Effects of secondary Tasks and Display Position on Glance Behavior during partially automated Driving.

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ABSTRACT

The driving task is becoming increasingly automated, thus changing the driver's role. Moreover, in-vehicle information systems using different display positions and information processing channels might encourage secondary task engagement. During manual driving scenarios, varying secondary tasks and display positions could influence driver's glance behavior. However, their impact on the driver's capability to monitor the partially automated driving systems has not yet been determined. The current study assessed both the effects of different secondary tasks (Surrogate Reference Task (SuRT) vs. text reading) and display positions (head-up display (HUD) vs. center console) on driver's glance behavior during partially automated driving. Participants engaged in several secondary tasks that were presented on different display positions while monitoring the partially automated system during a simulated car following task. Different automation system failures regarding the lateral and longitudinal control occurred while driving. A head-mounted eye-tracker recorded the participants' glance behavior. Repeated measures ANOVAs revealed that the HUD yielded considerably longer eyes-on display time (total and mean glance durations) than the center console. Moreover, the text reading task resulted in longer total and mean glance durations than the SuRT. Similar to manual driving scenarios, the results showed a consistent effect of display position and secondary task on the driver's glance behavior. Despite the longer eyes-on display time for the HUD, its proximity to the driving environment might enable a faster identification of and reaction to critical situations (e.g., due to system failures).

Keywords: partially automated driving, secondary task, eye tracking, head-up display, head-down display.

1 THEORETICAL BACKGROUND

In recent years, the driving task has become increasingly assisted (Flemisch, Kelsch, Löper, Schieben, & Schindler, 2008; Papadimitratos, de la Fortelle, Evenssen, Brignolo, & Cosenza, 2009), which has resulted in different levels of vehicle automation. Based on the Society of Automotive Engineers' (SAE) taxonomy (SAE International, 2014), partial automation (i.e., Level 2 automation) takes over both the lateral and longitudinal control (e.g., by combining adaptive cruise control and automated steering). With this level of automation, the driver's role changes from an active operator performing all aspects of the dynamic driving task to more of a passive system monitor (Merat, Jamson, Lai, & Carsten, 2012). Allocating some driving tasks to the vehicle's automation (e.g., lateral and longitudinal control) has been hypothesized (Wierwille, 1993) and shown to reduce the driver's workload (Ma & Kaber, 2005; Stanton, Young, & McCaulder, 1997; Young & Stanton, 2007). However, the extra cognitive resources now available to the driver due to partial automation use (Ma & Kaber, 2005), combined with a greater number of in-vehicle information systems (IVIS; Papadimitratos et al., 2009), might encourage the driver to engage in secondary tasks (Rudin-Brown, Parker, & Malisia, 2003). During fully manual driving, secondary task engagement has been shown to influence the driver's glance behavior (NHTSA, 2012). For example, glance durations away from the road due to secondary task engagement increased with secondary task complexity (Victor, Harbluk, & Engström, 2005). Furthermore, IVIS are typically displayed in different positions (Knoll, 2015). During fully manual driving, different display positions have been found to influence the driver's glance behavior (Hada, 1994). Previous research has noted significantly longer total and mean glance durations to a head-up display (HUD) than for different head-down displays (e.g., the center console; Ecker 2013). However, the proximity between the driving environment and the HUD display position could reduce the effort required to shift attention between different areas of interest (AOI). Consequently, information access might be enhanced (Wickens, Goh, Helleberg, Horrey, & Talleur, 2003) despite the longer glance durations towards the HUD (Ecker, 2013). Thus, driving safety could be improved as the number of missed critical events decreases (Wierwille & Tijerina, 1996). Therefore, both the glance duration to a specific AOI and the AOI's location in relation to the driving environment seem relevant to driving safety. Thus, automation requires even more attention regarding the human machine interface design (Lee, 2008). Nevertheless, prior research has not yet determined the impact different secondary tasks and display positions have on the driver's capability to monitor the partially automated driving systems.

