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Situation awareness increases when drivers have more time to take over the wheel in a Level 3 automated car: A simulator study

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ABSTRACT

Vehicle automation may improve road safety because most crashes are caused by human error. However, reliable autonomous vehicles in which the 'driver' never has to take over the wheel are still in the distant future. At first, cars will only drive themselves under certain conditions. When these conditions are not met the car will prompt the driver with a take-over request (TOR).

In this study, a simulator was used to investigate whether drivers could spot latent hazards in the road and traffic scene immediately after manual driving had become obligatory (that is, after a TOR). A latent hazard is a traffic situation in which precursors of a hazard are visible. The number of latent hazards spotted was assumed to be an indicator of the driver's situation awareness. Latent hazards may or may not materialize into acute threatening situations in which a crash is very likely. The simulator drive contained eight latent hazards (that did not materialize). The default mode was automated driving; however, when participants approached a latent hazard a TOR was prompted. Fifty participants were randomly assigned to one of two groups: in the *4 s group* the TOR was prompted four seconds before participants had to resume manual driving, and in the *6 s group* the time allowed was six seconds. All participants played a computer game on a tablet while the simulator car was in automated mode. Their gaze directions were recorded with an eye tracker during the entire trip of approximately 45 min.

On average, participants in the 4 s group gazed at 29% ($SD = 16.5$) of the latent hazards, and participants in the 6 s group gazed at 47% ($SD = 17.8$). A generalized linear model for binomial data revealed that this difference was significant (χ^2 (1, $N = 43$) = 11.23, $p < .01$).

This result indicates that drivers need time to develop situation awareness when they have to resume driving. It could be that, after having been out of the loop, drivers have to construct a mental representation of the traffic situation before they can recognize latent hazards.

1. Introduction

A car that drives itself, but requests that the driver take control when certain conditions are not met, is called a Level 3 car (SAE_International, 2016). When a Level 3 car is in autonomous mode and the 'driver' is involved in an unrelated task (e.g., texting) without attending to the forward roadway, he or she will not be aware of the developing traffic situation.

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Naturalistic driving research has revealed that when drivers' eyes are off the road for as little as two seconds, the crash risk already increases substantially (Dingus et al., 2016). When a Level 3 car is in autonomous mode, drivers' eyes can be off the road not just for seconds but for minutes. It is likely that due to system boundaries or system failures, the first Level 3 cars on the open road will have to prompt frequent take-over-requests (TORs). Simulator studies indicate that when an acute threatening situation arises (e.g., a lead vehicle suddenly brakes), drivers respond (i.e., by braking and/or swerving) more slowly after they just have resumed manual driving than when they have been driving the entire trip manually (e.g., Gold, Damböck, Lorenz, & Bengler, 2013; Strand, Nilsson, Karlsson, & Nilsson, 2014). Although drivers in this situation react more slowly, most of them react adequately—even when the transition-of-control time is as short as four to five seconds and they were completely out of the loop while not driving (e.g., Gold et al., 2013; Melcher, Rauh, Diederichs, Widlroither, & Bauer, 2015). The present study is not concerned with these acute threatening situations; rather, it considers the time period directly after the resumption of manual driving, when subtle precursors in the road and traffic environment indicate the possible development of a hazard. It seeks to answer the question: Is a short transition-of-control time of four seconds sufficient for drivers to recognize the subtle cues that may indicate a potentially hazardous situation after they been out of the loop while not driving?

In order to detect these cues, drivers have to know what is going on around them. This means that they must have situation awareness. Endsley (1995b) defined situation awareness as consisting of three levels: the perception of elements in the environment (Level 1), the integration of those elements into a coherent meaning (Level 2), and the projection of that meaning into the future (Level 3). Endsley (1995a) hypothesized that the factors impacting situation awareness are working memory, attention distribution, goal-directed processing, mental models, schemata, and automaticity. All these factors are relevant when reconstructing situational awareness of the road and traffic scene after having resumed manual driving in a Level 3 car. For example, Altmann and Trafton (2007) found that when participants played a cognitively demanding computer game which was interrupted for approximately 40 s by a totally different but simple task, the game performance was impaired during the first 15 s after resumption. Based on their memory-for-goals theory, the authors hypothesized that this long recovery phase is due to the fact that in order to resume a task, an episodic mental context needs to be reconstructed (Altmann & Trafton, 2002). The theory postulates that activation of the goals from before an interruption (in our case, scanning for possible hazards) depends on three things: the duration and complexity of the interrupting task and the availability of contextual retrieval cues after the interruption. The first and second would imply that the longer the Level 3 car is in autonomous mode and the more drivers are engaged in cognitively demanding tasks not related to driving, the longer they will take to be fully aware of what is going on around them after resumption of the driving task. The third may imply that when the road and traffic scene from before the driver started to drive in autonomous mode resembles the road and traffic scene at the moment of the TOR, reactivation of the 'driving mindset' will be faster than when the road and traffic environment is entirely new for the driver. Gartenberg, Breslow, McCurry, and Trafton (2014) have incorporated the memory-for-goals theory into the concept of situation awareness. They found evidence for a process they call 'situation awareness recovery': while a driver executes a secondary task that fully replaces the primary task, memory traces concerning the primary task decay. The longer and more cognitively demanding the secondary task is, the weaker the traces. To regain situation awareness after an interruption, drivers first engage in situation awareness recovery by attending to elements in the environment from before the interruption. These elements will prime the activation of previous goals and plans. In turn, this will promote the recovery of situation awareness. Only after situation awareness is recovered will drivers start to scan for new elements in the road and traffic environment.

The concept of situation awareness is closely related to the concept of hazard perception (Horswill & McKenna, 2004). Hazard perception is the ability to notice cues that indicate that a hazardous situation may be developing (Crundall et al., 2012). In terms of situation awareness, hazard perception thus can be defined as the ability to detect (Level 1) and recognize (Level 2) latent hazards, and to predict (Level 3) how these latent hazards could develop into situations in which a crash is likely. Latent hazards are not acute threatening situations that require immediate evasive action (e.g., braking, swerving). They can be other road users who are visible to the driver that require attention because they can start to behave dangerously in road and traffic situations like this. They can also be possible other road users the driver could collide with who the driver cannot see because the view of the driver at these possible other road users is obscured (e.g., by parked cars, bushes, trucks) (Crundall et al., 2012). Drivers with poor hazard-perception capabilities have a higher crash risk than drivers with good hazard-perception skills. For example, Horswill, Hill, and Wetton (2015) found that novice drivers who failed a hazard-perception test (incorporated into the driving license system of Queensland in Australia) were 25% more likely to get involved in a crash in the first year after the test than novice drivers who passed the test. Hazard perception has been associated with driving experience. The more experienced drivers are, the higher they score on hazard-perception tests (e.g., Scialfa et al., 2012). It has also been associated with risk-taking propensities (e.g., Grayson, Maycock, Groeger, Hammond, & Field, 2003). The more drivers are inclined to take risks, the poorer their scores on hazard perception tests are. Furthermore, it has been associated with distraction (Borowsky et al., 2014). Drivers who experienced a brief interruption of 2 s (during which they completed a visual secondary task consisting of looking at a display inside the vehicle) gazed at fewer latent hazards immediately after the interruption than drivers who did not perform the secondary task. Their study measured gaze direction with an eye tracker to assess hazard perception. The same method is used in the present study, albeit applied to evaluate situation awareness after a much longer interruption in which participants do not have to drive.