., 2013; Merat et al., 2014; Samuel et al., 2016; Wright et al., 2016), the authors provided groups of drivers informative audio cues 4 s 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 (conditional) automation, those who were given environment or combination cues anticipated approximately 40% more latent hazards than those who were given no hazard specific information (general cues). Moreover, the levels of hazard anticipation observed with these informative cues that were presented 4 s 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 and an alert that occurred so close in time to the potential hazard, it is unclear whether the brief 4 s 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 and van Schagen, 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.

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 ° of horizontal field of view. The images are displayed using projectors, and appropriate environment sounds and doppler are 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 ° of visual angle.

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]”