How the Duration of Automated Driving Influences Take-Over Performance and Gaze Behavior

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Abstract. The take-over of the driving task in highly automated vehicles at system limits is subject to latest research in ergonomics and human-machine-interaction. Most studies focus on driving simulator studies, examining the take-over performance mainly after short periods of automated driving, although take-over requests may not occur such frequently in future automated vehicles.
This study tries to close this gap and compares driving performance and reaction times of a take-over after 5 and 20 minutes of automated driving. Further, the gaze behavior in the beginning and end of the 20 minutes period is compared.
While the duration of automated driving did not show to influence the take-over performance, gaze behavior changed within the 20 minutes of automated driving. The SuRT and the 20 minutes automation period induced slower reactions, but no significant changes regarding accelerations and time to collision.

Keywords. Take-Over, Automated Driving, Automation Effects, Gaze Behavior

1. Introduction

In highly automated vehicles (Gasser, 2012) or conditional automation (SAE International, 2014), the driver is not required to monitor the system but be available to take over control at system limits. The performance of the driver in such take-over situations is a crucial aspect when considering controllability of highly automated vehicles. Within the last years, several studies focused on this take-over and the influencing factors on take-over performance, like non-driving related tasks, performed while driving automated (Gold, Berisha, & Bengler, 2015; Radlmayr, Gold, Lorenz, Farid, & Bengler, 2014; Neubauer, Matthews, & Saxby, 2012), drivers' age (Körber, Gold, Lechner, & Bengler, 2015; Petermann-Stock, Hackenberg, Muhr, & Mergl, 2013), or complexity of the situation (Gold, Körber, Lechner, & Bengler, 2016). Next to those factors a long duration of non-interrupted automated driving previous to a take-over seems to influence the take-over performance of drivers (Neubauer et al., 2012). This is the only study known to the authors, where automation effects of longer automated driving periods are considered and deterioration of driver performance, likely caused by monotony or fatigue, became apparent. Drivers engaged in different phone tasks showed quicker brake reactions compared to drivers without non-driving related task in a take-over that occurred after 25 minutes of automated driving. This is likely to be an important finding, as other studies include only short contacts with the automated system and periods of automated driving previous to the take-over request (TOR) of less than 5 minutes or only a few seconds (e.g. Louw, Merat, & Jamson, 2015). These short periods could be an unrealistic scenario, as a system frequently requesting a take-over may lack acceptance and may be rated as unsafe and would not make it to series production or frequent use. Therefore, this study tries to replicate results of the simulator study of Neubauer et al. (2012) and measure take-over performance, based on drivers' input and gaze behavior in take-over situations after different durations of automated driving and under consideration of two different non-driving related task (NDRT) conditions.

2. Method

Driving Simulator. The present study is based on a high fidelity static driving simulator of the Institute of Ergonomics which consists of a full vehicle mockup. Six projectors create a 180 degree field of view and allow the use of the side mirrors as well as the rearview mirror.

Participants. In total 31 participants completed the simulation drive whereas one person had to be excluded due to technical problems. The remaining sample of 30 participants consisted of 14 females (46.67 %) and ranged in age from 21 to 28 years with a mean age of 24.17 years (SD = 2.09). Mean driving experience was 7.2 years (SD = 2.19). 25 participants (83.33 %) have never experienced highly automated driving before.

Experimental Design. During the 45 minutes simulated drive on a three-lane highway the participants experienced in total five take-over situations. The first three take-over situations followed on five minutes of automated driving served as training and are not considered for examining the proposed research question. To investigate the effect of the automation duration on take-over performance and gaze behavior, the participants drove five and 20 minutes before the fourth and fifth take-over situation. The sequence was counterbalanced between participants. Furthermore, it is assumed that a non-driving related task could compensate possible deteriorations due to underload during longer automated drives by maintaining a suitable vigilance level. Therefore, there were two different NDRT conditions during the experiment. In the non-underload condition, half of the participants were engaged in the visually distracting standardized Surrogate Reference Task (SuRT; ISO/TS 14198.) before the take-over occurred. To reduce monotony and avoid underload during the time period of automated driving, the SuRT was repeatedly offered for a short time (between 0.5 and 2.5 minutes). To generate the underload condition the other half of the participants did not have any task to perform during the entire time of automated driving.

