HOW TRAFFIC SITUATIONS AND NON-DRIVING RELATED TASKS AFFECT THE TAKE-OVER QUALITY IN HIGHLY AUTOMATED DRIVING

Jonas Radlmayr[1], Christian Gold[1], Lutz Lorenz[2], Mehdi Farid[2], Klaus Bengler[1]
[1]Technische Universität München – Institute of Ergonomics
[2]BMW Group Research and Technology

Highly automated driving constitutes a temporary transfer of the primary driving task from the driver to the automated vehicle. In case of system limits, drivers take back control of the vehicle. This study investigates the effect of varying traffic situations and non-driving related tasks on the take-over process and quality. The experiment is conducted in a high-fidelity driving simulator. The standardized visual Surrogate Reference Task (SuRT) and the cognitive n-back Task are used to simulate the non-driving related tasks. Participants experience four different traffic situations. Results of this experiment show a strong influence of the traffic situations on the take-over quality in a highway setting, if the traffic density is high. The non-driving related tasks SuRT and the n-back Task show similar effects on the take-over process with a higher total number of collisions by the SuRT in the high density traffic situation.

INTRODUCTION

The number of assistance systems that automotive companies are offering in cars has seen a steep incline over the past years. These systems assist the driver in the longitudinal and lateral control of the vehicle by taking over parts of the driving task. For example, Adaptive Cruise Control (ACC) allows the driver to transfer the longitudinal control of the vehicle to the system, while Lane Centering Assistants take over lateral control of the driving task. Traffic Jam Assistants incorporate complete control of the driving task for low vehicle velocities. Following the definition of the *Bundesanstalt für Straßenwesen* (Gasser, et al., 2012), highly automated driving constitutes a system taking over the complete driving task for a specific period of time. The driver does not need to monitor the system but is required to take-over control of the driving task if requested by the system. This marks an intermediate step between systems assisting the driver and autonomous vehicles that do not require a driver at all. Consequently, system boundaries that require a take-over must be detected with sufficient time for the driver to react safely and comfortably. This defines the conflict of goals, also mentioned in Herrtwich, (2013): when the system is activated, a complete transfer of the driving task to the system enhances the comfort for the driver, while a safe behavior during the take-over process is essential as well. The take-over process is influenced by the time available for the driver to regain complete control of the driving task, and a safely executed response to the situation at hand. The work of Damböck, Farid, Tönert & Bengler, (2012), and Gold, Damböck, Lorenz & Bengler, (2013) look at different time budgets and their effects on quality and safety of the take-over process.
In this paper, the take-over time is kept constant during the experiment while focus is put on different traffic situations and non-driving related tasks prior to the take-over. In order to predict potential driver behavior during a take-over, the valid model of situation awareness after Endsley, (1988) can be used: “Situation awareness can be conceived of as the […] internal model of the world around […] at any point in time.”
In combination with Wicken’s, (1984) multiple resource theory, that incorporates limited cognitive resources for the different steps and modes of information processing, the following assumptions can be drawn. During highly automated driving, drivers do not need to monitor the system and the traffic situation and are potentially free in occupying themselves with non-driving related tasks. This out-of-the-loop-behavior can lead to a contingently serious deterioration of situation awareness caused by a shift in driver attention to the non-driving task without paying attention to the surrounding traffic situation and the vehicle status. If the system requires a take-over, lost situation awareness has to be regained in order to perform safely and comfortably. This paper compares a cognitive with a mainly visual non-driving related task prior to the take-over process. While a visually demanding task clearly affects the driver’s situation awareness by leading to an eyes-off-road occupation, the cognitive task simulates a mind-off-road engagement. The question arises whether both tasks have similar or different effects on the take-over process.
Furthermore, the regaining of lost situation awareness during the take-over depends on the current traffic situation. Also, individual differences in cognitive resources and their distribution to the different steps (Wickens, 1984) during the take-over have to be taken into account. Depending on the necessary driver reaction during a take-over, the varying complexity and criticality of these situations affects the take-over quality.
The design of the experiment incorporates well-known negative effects of increasing automation (Bainbridge, 1983) in general, existing research on loss of situation awareness, non-driving related tasks, driver performance in the context of highly automated driving (Merat & Jamson, 2009; Merat, Jamson, Lai & Carsten, 2012) and the results from similar experiments (Gold, et al., 2013; Gold, Lorenz & Bengler, 2014).

