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Effectiveness of visual warnings on young drivers hazard anticipation and hazard mitigation abilities

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ABSTRACT

Previous studies have demonstrated that young drivers fail both to scan for and mitigate latent hazards mostly due to their cluelessness. This study aims to investigate whether these skills could be improved by providing young drivers with alerts in advance of the upcoming threat using a driving simulator experiment. In particular, the warning was presented on the head-up displays (HUD) either 2 s, 3 s or 4 s in advance of a latent threat. The hazard anticipation, hazard mitigation and attention maintenance performance of forty-eight young drivers aged 18–25 was evaluated across eight unique scenarios either in the presence or in the absence of latent threat alerts displayed on a HUD. There were four groups overall: one control group (no alert) and three experimental groups (2 s alert, 3 s alert and 4 s alert). The analysis of the hazard anticipation data showed that all three experimental groups with HUD warnings (2 s, 3 s, 4 s) significantly increased the likelihood that drivers would glance towards latent pedestrian and vehicle hazards when compared to the control group. The hazard mitigation analysis showed that in situations involving a pedestrian threat, HUD alerts provided 3 or 4 s in advance of a potential threat led drivers to travel significantly slower than the control group or the 2 s group. No significant effect of a HUD alert on drivers' speed was found when the latent hazard was a vehicle. An analysis of eye behaviors showed that only 7 out of 597 glances at the HUD were longer than 2 s safety-threshold, indicating that the warnings do not seem to distract the driver.

1. Introduction

According to the U.S. Department of Transportation (DOT), drivers between 16–24 years are more likely to be involved in motor vehicle crashes than drivers in any other age cohort (IIHS, 2017). The prevailing view for much of the previous fifty years was that young drivers were careless, not clueless. That is, the young drivers ignored potential hazards and engaged in more risky behaviors such as speeding (Hatfield and Fernandes, 2009), not because they were unaware of the risks (clueless), but because they were risk seeking (careless). However, this view has changed over the past decade and so too the view of just how one could reduce novice driver crashes. Below we describe how this view has changed, what countermeasures are now in place, and, most importantly, motivate the countermeasure we evaluated.

The prevailing view changed in the early 2000 s when Mcknight and Mcknight (2003) analyzed more than 2000 crashes involving young drivers aged 16–19 years. They found that errors in attention and the failure to recognize and respond to potential dangers, rather than thrill-seeking or deliberate risk-taking, accounted for most non-fatal crashes. These safety-critical cognitive skills were later summarized as attention maintenance, hazard anticipation, and hazard mitigation. In particular, hazard anticipation skills are those used to decided where to scan the areas of the roadway where potential (as opposed to actual) hazards may exist (Crundall et al., 2012; Pradhan and Crundall, 2016), hazard mitigation skills are those used to avoid or mitigate visible and potential hazards (Muttart, 2013; Muttart and Fisher, 2016), and attention

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maintenance skills are those used decide how to divide attention between monitoring the forward roadway and glancing at secondary, in-vehicle tasks (Chan et al., 2010).

Not only are the above three skills – hazard anticipation, hazard mitigation, and attention maintenance – ones which explain a large majority of novice driver crashes, but it has been well documented over the last ten years or so that in young drivers the above three skills are underdeveloped compared to older and more experienced (Pradhan et al., 2005; Chan et al., 2010; Crundall et al., 2012; Muttart, 2013). The question is then what can be done to improve these skills. Training programs are one possibility. They have been developed for hazard anticipation (Pollatsek et al., 2006), hazard mitigation (Muttart and Fisher, 2016) and attention maintenance (Pradhan et al., 2011). Most of them have been proven to be effective, as evaluated on simulators (Pradhan et al., 2009), in controlled field experiments (Fisher et al., 2007) and through the analysis of crash reports (Thomas et al., 2016; Zhang et al., 2016a,b). However, they have one inherent weakness. Their implementation depends on states (or other jurisdictions, depending on the country) requiring that novice drivers receive the training that has proven effective at reducing crashes and at changing the behaviors that lead to crashes. This has been difficult to do, at least in the United States, though perhaps less so in other countries (Nepomuceno et al., 2016).

If young drivers are clueless, then another way to help them anticipate a latent hazard (and perhaps mitigate the hazard without distracting them) would be to provide the young drivers with alerts in advance of the upcoming threat. Many cars are now equipped with collision warning systems that can alert the drivers in the event of impending collisions. For instance, studies report that forward roadway collision warning systems reduce rear-end crashes (Maltz and Shinar, 2004; Cicchino, 2016). The warning systems are getting even more sophisticated, telling the driver not only that a threat exists but highlighting the actual threat in the road ahead. For example, two studies have tried to direct drivers' attention to the roadside hazards (pedestrians, vehicles and warning signs) using augmented reality cues (i.e., visually directing the driver's attention to the actual threat) (Schall et al., 2012; Rusch et al., 2013). They found that the cues could decrease drivers' response times (marginally significant) and increase the likelihood that pedestrians and warning signs were detected, but had no effect on the likelihood that vehicles were detected.

