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Transitioning to manual driving requires additional time after automation deactivation

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ABSTRACT

Previous research has shown that drivers are generally able to deactivate the automation in an automated vehicle after a Take-Over Request (TOR) in a relatively short time frame of approximately 3–5 s on average (e.g. Gold, Körber, Hohenberger, Lechner, & Bengler, 2015; Melcher, Rauh, Diederichs, Widlroither, & Bauer, 2015). However, it is yet unclear if drivers are able to adequately react to unexpected traffic events shortly after the transition of control and some studies have shown that stabilizing the vehicle after this transition may take longer than deactivating the automation (e.g. Merat, Jamson, Lai, Daly, & Carsten, 2014). This study addresses this issue by examining the drivers' reactions following a TOR during an automated drive with highly distracting Non-Driving Related Tasks (NDRTs). We investigated the reactions of $N = 60$ participants to five complex take-over scenarios with unexpected events after the TOR in a driving simulator study. Participants were assigned to two distracted conditions with automation (playing a game on a tablet pc, reading on a tablet pc), a no task condition and a manual driving condition.

90% of the participants in the distracted conditions deactivated the automation after 7–8 s. Brake reaction times to the unexpected event were comparable between automation and manual driving conditions. However, compared to manual drivers, distracted drivers with automation showed a delay of up to 5 s regarding the time to the first gaze to the side mirror and the first gaze to the speedometer after the TOR.

Distracted drivers are relatively fast at taking back control over the vehicle after an automated drive and are generally able to react to the onset of sudden events. However, they may require additional time and assistance to fully perceive and understand complex traffic situations and to reach a level of situation awareness comparable to manual drivers. Future research should therefore aim to support the driver during the transition to manual driving, in order to avoid critical situations and to systematically build up situation awareness.

1. Introduction

Future automated driving systems will no longer require active driver supervision in certain driving environments. However, if system boundaries are reached, the driver has to retake manual control and effectively remains a fallback level

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for the automation. Therefore, one focus for the development of automated driving functions should be on the transition of authority from the car to the driver (Saffarian, De Winter, & Happee, 2012). In conditional automation (cf. SAE, 2014), the system needs to provide a sufficient period of time in which the driver can safely and comfortably regain control over the vehicle. However, during the time periods when driving is automated, drivers are taken out of the control-loop (Endsley & Kiris, 1995) and need time to switch back to the driving task. Additionally, drivers of automated vehicles with conditional automation may be distracted by Non-Driving Related Tasks (NDRTs), which will become more frequent with higher levels of automation (Carsten, Lai, Barnard, Jamson, & Merat, 2012; Jamson, Merat, Carsten, & Lai, 2013).

If an insufficient period of time for the transition of control is provided by the system, drivers cannot build up awareness of the driving situation in which the Take-Over Request (TOR) is triggered. This can lead to behavior different from continuous manual driving, such as increased reaction times (Merat & Jamson, 2009), risky driving behavior (Brandenburg & Skottke, 2014; Varotto, Hoogendoorn, Van Arem, & Hoogendoorn, 2015), or even crashes (Stanton & Young, 1998). With insufficient time for the transition to manual control drivers can react slowly, or not at all, when faced with take-over situations (De Waard, van der Hulst, Hoedemaeker, & Brookhuis, 1999; Stanton & Young, 1998). Vollrath, Schleicher, and Gelau (2011) argue that such effects may result from the additional cognitive demands of mentally processing the traffic situation and preparing the motoric sequence required to react to the situation.

1.1. Current propositions for take-over times

A number of take-over times (defined as the time taken by a driver to disengage the automation after a TOR) have been proposed as safe for the transition to manual driving. In a study by Petermann-Stock, Hackenberg, Muhr, and Mergl (2013) a distraction through cognitive-visual-motoric tasks caused the longest take-over time of $M = 3.4$ ($SD = 1.6$) seconds. This is loosely comparable to take-over times in other studies where a high visual, cognitive and motoric demand was placed on the participants through a NDRT. For these types of tasks, take-over times vary from $M = 2.3$ ($SD = 0.7$) seconds in Zeeb, Buchner, and Schrauf (2015), through $M = 3.0$ ($SD = 0.9$) seconds in Lorenz, Kerschbaum, and Schumann (2014), $M = 3.5$ ($SD = 1.2$) seconds in Gold et al. (2015) and $M = 3.5$ ($SD = 1.2$) seconds in Melcher et al. (2015) to $M = 4.4$ ($SD = 0.7$) seconds in Gold, Damböck, Lorenz, and Bengler (2013a).

1.2. Influencing factors on take-over times

Additional factors seem to influence the time to transition back to manual driving. Three factors have emerged in several studies as likely causes for delayed reactions in a take-over situation: The quality of automation monitoring through the driver, the characteristics of the NDRT and the complexity of the situation to which the driver has to react.

1.2.1. Monitoring behavior and monitoring quality during automated driving

The degree to which automation is monitored can affect the transition from automated to manual driving. According to the definition by Gasser et al. (2012) and SAE (2014), in conditional automation (i.e. 'highly automated driving' according to the German BASt) the driver is not required to continuously monitor the automation. Some studies therefore instructed participants not to monitor the automation and focus on the NDRT instead (Damböck, Farid, Tönert, & Bengler, 2012: ~6–8 s; Gold et al., 2013a: ~4–5 s; Petermann-Stock, Hackenberg, Muhr, Josten, & Eckstein, 2015: ~2–3 s). Other studies issued no instructions regarding the monitoring of the automation or told participants to supervise the automation (Helldin, Falkman, Riveiro, & Davidsson, 2013: ~2–3 s; Strand, Nilsson, Karlsson, & Nilsson, 2014: ~2–3 s; Zeeb et al., 2015: ~2–3 s). The resulting reaction times from different studies seem to point to a faster take-over time when automation is monitored, in comparison to automated drives where participants were not instructed to monitor the automation (Gold et al., 2013a; Radlmayr, Gold, Lorenz, Farid, & Bengler, 2014; Shen & Neyens, 2014). Accordingly, Zeeb et al. (2015) found road monitoring behavior during NDRTs in automated driving to be predictive of some aspects of take-over performance, including speed and appropriateness of the reaction to the situational demands. While visual monitoring may lead to faster reaction times to a TOR after automated driving, mental and verbal distraction during visual monitoring of automated drives may still increase reaction times when compared to the same distraction during manual driving as shown by Radlmayr et al. (2014).

1.2.2. Distraction through non-driving related tasks (NDRTs) during automated driving

Characteristics of the tasks performed during automated driving can influence the ability to take back manual control and the speed of the transition to manual driving. On the level of motor reactions, tasks performed on handheld devices as compared to devices fixed to the cars dashboard can prolong reactions by adding the time needed to store away the device, in contrast to tasks on integrated screens (as discussed for example in Zeeb et al., 2015). On a level of perception, the sensory modalities employed for the non-driving task (auditory, visual, haptic, motor) also seem to influence the reaction time after a TOR, inducing the slowest reaction times if multiple modalities are combined (Petermann-Stock et al., 2013).

Petermann-Stock et al. (2013) identified naturalistic NDRTs which provide an intrinsic motivation (e.g. performing office tasks, gaming). Intrinsically motivating tasks such as gaming can also have an *immersive quality* (e.g. Jennett et al., 2008) or *flow* (e.g. Nakamura & Csikszentmihalyi, 2014), which has the potential to hinder the switch from the immersive task back to an unwelcome driving task. To our best knowledge this intrinsic motivational component has not yet been systematically