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METHOD

The experiment is conducted in a high-fidelity driving simulator of the BMW Group Research and Technology. The simulator consists of a full BMW 5 series mockup which is centered in the projection dome. A more than 200 degree field of view is realized by several projectors and screens incorporating rearview and side mirror projections as well. The dome rests on a hexapod allowing for a realistic simulation of the vehicle motions. Various vehicle and situational parameters, e.g. velocity, longitudinal and lateral acceleration, hands-on detection, brake and steering wheel parameters are recorded along with video and audio information of the vehicle, the driver and the traffic situation. Additionally, the eye tracking system *Dikablis* is used to analyze gaze behavior.

A total of 48 participants take part in the experiment. All of them are employees of the BMW Group and consist of 38 men and ten women with a total mean age of 33.5 years (SD=9.0). The participants are divided into three groups of 16 leading to a between-subjects design for the parameter non-driving related task modality (visual versus cognitive). Group 1 (Baseline-Group) was defined as a reference group without the highly automated driving system. Consequently, drivers in the Baseline-Group experience the identical track but have to drive manually all the time. This baseline is used to range the results in comparison with existing driver behavior during manual driving. Drivers in group 2 and 3 use the highly automated driving system and have to take over control of the vehicle from the system during the experiment. In group 2 (n-back-Group), the cognitive n-back Task (e.g. Reimer, Mehler, Wang & Coughlin, 2010) in the form of a two-back Task is used as the non-driving related task prior to the take-over process. In group 3 (SuRT-Group), the visual Surrogate Reference Task (SuRT, ISO14198, 2012) is used. Drivers in the Baseline-Group, who drove manually during the experiment also had to perform a two-back task. The cognitive demand of all drivers is also recorded and analyzed using the Detection Response Task (e.g Bengler, Kohlmann & Lange, 2012; Conti, Dlugosch, Vilimek, Keinath & Bengler, 2012). The tactile detection response task (DRT) used in this experiment, measures the reaction time between a tactile signal presented on the participant's neck via a vibrating node and the affirmation of noticing the signal by pushing a button. Reaction time correlates with the cognitive demand of parallel tasks.

In order to analyze the effect of the traffic situation on the take-over quality, a within-subjects design is chosen. Throughout the three groups, the track and situations are kept the same. Drivers have to experience four take-over situations during the experiment. In the manually driven Baseline-Group, the same situations were presented. A comparison with take-over behavior allows a classification of potentially dangerous maneuvers: driver reactions during a take-over process have to compete with the performance of manual drivers coping with the identical situation regarding safety and comfort issues.

Experimental setup and realization

After completing a demographic questionnaire, participants are briefed on the experiment, the vehicle, the highly automated driving system and the non-driving tasks. During a short test drive, participants are able to familiarize themselves with the driving experience in a high-fidelity driving simulator and the highly automated driving system is presented. The system performs longitudinal and lateral control of the driving task with a maximum velocity of 120 km/h, representing the maximum speed on highways in most countries. The system conducts lane changes, controls the velocity of the vehicle depending on preceding vehicles and drivers are told to fully retreat from the driving task. To ensure high confidence in the automation, participants are promised a flawlessly functioning system without the need for monitoring the vehicle or system state. Participants also experience a take-over process during the test drive. In case the system reaches a system boundary, a take-over request (TOR) is issued with a high-pitched tone in combination with an icon change in the instrument panelling. Participants are told that they need to take-over the driving task as soon as they notice the TOR. This can be done by relocating hands and feet to the steering wheel and brake pedal to cope with the traffic situation. The non-driving related tasks are presented to the participants roughly every three minutes with a duration of 45 seconds to one minute. Prior to a take-over request, drivers always attend to the DRT in combination with either the SuRT or the two-back Task. Consequently, the highly automated driving system is not explained during the test drive in the Baseline-Group. However, the identical high-pitched tone from a TOR as additional warning of a potentially dangerous situation ahead is presented to drivers in the Baseline-Group.

