Should I stop or should I go? Evaluating Human Capabilities of Cooperative Manoeuvre Strategies on Automated Driving

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Abstract

The cooperative driving framework in combination with adaptive automation provides a suitable solution for overcoming legal and system limitations by sharing responsibilities and tasks between driver and automation. The evaluation of human capabilities of partial take-overs in traffic is required as foundation for this approach. A basic cooperative manoeuvre strategy was tested in a driving simulator using a traffic light scenario. Participants drove on a rural road either with assisted or partial automation while occasionally approaching red or green traffic lights. For half of the trials they received a cue, indicating an upcoming traffic light. Drivers (N=24) had to decide for the appropriate oncoming behaviour of the automation while not or only partly taking operational control of the automated car. Results of behavioural and gaze data showed that attentive drivers were capable to perform cooperative manoeuvres. Due to transparent and distinct system behaviour, drivers were successful in acting cooperatively in low levels of automation. Implications for conditional or high automation, more complex driving tasks and distracted driving are discussed.

Introduction

The dissemination of automated driving increases continuously (Lu, Happee, Cabrall, Kyriakidis, & de Winter, 2016) even though different challenges exist (Casner, Hutchins, & Norman, 2016). The current highest level of automation available on the market is partial automation (level 2 by SAE, 2016) as the human driver still has to monitor the driving task. The human driver is responsible for the observation of the surroundings and serves as fall-back solution as the driver has to take-over control as soon as the automation is not able to handle the current situation. This kind of task sharing between driver and partial vehicle automation requires that the driver is able to construct an adequate situation representation including the state of the automation at all times. Research has shown that driving with assistance systems such as adaptive cruise control (ACC) or ACC and lane keeping assist, increased drivers situation awareness and decreased workload compared to manual driving (de Winter, Happee, Martens, & Stanton, 2014). However, in case of take-over situations several studies showed the detrimental

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impact of driving with partial or conditional automation (SAE level 2 and 3) on subsequent manual driving behaviour and situation awareness (e.g. Brandenburg & Skottke, 2014; Merat, Jamson, Lai, Daly, & Carsten, 2014). Consequently, take-over situations are “one of the most crucial aspects of vehicle automation in the future” (Gold, Damböck, Bengler, & Lorenz, 2013).

To avoid such negative effects of automation resulting from the idea to substitute the human driver by automation, an alternative might be to design the automation as an effective team player of the human driver (e.g. Christoffersen & Woods, 2002; Hoc, 2000; Walch et al., 2017). Within this framework human and automation support and complement each other like team players. The dynamic allocation and shift of subtasks of the driving task between the human driver and the automation is necessary. This partial task-sharing process should be based on their current capabilities to guarantee an optimal performance of the driver-automation team.

Hundreds of subtasks are controlled while driving, which requires multitasking skills (Walker, Stanton, & Young, 2001). In general, the manual driving task can be structured by three levels of skills and control (Michon, 1985). Drivers have to keep manual lateral and longitudinal control (control level). They have to execute manoeuvres like overtaking (manoeuvring level), generate and pursue plans like the navigation destination (strategical level, Michon, 1985). Successful implementations of the integration of these tasks with different levels of automations already exist (see overview of Banks, Stanton, & Harvey, 2014). For instance, navigation systems support drivers by generating and selecting the correct way. This leads to reduced workload and increased attention to safety critical behaviour on a strategical level (Srinivasan & Jovanis, 1997).

Endsley and Kaber (1999) propose several possibilities of adapting automation by task-sharing. Based on the ten levels of automation with regard to decision making and action execution ranging from manual control (Level 1) to full automation (Level 10) from Sheridan and Verplank (1978), they developed a hierarchy of levels of automation applicable to dynamic cognitive and psychomotor control task performance.

So far, only some investigations on adaptive automation in highly automated driving exist. Banks, Stanton and Harvey (2014) proposed different propositions of subtask responsibilities for a pedestrian warning and detection system based on the taxonomy of Endsley and Kaber (1999) but missed to evaluate their concept within a user study.

