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Why is steering not the same as braking? The impact of non-driving related tasks on lateral and longitudinal driver interventions during conditionally automated driving

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ABSTRACT

With the ongoing trend towards conditional automation in the automotive industry, it is vital to ensure that drivers are able to resume vehicle control within the given time budget – even when engaging in non-driving related tasks. A driving simulator study was conducted to examine the impact of non-driving related tasks on drivers' ability to take over vehicle control. The task consisted of reading or proofreading a text (low vs. high visual-cognitive task load) on a tablet which was either handheld or mounted in the vehicle (low vs. high manual task load). Data from 95 participants (mean age 38 years, 47 females) were used to examine reaction times and take-over quality in time-critical steering and braking maneuvers.

Manual task load was found to prolong reaction times and to deteriorate take-over quality. Surprisingly, drivers needed even longer for the first gaze at the roadway when holding the tablet in their hands. As expected, these effects were stronger in the steering compared to the braking maneuver. Effects of cognitive task load were found to be dependent on the type of driver intervention. While reaction times and take-over quality deteriorated with increasing cognitive load in the steering maneuver, hardly any effects were found in the braking maneuver. A possible explanation for this surprising finding could be that especially drivers who are intensively engaging in non-driving related tasks spontaneously react with braking to defuse the situation and gain more time.

It is thus argued that cognitively demanding non-driving related tasks during automated driving do not necessarily lead to deteriorated take-over performance. Depending on situational characteristics like the required reaction or the perceptual complexity of the situation, these might have different effects on the drivers' ability to take over.

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1. Introduction

In recent years automated driving has received a great amount of attention. Currently available driver assistance systems include, for example, Adaptive Cruise Control (ACC) and Lane Keeping Assist, which control either longitudinal or lateral guidance. The next generation of automated systems will fundamentally change the requirements of the driver and the driving task (Flemisch et al., 2012). So-called conditionally automated driving systems provide both longitudinal and lateral vehicle control (SAE International, 2016). While the system is activated, the driver does not have to monitor the system permanently and can be engaged in non-driving related tasks. The willingness to conduct non-driving related tasks was found to increase with higher levels of automation (Carsten, Lai, Barnard, Merat, & Jamson, 2012; De Winter, Happee, Martens, & Stanton, 2014; Llaneras, Salinger, & Green, 2013). In case a system limit is reached, the driver nevertheless serves as a fallback level. A take-over request is issued and the system provides a sufficient (to be defined) time budget within which the driver has to be able to resume control of the vehicle. In order to ensure a safe transition from conditionally automated to manual driving, it is thus vital to examine the impact of non-driving related tasks on driver take-over.

1.1. From concurrent to sequential multitasking

Research has demonstrated the huge impact of driver distraction on road safety during manual driving (e.g., Dingus et al., 2006; Engström, Johansson, & Östlund, 2005; Greenberg et al., 2003; Horrey & Wickens, 2007). It can be assumed that simultaneously executing both the primary driving task and the secondary task can lead to the driver's limited cognitive capacities being exceeded (Wickens, 1984). If this is the case, the interferences between the driving and the secondary task can result in performance decrements in both tasks. In contrast to manual driving, conditional automation relieves the driver entirely of the driving task while the system is activated. The critical aspect is thus no longer the simultaneous execution of multiple tasks, but rather the transition between tasks (see also Lorenz, Kerschbaum, Hergeth, Gold, & Radlmayr, 2015). This change from a dual to a sequential task paradigm will be elaborated further in the following.

In concurrent multitasking, switches between tasks typically occur every few seconds or even more frequently, whereas minutes to hours can lie between a task switch during sequential multitasking (Salvucci, Taatgen, & Borst, 2009). Switching tasks is associated with a so-called switch cost; reactions are often more error-prone and extended after a task switch (Monsell, 2003). This resumption lag (Trafton, Altmann, Brock, & Mintz, 2003) is assumed to be caused by the reconfiguration of cognitive processing modules in order to resume the other task. This may include shifting attention, retrieving task-specific goals and rules, or inhibiting and clearing out a prior task set (Monsell, 2003; Salvucci et al., 2009). Many studies on multitasking use rather simple tasks (e.g., classifying a digit as odd/even, high/low, or a letter as a consonant/vowel; Monsell, Sumner, & Waters, 2003; Rogers & Monsell, 1995). Resuming control from an automated system is of course a far more complex process, as will be described in the subsequent section.

1.2. Driver take-over

Switching from a non-driving related task to the driving task during automated driving takes varying amounts of time depending on the physical and cognitive processes involved (e.g., perception and mental processing of the situation, action selection, preparation and execution of the motor processes; see Zeeb, Buchner, & Schrauf, 2015 for a more detailed description). While the latencies due to the cognitive processes are difficult to measure, the time to eyes on road and time to hands on steering wheel after a take-over request was triggered can be assessed quite readily. Reaction times of about 0.7–1 s for the first road fixation, and of about 1.2–1.8 s for the first manual contact with the steering wheel have been reported (Gold, Damböck, Lorenz, & Bengler, 2013; Zeeb, Buchner, & Schrauf, 2016; Zeeb et al., 2015). Previous research has also highlighted the importance to consider take-over quality when examining driver take-over, as reaction times alone do not provide a comprehensive view (Gold & Bengler, 2014; Zeeb et al., 2016).

Take-over performance was found to be influenced by several factors, such as the given time budget (Gold et al., 2013; Zeeb et al., 2016), the modality of the take-over request (Naujoks, Mai, & Neukum, 2014), the complexity of the driving situation (Radlmayr, Gold, Lorenz, Farid, & Bengler, 2014), the drivers' strategy of monitoring the roadway (Zeeb et al., 2015), or whether a take-over request is expected (Merat, Jamson, Lai, Daly, & Carsten, 2014). One of the most important factors when switching from a non-driving related task to the driving task is presumably the non-driving related task itself. There are, however, mixed findings on the effects of non-driving related tasks on drivers' ability to regain vehicle control.

1.3. Previous research on non-driving related tasks during automated driving

Some authors found deteriorated take-over performance, especially take-over quality, due to the engagement in non-driving related tasks. Merat, Jamson, Lai, and Carsten (2012) reported that drivers engaging in a quiz game adapted their speed in a critical incident less effectively than drivers without a non-driving related task, even though no differences in response time could be found. Similarly, Zeeb et al. (2016) found deteriorated take-over quality but little impact on reaction times due to the engagement in visual-cognitive non-driving related tasks. Other studies, however, report positive effects of non-driving related tasks. Neubauer, Matthews, and Saxby (2012) found shorter braking reaction times after automated