Take-Over Situation. The take-over situation was identical for both automation durations (five and 20 minutes). The ego-vehicle was located on the left lane of the three-lane highway while the remaining two lanes were free from additional traffic. The take-over due to a system limit was initiated by a suddenly appearing stationary vehicle on the lane of the ego-vehicle and was requested by an auditory alert. The time budget for taking over the driving task was set to 6 seconds which corresponds to a distance to the collision object of 200 meters at a velocity of 120 km/h. To ensure that each participant had the same time budget for taking over control, the stationary vehicle appeared in front of the ego-vehicle at the same time as the TOR sounded. Especially for the group in the condition without SURT (underload) this is crucial as without visual distraction the participant could monitor the driving and traffic situation the entire time and could therefore discover the obstacle too early.

Dependent Variables. With the present study the effect of different automation durations on the take-over performance and the gaze behavior is investigated. In order to assess the take-over performance, the reaction time (RT), the take-over time (TOT), the maximum longitudinal (Acc_{long}) and lateral acceleration (Acc_{lat}) of the ego-vehicle that occur during the take-over and the time to collision (TTC) are considered as dependent variables. The RT represents the time that the participants need for directing the first gaze away from the SuRT after the TOR. This measure is only applied in the SuRT condition. The TOT is the time that the participants need to start a maneuver as a reaction to the TOR, while a driver input is considered a conscious maneuver as soon as the steering wheel angle exceeds 2 degrees or the braking pedal position exceeds 10 % (Gold, Damböck, Lorenz & Bengler, 2013). The time that theoretically remains until a potential collision with an obstacle assuming constant speed of both, the ego-vehicle and the obstacle, is considered as the minimum occurred TTC within the take-over situation. Together with the longitudinal and lateral acceleration the surrogate safety measure TTC corresponds to the criticality of the take-over. These dependent variables are measured in the two take-over situations with different previous automation durations. The sample size for comparing the RT after 5 and 20 minutes diminishes from 30 to 12 participants as only half of them performed the SuRT during the TOR and three had to be removed from the analysis due to technical reasons. In order to assess changes in the gaze behavior due to automation duration, the participants wore a head mounted eye tracking system (Dikablis) during the experiment. The driving scene which corresponds to the area of the windshield is defined as an area of interest (AOI). Here, the cumulative duration of the gazes, the average duration of one gaze, the maximum duration of one gaze and the number of gazes towards this AOI within 60 seconds are set as dependent variables. They are compared for the 3rd and 18th minute of the 20 minute uninterrupted automated driving. Within these periods, no SuRT was presented.

In order to assess the impact of underload, the dependent variables of the take-over performance (TOT, Acc_{lat}, Acc_{long} and TTC) and of the gaze behavior (the cumulative duration of the gazes, the number of gazes, the average duration of one gaze as well as the maximum duration of one gaze towards the AOI within 60 seconds) are compared the conditions with SuRT to without SuRT.

Statistical Analysis. Statistical analysis was performed using IBM SPSS Statistics 22 software and consisted of two mixed analyses of variance (ANOVA). The first one focused on take-over performance and included task condition (SuRT vs. without SuRT) as between-subjects factor and duration of automated driving prior to take-over (5 vs. 20 minutes) as within-subjects factor. For the comparison of the RT in the SuRT group, a two-sided t-test for paired samples was conducted. Throughout the whole analysis p-values smaller than 0.05 were considered significant.

3. Results

Figure 1 presents the results regarding driver performance following the take-over request. The duration of automated driving prior to the take-over had no significant main effect, whereas the introduction of the SuRT led to an extended take-over time (F (1.28) = 12.19, p = .002, r = .55). Consistently, the group engaged in the SuRT also showed a non-significant tendency towards a smaller minimum time to collision (F (1.28) = 3.62, p = .067, r = .34). No differences were observed concerning lateral and longitudinal acceleration. There were no significant interaction effects.

Regarding the reaction time in the SuRT condition, participants were significantly faster after 5 minutes (M = .55s, SD = .08s) when compared to the take-over after 20 minutes (M = .64s, SD = .09s; df = 11, p = .014, r = 0.46).

In Figure 2 the drivers' gaze behavior in the 3rd and 18th minute of uninterrupted automated driving is compared. Towards the end of the 20 minutes period, the time spent looking at the driving scene decreased (F (1.28) = 5.37, p = .028, r =.40). Gazes towards