The above two studies focused either on elderly drivers (Rusch et al., 2013) or middle-aged drivers (Schall et al., 2012). The effect of augmented reality HUD forward collision alerts on young drivers, the cohort shown to have the worst hazard anticipation skills, has not yet been investigated. Moreover, the hazards in the above two studies which triggered the alerts were always visible from a distance, were never obscured on approach, and always materialized as real threats as the driver passed the nearby the threat. This is important to note because the alerts provided by forward collision warning systems do not activate in those scenarios where novice drivers differ most from experienced, scenarios where latent or potential hazards exist (Crundall et al., 2012). The sensors, like drivers, cannot see the threat in such scenarios.

An example of such a scenario may help the reader at this point understand more concretely what we mean by latent hazards and why sensors are not useful upstream of the threat. Suppose that a driver is traveling a two-lane road (one travel lane in each direction) with a parking lane on each side. The driver is approaching a marked mid-block crosswalk. A large vehicle is parked immediately upstream of the crosswalk of the crosswalk, obscuring the driver's (and sensor's) view of a pedestrian that may have entered the crosswalk. As the driver approaches the crosswalk he or she should slow, steer to the left, and scan to the right for any potential pedestrians that might emerge suddenly from in front of the parked vehicle.

Although not currently available, forward collision warning systems in the very near future may be able to recognize latent threats, threats which they cannot see using video analytics. Video analytics can now easily recognize pedestrians from camera based systems and predict whether they would collide with a vehicle (Castro et al., 2011). Video analytics is now being used to recognize more complex traffic configurations, e.g., work zones (Seo et al., 2014). It seems only a matter of time when video analytics could progress to the point where it could be used to recognize scenarios in which latent threats might materialize (e.g., to recognize a marked mid-block crosswalk and a truck or other large vehicle obscuring a potential pedestrian). With this as background, we wanted to know whether novice drivers, drivers who we know from previous research do not look for latent threats, would increase their likelihood of looking for a latent threat if given some information about the presence of the latent threat.

We chose to display the information on a HUD because it is well documented that a HUD is less distracting than a head-down display (Yeh et al., 2003; Liu and Wen, 2004; Ablabmeier et al., 2017). However, it is not totally distraction-free (He et al., 2015). Perceiving the information on the head-up display still requires drivers to glance away from the roadway directly ahead to the warning itself, and glances greater than 2 s away from the roadway directly ahead have been shown to significantly increase the crash risk (Horrey and Wickens, 2007). This may not be as much of a problem with HUDs as it is with head-down displays however since glances towards a head-up display have been found to be relatively short, with an average glance duration of 0.13 s as reported by Pierowicz et al. (2000) and about 0.24 s as reported by Caird et al. (2008).

While it is important to present information about latent threats to the driver, particularly for novice drivers, the timing of the warnings is equally critical. Poorly timed warnings may undermine the driver's safety (Mcgehee et al., 2002). An early alert may be ignored or interpreted as a false alarm by the drivers while, late alerts may disrupt a concurrent vehicle maneuver (Lee et al., 2002). Abe and Richardson (2006) showed that an early forward collision warning (about 0.8 s after the braking of the lead vehicle) was effective in reducing the brake onset time when the headway to the lead vehicle was both short (imminent) and long (not imminent) while a late warning (about 1.4 s after the braking of the lead vehicle) was ineffective when the collision was not imminent and actually delayed the brake onset time when the collision was imminent. Similar results have been reported by Werneke and Vollrath (2013) where they compared the effectiveness of an early warning (approximately 70 m before the hazard) and two types of late warnings (approximately 18.5 m before the hazard) designed to assist drivers in detecting and reacting to the hazardous vehicles at intersections. In total there were three types of warnings in their study, an early warning projected on a standard HUD, a late warning projected on a standard HUD, and a late warning projected on an augmented reality HUD. Subject drivers in their study were either in the control group without any warning, or in one of the three warning groups described earlier. It was found that among the three warning conditions only the early warning signals significantly reduced the collision risk compared to the control group, and was rated by drivers as "useful".

In a recent driving simulator based experiment, Yan et al. (2015) compared the performance of seven sets of warning delivery times, ranging from 2.5 s to 5.5 s (with 0.5 s increases), in helping drivers respond to red-light-running events at intersections. The results when compared with the reference control group (no warning) indicated that earlier warning timings (from 4.5 s to 5.0 s) significantly reduced the brake reaction times of drivers while the late warning times (from 2.5 s to 3.0 s) did not. The 3.5 s warning time was also associated with faster reaction times. The analysis of the eye data further showed that while