2 OBJECTIVES

The objectives of the current study were to assess the effects of different secondary tasks and various display positions on the driver's glance behavior (i.e., eyes-on display time) during partially automated driving in a simulated environment. A methodological approach based on a previous study (Rauh et al., submitted for publication) was used to examine the effects of secondary task engagement (Surrogate Reference Task (SuRT; Mattes, & Hallén, 2009) vs. text reading) and display position (HUD vs. center console).

3 METHOD

2.1 Participants

A total of N = 58 participants were included in the study. Due to either system errors or simulator sickness, the data for only N = 50 participants (23 females, M_{age} = 37.90) could be analyzed. Participants were recruited via an announcement on the webpage of Chemnitz University of Technology. After completing an initial screening questionnaire, participants were selected based on their gender and age group. All participants received payment for their participation.

2.2 Material and procedure

Data was collected in a fixed-based driving simulator. A head-mounted Tobii Pro Glasses eye-tracker (Tobii AB, 2016) recorded participants' glance behavior and the Tobii Pro Lab (Tobii AB, 2016) software was used to analyze the data. The simulated driving scenario was based on one used in a previous study (Rauh et al., submitted for publication). An 11 km long car following task on a highway was simulated while participants drove in a partially automated mode (i.e., the ego car took over the lateral and longitudinal control). The ego car's velocity (80 km/h) and following distance to the car ahead (of 70 m) was held constant (provided no automation failure occurred). No other vehicle traffic was included. Two types of system failures regarding either the a) lateral or b) longitudinal control occurred four times per drive (Figure 1; see also Lorenz & Hergeth, 2015). The types of system failure as well as the time onset of the failures were randomized. Only the first and third system failure occurrence (always including both lateral and longitudinal system failure) were analyzed to ensure that the occurring failure was not predictable by the participants. Participants were instructed to detect and respond to the system failures as quickly as possible (e.g., manually breaking when the ego car fails to react to the lead vehicle slowing down). After the failure occurred, the driver had to manually reactivate the system by pushing a button on the steering wheel.

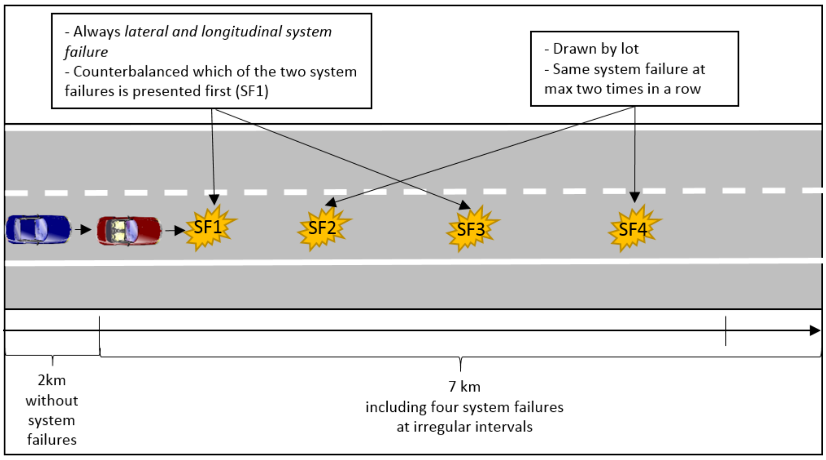

Figure 1 – Types and order of system failures during each test drive. SF = system failures (adapted from Rauh et al., submitted for publication).