During the experiment, drivers experience a take-over in four different traffic situations. These situations share the following aspects.

- Drivers are always driving on a three lane highway with regular traffic conditions while the highly automated driving system is in control of the vehicle in the n-back and the SuRT-Group.
- The four situations in which a take-over request occurs, consist of a sudden end of lane due to an obstacle. A car crash with two stationary cars that both have flashing warning lights, represents the system boundary.
- The obstacle appears suddenly to guarantee a seven seconds (= 233 meters at 120km/h) take-over time budget for the drivers.
- Lane changes prior to the TOR assure that the vehicle is on the same lane than the upcoming obstacle. Manual drivers in the Baseline-Group are instructed via the control center to change into the appropriate lane.
- SuRT/n-back Task and the DRT are deactivated with the TOR. Additionally, participants are told that the driving task always has a higher priority than the non-driving related tasks.

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- After the TOR, drivers are expected to relocate their hands and feet to the steering wheel and the brake pedal to take over the driving task.

The lane in which the obstacle appears, changes between the situations in order to alternate options for the drivers. In situation No. 1, the obstacle appears in the middle lane, while the right and left lane are blocked by vehicles at the time of the TOR. In situation No. 2, the obstacle appears on the right lane while no other vehicles are present during the situation. In situation No. 3, the obstacle appears on the left lane. Situation No. 4 closely resembles situation No. 1: the obstacle also appears on the middle lane but in this case, no other vehicles are present during the take-over process in situation No. 4.

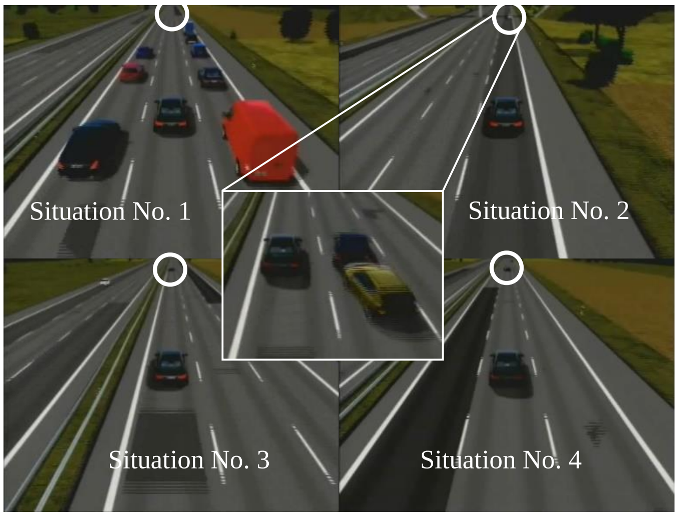

Figure 1: Situations No. 1 – 4 at the TOR. The obstacles are magnified in the white-rimmed middle figure.

Figure 1 shows situations No. 1 – 4 from a third-person perspective. The blocked lanes in Situation No. 1 at the TOR can be seen. Situations No. 2 – 4 also display the situations at the moment of the TOR. The white-rimmed subfigure in the middle shows the obstacle in form of the two conjoined crash vehicles, with the ego-vehicle passing the obstacle on the left lane. Figure 1 illustrates the need for drivers to either perform a lane change or braking maneuver in order to safely cope with the situation after the TOR.

Hypothesis and parameters

The independent variable for the between-subjects design is the group and thus the non-driving related task. The question needs to be answered whether a mind-off-road task (two-back Task) has a different effect on the take-over process than an eyes-off-road task (SuRT). The independent variable for the within-subjects design is defined as the different situations. Effects of a high or low number of options during the take-over process for drivers to react are evaluated.

The dependent variables are take-over time, defined as the time passing from the TOR until drivers actively engage in a lane change or braking maneuver (take-over time). An active engagement is defined by surpassing at least 2° steering wheel angle or 10% brake pedal application. Furthermore, longitudinal acceleration, time to collision (TTC), the total number of collisions during take-over, DRT results and the subjective rating of the participants are used for analysis of the take-over process. The TTC can be understood as a measure of criticality of driver behavior. A low TTC can be deducted as a late beginning of the lane change or braking maneuver thus a more critical maneuver. The dependent variables are analyzed using an analysis of variance (ANOVA).

