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The role of system description for conditionally automated vehicles

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Objective: We studied how system descriptions of conditionally driving vehicles (SAE International, 2014) influenced drivers' knowledge/mental model, trust, and acceptance.
Background: The increasing proliferation of assisted and conditionally automated vehicles urge a proper understanding of knowledge about, acceptance, and trust in the system. Up to now there is a lack of studies for automated systems and system knowledge which will be served in this study.
Methods: We provided $N = 120$ participants with correct, incomplete, and incorrect descriptions about the conditionally automated vehicle. Thereafter, they watched five video clips with different situations where the driver has to resume control of the driving task or do nothing. Immediately before such a situation, the videos were frozen and knowledge questions were asked according to the SAGAT method (Endsley, 1995). Further, trust and acceptance before and after watching videos were measured.
Results: The knowledge questions differed in groups for level 2 (comprehension) and level 3 (projection) of situation awareness (SA). The difference is significant for the groups in level 2 situation awareness (comprehension) with correct vs. incorrect and incomplete vs. incorrect descriptions. The overall trust in their answer behavior was the highest for the group with the correct description followed by the group with the incomplete description. Furthermore, trust and acceptance did not differ between groups and even not between measurement time (before vs. after watching videos).
Conclusion: An incorrect preliminary system description leads to an incorrect mental model which in turn leads to incorrect comprehension and projection of traffic situations. This effect can be minimized over time, but is relevant to the safety of the driver.
Application: Accurate system descriptions might reduce the number and the gravity of most accidents with conditionally automated systems in driving. Moreover, repeated exposure will reduce the possibility of accidents.

1. Introduction

Automated vehicles are becoming more and more important in modern life. As the range of functions and, therefore, the complexity of these systems increases, intensive reading of the instruction manuals is considered to be mandatory to build up an adequate mental model representing the functioning of the automated vehicles. One frequently described automation

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for vehicles is adaptive cruise control (ACC). Recent research has demonstrated that drivers' mental models adapt quite quickly to the actual functioning of the ACC of the vehicle. Here, we conceptually replicate a study by Beggiato and Krems (2013) in which participants were provided with incorrect, incomplete, or correct information about the ACC, thus manipulating the drivers' mental models. In contrast to Beggiato and Krems (2013), who tested participants' knowledge with questionnaires after simulated driving experiences, we assessed drivers' mental models more directly using Endsley's situation awareness approach with the help of the SAGAT method (Endsley, 1988).

1.1. Situation awareness and mental models

Knowledge about system limits has to be learned (see Rajaonah, Anceaux, & Vienne, 2006; Seppelt & Lee, 2007). The most frequent method to build up knowledge about the limitations of a system with longitudinal control (e.g., ACC) is reading the instruction manual (e.g., Jenness, Lerner, Mazor, Osberg, & Tefft, 2008; Mehlenbacher, Wogalter, & Laughery, 2002). Therefore, studies were conducted to identify the importance of descriptions for drivers to adopt knowledge on system functionality and its limits. Beggiato and Krems (2013) reported that the knowledge about system functionality (including its limits) can be manipulated by instructions. The authors provided participants with correct, incomplete, or incorrect information about the functioning of the ACC. Importantly, they could show that the knowledge differences between the three experimental groups leveled out over the course of confronting the drivers with four base situations (cut-in situation, construction zone, queuing, missing leading car). Thus, the drivers' mental models (representing the core functions of the ACC) adapted to the actual functioning of the ACC. Yet, because Beggiato and Krems (2013) measured participants' mental models based on their knowledge after a simulated driving experience, it is an open question which perceptual and cognitive processes are involved in this mental model building process.

In this context, the concept of situation awareness (SA) offers a way to describe how instructions might influence mental model construction and driving behavior of conditionally automated driving vehicles (SAE International, 2014). According to Endsley, SA "depicts the current state of the system model" (Endsley, 1995, p. 43) and is based on "complex schemata that are used to model the behavior of systems" (Endsley, 1995, p. 43). Endsley further specified SA using the three levels "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." Thus, whereas "perception" (level 1) includes the elements in the environment within a volume of time and space, "comprehension" (level 2) focuses on their meaning, and, finally, "projection" (level 3) targets their status in the near future. To overcome the bottlenecks of attention (e.g. Broadbent, 1958; Treisman, 1964; Wickens, 2008) and working memory (Fracker, 1988) and to benefit from the long-term memory structures, mental models should adequately represent the elements of the environment.

However, the process of building-up and adapting a mental model can be problematic. Fracker (1988) warns of significant problems while biasing the selection and interpretation of information that may create errors in SA. Central is the confirmation error, which is defined as "the tendency to attend only to those sources of information that confirm our previous beliefs" (Fracker, 1988). The mental model guides the driver's attention to cues already included in the present mental model. In case this mental model does not represent the situation in an accurate way, a cascade of errors might follow, e.g. believing the system might brake due to stationary vehicles, whereas it wouldn't do.

In this context, it is important that Jones and Endsley (1996) reported that approximately 7% of SA errors could be traced back to an incomplete mental model (e.g., an altitude overshoot while flying occurred because a new pilot did not know that in the manual position the autopilot would not hold altitude during a turn).

SA is measured with the SAGAT (Situation Awareness Global Assessment Technique) method (Endsley, 1988; Endsley & Kaber, 1999). Participants experience a simulation of a certain mission scenario. At a – for the participant unpredictable – point in time, the simulation is stopped and a white screen masks the simulation. Then, the participant is required to answer a series of questions concerning the specific situation. These questions target the specific SA levels, thus corresponding to the participant's SA requirements (Endsley, 1995). For example, Endsley and Kaber (1999) asked for color and size of a target object for level 1 of SA–perception questions. Questions about distance, speed and penalty concerned level 2 of SA-comprehension. Level 3 of SA-projection was assessed by questioning what will happened if a target would reach a certain point. Taken together, SA is a promising concept to study the evolvement of mental models during driving as it allows the involved perceptual and cognitive processes to be specified.

1.2. Trust and acceptance

Trust in the system and acceptance of the system are central concepts when it come to the actual usage of ACC. The probability of using a system increases with increasing trust and acceptance scores. Lee and See (2004, p. 51) defined trust as "[...] the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability". Studies within other domains (e.g., aviation) illustrate that trust does not only depend on the technical optimization of systems, but also on the quality of human machine interaction. Hence, both technical and human errors that will not be discovered by the driver himself will lead to a decrease in trust (Madhavan & Wiegmann, 2007; Moray, Inagaki, & Itoh, 2000). Nevertheless, it is not the extent of error determining trust, it is predictability of errors (Hergeth, Lorenz, Vilimek, & Krems, 2016; Lee & See, 2004). Thus, if expectations and the real system behavior differ, trust will decrease even if the system performs well (Lee & See, 2004).