Additionally, participants performed several secondary tasks (i.e., SuRT, text reading, video task, manual radio-tuning task) on various display positions (i.e., HUD, center console, display behind the steering wheel, smartphone, separate display below the center one for the manual radio-tuning task). Only the results regarding two secondary tasks (SuRT and text reading) as well as two display positions (HUD and center console) will be reported in this paper (complete results will be presented elsewhere). The SuRT and text reading secondary tasks were chosen due to their opposite ecological validities (i.e., SuRT considered more artificial than the common task of text reading). During the SuRT, participants had to identify a target stimulus among several distractors (Petzoldt, Brüggemann, & Krems, 2014). The text reading task required participants to scroll down continuously to read the entire text. A control question followed each text to ensure that participants read the full text (no rewards were given for correctly answering questions). Participants practiced each secondary task twice prior to the respective test drive. The secondary tasks were conducted on two randomly assigned display positions, including a) the HUD and b) the center console, which differed by their distance to the road environment. Participants were previously instructed to prioritize the system monitoring task, which included scanning the surrounding driving environment. The glance behavior began being recorded (i.e., total and mean glance durations of eyes-on display time) one kilometer prior to the system failure, which served as an indicator of participants' monitoring behavior.

4 RESULTS

Data were analyzed using repeated measures ANOVAs with type of secondary task and display position as independent variables, as well as total and mean glance duration on the respective display position as dependent variables. Effect sizes were interpreted based on Cohen's recommendations (Cohen, 1988). A large effect ($F(1,37) = 14.87$, $p < .05$, $\eta_p^2 = .29$) revealed longer eyes-on display time in terms of total glance duration for the text reading task ($M_{total} = 36.80s$, $SD_{total} = 4.77s$) than the SuRT ($M_{total} = 33.87s$, $SD_{total} = 6.77s$). Additionally, a medium effect ($F(1,36) = 2.31$, $p = .14$, $\eta_p^2 = .06$) showed the mean glance duration was also longer for the text reading task ($M_{mean} = 7.24s$, $SD_{mean} = 9.69s$) compared to the SuRT ($M_{mean} = 4.76s$, $SD_{mean} = 5.42s$). Regarding display position, a large effect ($F(1,37) = 30.75$, $p < .05$, $\eta_p^2 = .45$) indicated a considerably longer eyes-on display time in terms of total glance durations for the HUD ($M_{total} = 39.23s$, $SD_{total} = 4.25s$) in relation to the center console ($M_{total} = 32.18s$, $SD_{total} = 3.68s$). Further, a large effect ($F(1,36) = 20.80$, $p < .05$, $\eta_p^2 = .37$) revealed that the mean glance durations to the HUD were longer ($M_{mean} = 9.42s$, $SD_{mean} = 6.88s$) compared to the center console ($M_{mean} = 2.37s$, $SD_{mean} = 0.73s$).

5 DISCUSSION

The current study investigated the impact of different secondary tasks and display positions on two analyzed glance parameters using a partially automated driving simulator. Text reading resulted in longer eyes-on display time compared to the SuRT. Furthermore, results indicated an effect of display position on driver's glance behavior regarding the eyes-on display time. A large effect showed a difference between the two display positions regarding the eyes-on display time, which was based on the two analyzed glance parameters (i.e., total and mean glance durations). The HUD display position led to consistently longer eyes-on display times than the center console position. These findings corroborate previous studies on manual driving (e.g., Ecker, 2013; Hada, 1994). Furthermore, mean glance durations to the center console remained below three seconds in the current study, which is also consistent to previous findings across manual driving scenarios (Wikman, Nieminen, & Summala., 1998). The results of the current study might indicate participants' awareness of potentially missing critical events (Tijerina, 2000) when glancing away from the road (Vollrath & Krems, 2011) during partially automated driving even when engaged in a secondary task. Moreover, the glance durations towards the HUD are potentially overestimated due to the participants possibly observing the driving environment peripherally or by looking straight through the display. Despite the longer eyes-on display time for the HUD, its closer proximity to the driving environment might enable a faster identification of and reaction to critical situations (e.g., caused by system failures) due to the reduced effort needed to shift attention between the AOIs (Wickens et al., 2003). Further research is needed to examine how longer eyes-on display times influence driver's ability to monitor the system and instantly react to critical situations. Therefore, reaction times to and performance during critical events should be considered in further research.

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