RESULTS

In the SuRT-Group, two drivers are discarded from the analysis since they were looking up from the SuRT at the TOR. In the Baseline-Group, a simulation error caused the appearance of a rogue vehicle, rendering the results of one participant invalid.

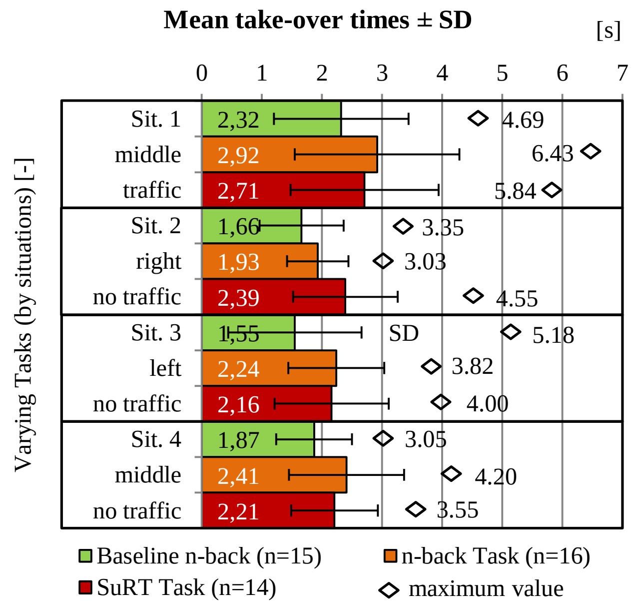

Figure 2: Mean and standard deviation of take-over times for the different groups and situations.

Figure 2 shows the mean take-over times for the four situations and three groups. The ANOVA shows a significant effect of both the experimental factor group, $F(2, 42) = 4.53$, $p = .02$ and the factor situation, $F(3, 126) = 5.46$, $p = .001$. Pairwise comparisons with Bonferroni corrected adjustments reveal a significantly lower take-over time in the Baseline-Group. While the term take-over time might be misleading considering the Baseline-Group, manual drivers have to cope with the situation and the results show the potential effect of low situation awareness throughout the groups. Pairwise comparisons (Bonferroni) reveal a significant difference between situation No. 1 and No. 2, with No. 1 featuring a higher mean take-over time.

In addition, the time to collision (TTC) is analyzed. It is important to notice in Figure 3, that the number of drivers taken into account is different from the analysis of the take-over time. Values of zero for the TTC are disregarded since they represent a collision. The ANOVA shows a highly significant result for the situations, $F(3, 84) = 16.87$, $p < .001$. Pairwise comparisons (Bonferroni) show situation No. 1

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having significantly lower values of the TTC in comparison with the other situations.

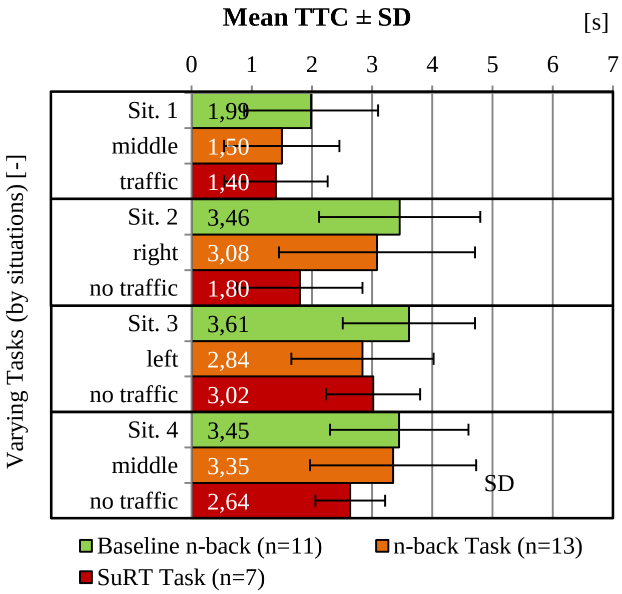

Figure 3: Time to collision. Values of zero are neglected for the ANOVA since they represent a collision.