In order to prevent a full take-over, Gold and colleagues (2013) introduced a monitoring request. The automated car was still able to execute the whole driving task but the driver was prompted to attentively monitor this process and intervene if necessary. In general, the monitoring request was rated positively with regard to comfort and usefulness, but monitoring reduced the probability to intervene in case of critical situations. In contrast, interventions in manual driving appeared already before the situation became critical. Consequently, this implementation of partial take-over seemed not successful in high-risk situations (Gold et al., 2013). However, take-overs in critical situations were observed to elicit better performance, if the system offered partial deceleration support compared to a complete system fail (Strand, Nilsson, Karlsson, & Nilsson, 2014).

Due to technical limitations of the automation, the human driver needs to resume responsibility from time to time. In terms of traffic safety, it would be an advantage if lateral and longitudinal control was kept by the automation (Golias, Yannis, & Antoniou, 2002) and decision making was controlled by the human. As this reduces the task complexity for the driver, it should avoid a gaze focus on the road centre as this is associated with higher driver workload (Victor, Harbluk, & Engström, 2005) and lead to a broader scanning of the traffic environment. This fosters enhanced situation comprehension and as a result improved decision performance (Baumann & Krems, 2007, 2009) in an uncritical driving situation.

Therefore, in this experiment we tested a basic task sharing approach where the control of the operative level was still assigned to the automation in a non-safety critical situation. The automation was not able to make decisions on the manoeuvre level but initiated safe mode manoeuvres in case the human did not make a decision. Lateral and longitudinal control were either completely performed by the automation which we named as AUTOpilot (level 2) or only longitudinal control was controlled by the automation representing a traditional adaptive cruise control (ACC, level 1). Prior findings showed that ACC compared to AUTOpilot enabled faster and more appropriate reactions in critical situations with automation failure (Strand et al., 2014). The authors explained the results by reduced situation awareness and the more passive role of the driver. To increase engagement of the driver, an explicit clarification of strength and limitations of system behaviour was shown to improve monitoring performance (Dogan et al., 2017). Furthermore, the ability to regain control was ameliorated if system boundaries or take-over could be anticipated (Dogan et al., 2017; Merat et al., 2014). Providing cues and appropriate knowledge about the automated driving behaviour contributes to an enhanced shared situation representation and mutual predictability as a basis of cooperative driving.

Consequently, we deduced the following hypotheses:

I. Increased situation awareness with *ACC compared to AUTOpilot* is assumed, leading to *faster recognition and activation of an oncoming partial take-over*.
II. Additional *cues* enabling the anticipation of upcoming events result in *faster recognition and activation of an oncoming partial take-over*.

These assumptions were tested in a driving simulation using a traffic light scenario for manoeuvre control. It served as a foundation for investigating human capabilities of handling cooperative situations.

Method

Participants

Twenty-four (33% female) highly-educated drivers (83% got a general qualification for university entrance or even a university degree) participated in the driving simulator study. On average they were 27 years old (*SD* = 6.64) and held a valid driving license for about 9.79 years (*SD* = 7.71). The sample covered a wide range of driving experience including 37,5% daily drivers, 41,6% regular drivers (driving once to four times a week) and 20,9% occasional drivers (driving three days or less per month). 71% of participants reported to have experience with driver assistance systems like (adaptive) cruise control. The participants received course credits or money for their participation.

Apparatus and material

The study was conducted in a fixed-base driving simulator consisting of a cockpit mock-up in front of three large projection walls providing a view of 190° (see Figure 1). The simulation software SILAB (5.1, WIVW GmbH) was used. Gaze data were gathered by three built-in eye-tracking cameras (sampling rate 60Hz, Smart Eye AB). Manual input and feedback was provided by the touch display in the centre console (16 x 21 cm, 1920 × 1080 pixels).