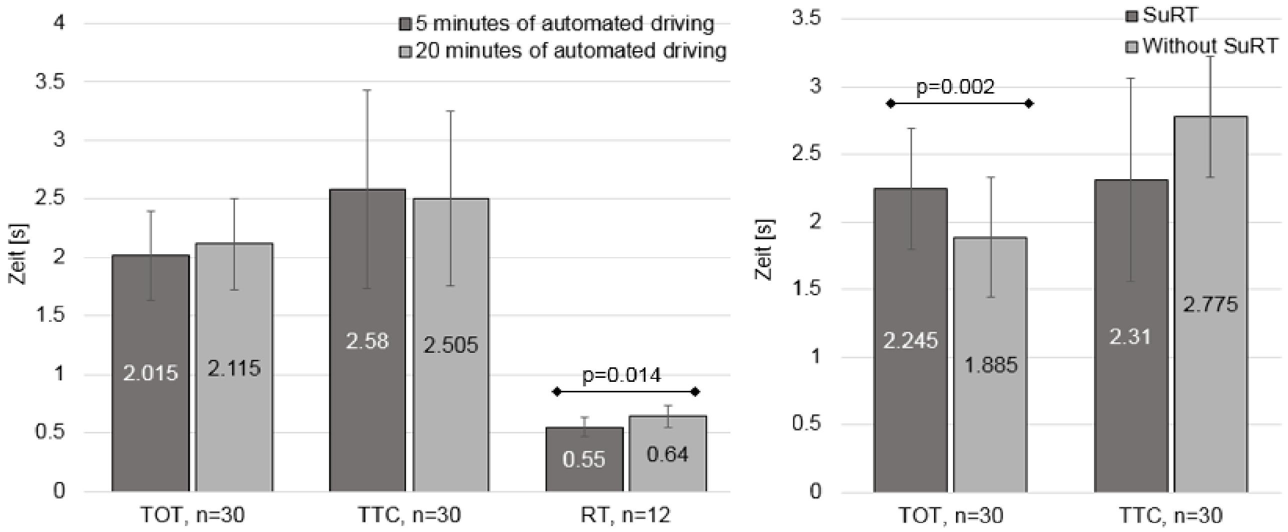

Figure 1. *Left: Take-over time (TOT), minimum time to collision (TTC) and reaction time (RT) compared after 5 and 20 minutes of uninterrupted automated driving. Right: TOT and TTC compared in the two NDRT conditions (SuRT vs. Without SuRT), error bars represents the standard deviation.*

the driving scene tended to be shorter but more frequent, although values for the average duration (F (1.28) = 3.56, p = .070, r = .34) and the number of gazes (F (1.28) = 3.60, p = .068, r =.34) did not reach significance. The maximum duration of single gazes decreased (F (1.28) = 9.70, p = .004, r = .51). The SuRT led to an increase in the number of gazes (F (1.28) = 9.48, p = .005, r = .50) but did not affect any other variable. Again, no significant interaction effects were observed.