Furthermore, the longitudinal acceleration of the drivers is analyzed in Figure 4.

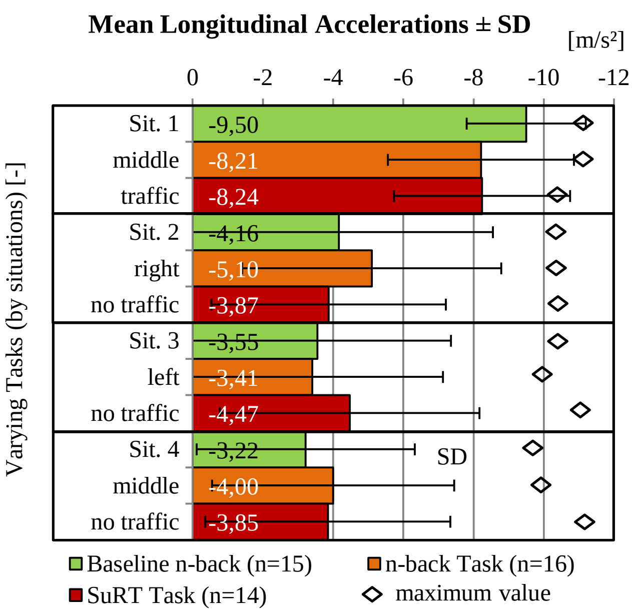

Figure 4: Longitudinal Accelerations. The maximum values represent the physical maximum of the braking procedure.

The ANOVA yields a highly significant result for the situations, $F(3, 126) = 39.93$, $p < .001$ with situation No. 1 showing significantly higher (Pairwise comparisons (Bonferroni), $p < .001$) negative longitudinal accelerations. The maximum values of the braking maneuvers center around 11m/s², since a typical car can only enable higher braking accelerations with special tires (adhesion) or additional down force due to spoilers. In addition to the results of the TTC analysis, the longitudinal acceleration intensifies a possible identification of situation No. 1 as being highly critical. Figure 5 shows the total number of collisions. These can either be a collision with the obstacle or a collision with the vehicles on the right and left lane in situation No. 1. While situation No. 1 features the most collisions, analysis shows a significant difference between the SuRT-Group (Exact Test after Fisher, $p = .04$) and the other groups.

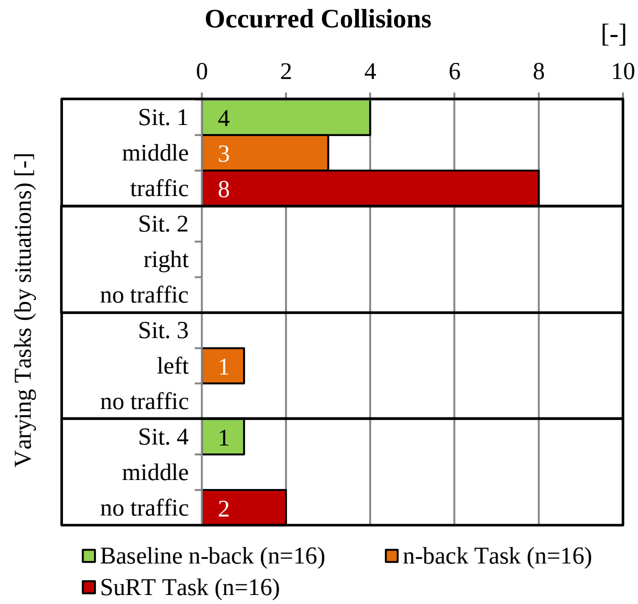

Figure 5: Occurred Collisions in total numbers. All participants are regarded.

