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Transition of control in a partially automated vehicle: Effects of anticipation and non-driving-related task involvement

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ABSTRACT

Vehicle automation is expected to improve traffic safety. However, previous research indicates that high levels of automation may bring about unintended consequences, specifically in relation to being out of the control loop of the vehicle, such as reduced monitoring of the task, situation awareness, and attention. These changes in driver behavior become especially important in the case of a manual takeover request by the vehicle. A driving simulator study was carried out to investigate the effect of anticipatory information and non-driving-related task involvement on drivers' monitoring behavior and transition of control while driving with a Traffic Jam Assist. The traffic jam assist handled lateral and longitudinal control at speeds below 50 km/h on a highway and required drivers to resume control beyond this system boundary. Anticipation was tested by sending a takeover request to the driver at 50 km/h (i.e. [anticipated] system boundary) or at 30 km/h (i.e. [unanticipated] system failure) and by traffic density preceding the takeover request, depending on the experimental condition. The results showed that the anticipatory information from the automated system influenced the monitoring behavior of the drivers preceding the transition of control, but not their performance during the takeover of control from the vehicle. Furthermore, despite relatively short reaction time to take over control of the vehicle, drivers needed a prolonged period to gain vehicle lateral control, regardless of the presence of anticipatory information or of a non-driving-related task. Performing a non-driving-related task resulted in a longer reaction time. Nevertheless, non-driving-related task involvement did not have an effect on the vehicle lateral control or monitoring of the traffic environment. The results of this study highlight the importance of a transition period rather than pure reaction time during a takeover process. We discuss the theoretical and practical implications of these findings.

1. Introduction

Technological developments in sensors and wireless communication facilitate the development of sophisticated advanced driving assistance systems (ADAS), which increase the level of automation of our vehicles. While the expected

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safety and efficiency benefits of an automated vehicle render it attractive, especially in monotonous driving conditions, such as a traffic jam or a long highway-drive, a growing amount of human factors research indicates that vehicle automation needs to be approached cautiously (e.g. De Winter, Happee, Martens, & Stanton, 2014; Gold, Damböck, Lorenz, & Bengler, 2013; Merat, Jamson, Lai, Daly, & Carsten, 2014). This is mainly due to changes in the nature of the driver's task, as well as sharing the subtasks of driving with an automated function at increasing levels of automation. Several taxonomies of levels of automation have been proposed for driving (e.g. German Federal Highway Research Institute, BASt, 2012, cited from Gasser & Westhoff, 2012; National Highway Traffic Safety Administration, NHTSA, 2013; Society of Automotive Engineers, SAE, 2016). The interest of the current study corresponds to Level 2 automation in NHTSA taxonomy, namely, combined function automation.

Level 2 automation indicates that at least two of the primary control functions are automated (e.g. acceleration and braking for longitudinal control, and steering for lateral control). The driver's task consists in monitoring the road, supervising the vehicle, and taking over control immediately when required by the vehicle (NHTSA, 2013). Under current legislation, drivers should not be fully removed from vehicle control (SMART, 2010). Thus, they will have a supervisory role. The central question in the current study is whether drivers can monitor the driving environment and anticipate a possible takeover situation to ensure a safe and successful transition of control. Could the driver's situation awareness improve with the provision of information from both the automated system and the driving environment, thus helping the driver to anticipate a takeover request in a partially automated vehicle?

Situation awareness is defined as "the perception of the elements in the environment within a volume of time and space, and comprehension of their meaning and the projection of their status in the near future" (Endsley, 1995, p. 36). Automation is likely to reduce the operator's situation awareness as it changes the nature of the task from active manual control to passive supervisory control, for which human operators seem to be ill suited (Bainbridge, 1983). Automation also changes the form and the quality of the feedback (Kaber & Endsley, 2004). This shift in operator's task and role is referred to as "out-of-the-loop performance" (Endsley & Kiris, 1995; Kaber & Endsley, 2004). One of the consequences of such change is a reduced amount of monitoring of the automated system, its interface, and the task environment. Parasuraman and Menzey (2010) suggest that the operators' tendency to reduce their level of monitoring and to direct their attention to the manual tasks, rather than monitoring the automated tasks, in highly-reliable automated systems is an attention allocation strategy. For instance, in a study among pilots, researchers observed that the pilots performing a flight simulation task focused their attention to the manual fuel management task rather than the monitoring of the automated temperature and pressure management task (Parasuraman, Molloy, & Singh, 1993, cf. Parasuraman & Menzey, 2010). Moray (2003) proposes that the monitoring of automated systems should be proportional to their reliability, to assure that mental effort is not wasted on redundant monitoring instants. Thus, given that automation failures are rare events, reduced attention allocation to the automated system may seem reasonable (Moray, 2003). However, once there is a takeover request due to imminent system boundaries (that can be anticipated based on the specific use recommendations) or a system failure (that cannot be anticipated), the consequences may be severe for safety.

Safe driving depends largely on anticipation, allowing for timely, self-regulatory reactions in drivers. Hierarchical driving models indeed put an emphasis on anticipation for carrying out tactical maneuvers beyond that of basic vehicle control (e.g., Michon, 1985). Anticipation also helps drivers to decide whether to engage in a secondary task depending on the road conditions (Schömig, Metz, & Krüger, 2011). Although anticipation has been widely investigated in manual driving conditions, our understanding of its role in automated driving conditions is limited. In their review about the distribution of cognitive functions in an automated system, Banks, Stanton, and Harvey (2014) add an anticipatory phase to the traditional taxonomies of levels of automation based on information processing (Endsley & Kaber, 1999; Parasuraman, Sheridan, & Wickens, 2000). In this taxonomy the anticipatory phase is proposed as a feed-forward mechanism. The information acquired while monitoring the driving environment thus reinforces the anticipation of potential hazards and interactions in the driving environment.

In a partially or highly automated vehicle, drivers' monitoring of the driving environment and visual attention seem to be reduced (Barnard & Lai, 2010; Carsten, Lai, Barnard, Jamson, & Merat, 2012; Llaneras, Salinger, & Green, 2013; Zeeb, Buschner, & Schrauf, 2015). In a study investigating the driver behavior in a highly automated vehicle in varying traffic conditions, Jamson, Merat, Carsten, and Lai (2013) observed a substantial decrease in attention in the automated driving condition compared to the manual driving condition. Interestingly, during automated driving in a high traffic density, drivers paid slightly more attention to the road than in low traffic density. Hence, drivers may still be attentive to some information in the driving environment, which may prompt self-regulatory behavior and enable them to anticipate potential hazards, despite a lowered level of overall attention during automated driving.

However, some recent studies on automated functions indicate that anticipation may have different impacts on certain cognitive and behavioral aspects. For instance, Ruscio, Ciceri, and Biassoni (2015) divided the brake reaction into different steps corresponding to perception, decision making, and behavior execution. They observed that the anticipatory information enhanced the very early perception and decision making steps, but not the behavior execution. In a similar vein, Zeeb et al. (2015) observed that drivers' visual attention was related to readiness to take over control from the vehicle, but not to readiness to execute a motor behavior. Thus, the behavior execution after automated driving may not be sensitive to anticipation.

It is important to make a distinction between reactions to an instantaneous critical situation and the quality of the driving performance after takeover of control. There is growing evidence indicating that the mere takeover of control from the