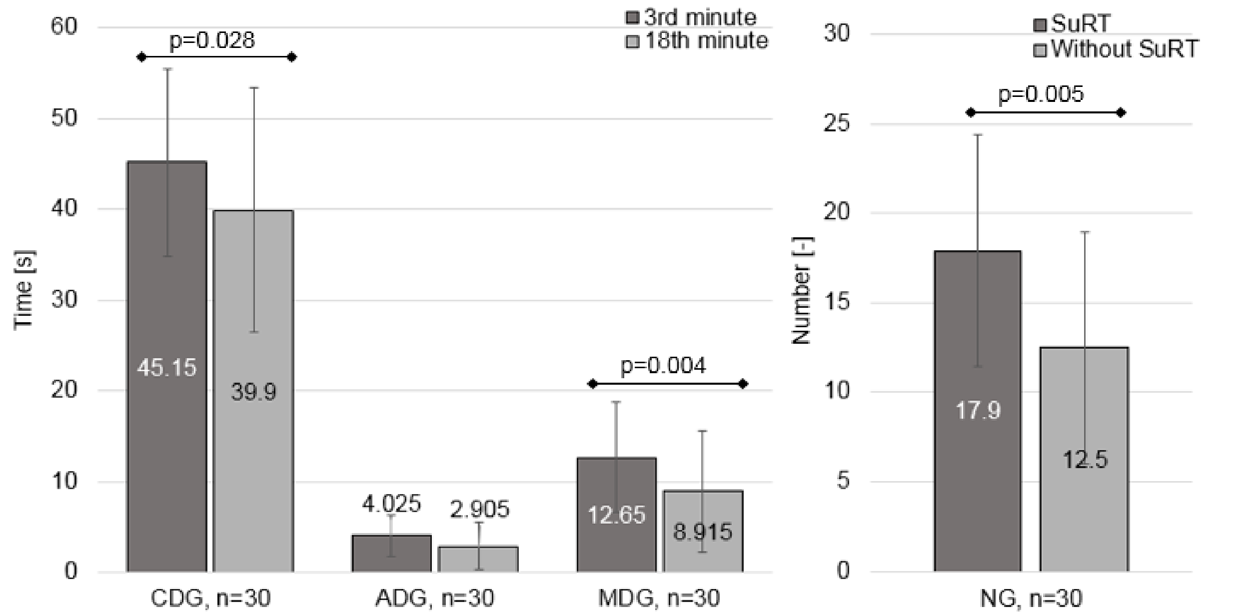

Figure 2. *Left: Cumulative duration of all gazes (CDG), average duration of one gaze (ADG) and maximum duration of one gaze (ADG) towards the driving scene within 60 seconds compared in the 3rd and 18th minute of uninterrupted automated driving. Right: Number of gazes (NG) towards the driving scene within 60 seconds compared in the two NDRT conditions. Error bars represent the standard deviation.*

4. Discussion & Limitations

The time for averting the first gaze from the SuRT towards the driving scene after a TOR significantly increased after 20 minutes of automated driving in the group with SURT. Longer reaction times may indicate a decrease in vigilance level and an increase in fatigue (Graw, Kräuchi, Knoblauch, Wirz-Justice, & Cajochen, 2004). Here, a duration effect seems to occur but it cannot be clarified whether it is due to automation or long term engagement in the SuRT. Concerning the remaining parameters of the take-over performance, no differences were observed comparing the five and the 20 minutes period. This lack of an evident deterioration due to fatigue is consistent with the findings of Neubauer et al. (2012) and Saxby et al. (2013). It is conceivable that due to an insufficient length of the chosen intervals no fatigue-related or hypovigilance-related deteriorations occurred. Additionally, it is also possible that after prior sufficient training, as it was provided in this study, deterioration effects on the take-over performance occurred already after five minutes of automated driving. Thus, no differences between the five and 20 minutes regarding the take-over performance could be found.

Regarding the task condition, results showed a significant increase of the TOT in the SuRT group. It is assumed that the extended TOT is caused by the visually and cognitively distracting SuRT. However, the remaining parameters for take-over performance did not show differences due to the task condition. Thus, it can be supposed that the extended TOT is induced by the time the participants needed to redirect the gaze from the visually distracting SuRT towards the driving scene. Therefore, Neubauer et al.'s (2012) finding that being engaged in a non-driving related task during automated driving enhances subsequent response speed could not be proved.

Comparing the task conditions regarding the gaze behavior, only the number of gazes towards the driving scene reached significance. As none of the other gaze parameters showed any effect or tendency, it is assumed that the SuRT group frequently controlled the availability of the task, which was presented on a display in the center console of the vehicle and thereby increased the number of gazes to the driving scene.

Towards the end of the 20 minutes period the percentage of time spent watching the driving scene diminished. This might be caused by more frequent or prolonged blinking, which is an indicator for fatigue (Schleicher, Galley, Briest, & Galley, 2008; Schmidt et al., 2009). However, there are more suitable metrics, like PERCLOS (Knipling & Wierwille, 1994), for assessing fatigue by eye-tracking data. A different approach to explain the diminished gaze duration towards the end of the 20 minutes period is that the participants did not spend the same attention to the driving scene. An increase in glance durations and glance numbers away from the AOI may be indicators for visual distraction (ISO 15007-1:2014). This may indicate that the participants showed more self-initiated distraction after longer duration of automated driving by averting the eyes from the driving scene and letting the gaze wander due to monotony and boredom. However, the number of gazes increased with longer automation duration. The assumption is that despite more visual distraction the participants still controlled the traffic and the driving scene by regular but short glances. As the glances towards the driving scene became shorter the participants tried to compensate the thereby reduced absorption of visual information by more frequent short glances (Damböck, 2013, p. 60). The more frequent control glances may also indicate that the participants did not trust the system enough to reduce checking the driving scene (Moray, 2000) with being simultaneously visually distracted by letting the gaze wander. This is feasible as due to the experimental design the participants have previously experienced at least 3 take-over requests and therefore probably expected another take-over situation.

5. Summary

In this study an effect of the duration of automated driving on the reaction time was found, while the remaining parameters for take-over performance did not show any differences. The gaze behavior was also affected by the duration of the automation. It is assumed that the drivers let wander the gazes and therefore showed self-initiated visual distraction due to monotony after 20 minutes of automated driving. In this experiment the non-driving related task, which was the visually distracting SuRT, did not show an effect on the take-over performance except for the take-over time. The longer times are presumably caused by the additional time the participants needed for redirecting the gaze from the SuRT to the driving scene after the take-over request.

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