Subjective and DRT results

The questions asked after every take-over in combination with the final questionnaire support the results from the ANOVA. Drivers identified situation No. 1 to be the most critical (Sit. No. 1: ~2.1 in comparison with Sit. No. 2-4: ~0.35 on a scale from -3 to 3) and complex (Sit. No. 1: ~1.6 in comparison with Sit. No. 2-4: ~-0.1 on a scale from -3 to 3). The results from the DRT show a significant difference in DRT reaction times between the n-back-Group and the SuRT-Group, $p = .007$, supporting the use of a DRT in order to determine the cognitive workload of participants.

DISCUSSION

Results show situation No. 1 (obstacle in middle lane, right and left lane blocked) to induce highly critical behavior during the take-over processes in the n-back and the SuRT-Group, with similar behavior from the manual drivers in the Baseline-Group, which do not experience a take-over but cope with the situation manually. While drivers initially have only the option of braking in situation No. 1 due to dense traffic, more options in the other situations do not seem to cause more critical maneuvers. On the other hand, it can be speculated that the presence of the vehicles blocking the right and left lane is the reason for the critical maneuvers. Prior to the take-over, drivers are occupied with the non-driving related task. In order to perform safely and comfortably drivers must replenish

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potentially low situation awareness. The perception and integration of the vehicles present in situation No. 1 and choosing an appropriate reaction can be identified as main reasons for the longer process of regaining situation awareness, and thus more critical reactions. This is supported by the analysis of the take-over time in Figure 2. Both group and situation show significant effects. Manual drivers that are permanently part of the driver-vehicle control loop show significantly lower take-over times. This can be explained by manual drivers starting to cope earlier with the situations by executing a lane change or braking maneuver. Analysis of TTC, longitudinal acceleration and occurred collisions clearly supports the identification of situation No. 1 to be highly critical.

Apart from a significantly higher collision rate in the SuRT-Group, the other parameters show no significant differences between the n-back-Group and the SuRT-Group. This means that cognitive non-driving tasks can lead to a similar distraction and thus low situation awareness compared with mainly visual tasks. Drivers transferring the driving task to the system and occupying themselves with only cognitive tasks do not show better take-over behavior due to the possibility of observing the surrounding traffic situation. This is especially important considering the development of highly automated driving systems that incorporate analysis of the driver state using gaze behavior. Eyes-on-road do not guarantee higher situation awareness compared to visual distraction in the case of highly automated driving. Nevertheless, Figure 5 suggests a visual distraction simulated by the SuRT to be significantly worse than the cognitive distraction by the n-back Task.

In the context of this experiment the time budget of seven seconds appears to be reasonable in the situations No. 2 – 4. A comparable criticality throughout the groups, including manual drivers, suggests this deduction for situation No. 1 as well. However, limitations of this experiment have to be considered. The highly automated driving system used in this experiment does not feature a safe minimum fallback level in case drivers do not react in time. The implementation of a fallback level guaranteeing a full brake application is necessary for systems to not only increase safety, but also allow for a high acceptance of highly automated driving. Additionally, no information regarding vehicle status and/or the traffic situation is presented prior or during the take-over. Rauch, Kassner, Krüger, Boverie & Flemisch (2009) identify this to positively affect safety and comfort for the drivers during the take-over.

In general, this experiment is limited due to its conduction in a driving simulator and a sample of only BMW employees. Accelerations are represented in scaled form and visibility of traffic situations might be better in real-life scenarios.

SUMMARY

This study shows the influence of different traffic situations and non-driving tasks on the take-over process during highly automated driving. Results indicate a strong influence of the traffic situation on take-over time and quality. A higher criticality of driver behavior can clearly be observed in situation No. 1 which features a high traffic density. On the other hand, take-over quality does not seem to significantly depend on varying the chosen non-driving related tasks prior to the take-over. The SuRT simulating a mainly visual distraction and the n-back Task simulating the cognitive distraction show similar effects on driver behavior during the take-over.

Further investigation is needed to determine the effect of different traffic situations more specifically. The various parameters of traffic situations and their influence on the process of regaining lost situation awareness need to be determined more closely. In combination with the potential need of having to predict situations in which the highly automated driving system reaches a system boarder and requests a take-over, extensive understanding of the traffic situations' influence on driver behavior could be crucial for developing highly automated driving systems regarding safety.

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