Furthermore, the mental workload was measured after driving with ACC and AUTOpilot respectively using the NASA-Task Load Index (NASA-TLX, Hart & Staveland, 1988). Additionally, two scales of Driving Activity Load Index (DALI) (Pauzie, 2008) which focused on visual and acoustic demand were assessed.

Figure 1. The driving simulation lab with the fixed-base mock-up and 190° view of rural driving environment.

Design and procedure

The effect of *automation level* (ACC and AUTOpilot), *availability of cues* (warning) and *scope of action* (traffic light status) on the human capability of cooperative manoeuvre strategies was evaluated using a within-subjects design to guarantee a high comparability and reduced intra-individual influences. The automation condition was presented as blocked-design and participants were randomly assigned to one of the two conditions. The order of automation conditions was counterbalanced. In each condition participants had to pass a rural, curvy road with a target speed of 80 km/h without oncoming traffic. They encountered four traffic lights in ACC and in AUTOpilot condition. The intervals between traffic lights varied between one and six minutes to reduce predictability. Beforehand, they were informed about the system limitation at traffic lights: due to low sensor reliability in bright lightening conditions and legal regulations, the car would always stop (safe mode) in front of the traffic light independently of the traffic light status. Therefore, participants had to support the automation by deciding on the oncoming action of the car using the green GO or the red STOP button on the touchscreen. To guarantee the observation and understanding of the situation we varied the scope of action by showing either red or green traffic light in an unpredictable sequence in all trials (half of trials had red light).

By passing a right hand bend, the traffic light became visible 200m before reaching it. Half of the traffic lights included a warning cue at that point in time indicating an oncoming traffic light. This was combined with either a red or green traffic light status (see Figure 2). Participants were encouraged to indicate the upcoming action as soon as they observed the traffic light status in order to guarantee a smooth and comfortable ride.

The study lasted about 50 min. Starting with a demographic questionnaire and a manual driving condition in order to get used to the driving simulator, participants experienced a practice trial (3 min) followed by the experimental condition (each 15 min) for ACC and AUTOpilot. Latencies of activation, time to first gaze to traffic light and subjective workload ratings were gathered as dependent variables. Participants were instructed to leave the right hand on the rack in front of the centre console in both automation conditions to enable the comparison of the input latencies.

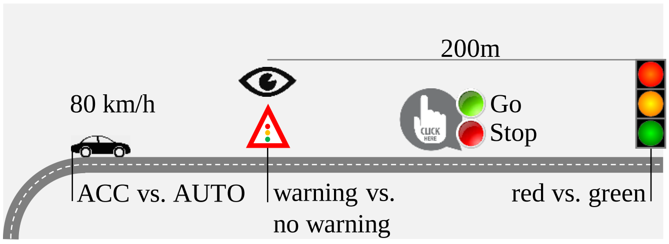

Figure 2. Methodological procedure of the driving simulation.

Results

Cooperative action – activation of partial take-over

First of all, every driver could handle the cooperative partial take-over by executing the correct action in all situations. The latency of activation was determined as the time between visibility of traffic light (equivalent to warning) and activation of STOP or GO, which was considered as cooperative action. Figure 3A shows averaged latencies with regard to automation level, warning availability and traffic light status. A repeated measures ANOVA was calculated for inferential analyses. Participants always reacted faster when they were driven by the AUTOpilot ($M = 4241$ ms) compared to ACC ($M = 5016$ ms), $F(1,23) = 14.25$, $p < .001$. As expected, warning cues reduced the reaction time (reduction of $M = 1147$ ms, $F(1,23) = 46.48$, $p < .001$). Moreover, traffic light status influenced the latencies: Participants were faster when they saw a green ($M = 4308$ ms) compared to a red traffic light ($M = 4989$ ms), $F(1,23) = 18.90$, $p < .001$. No interactions were observed.

Gaze behaviour – recognition of partial take-over

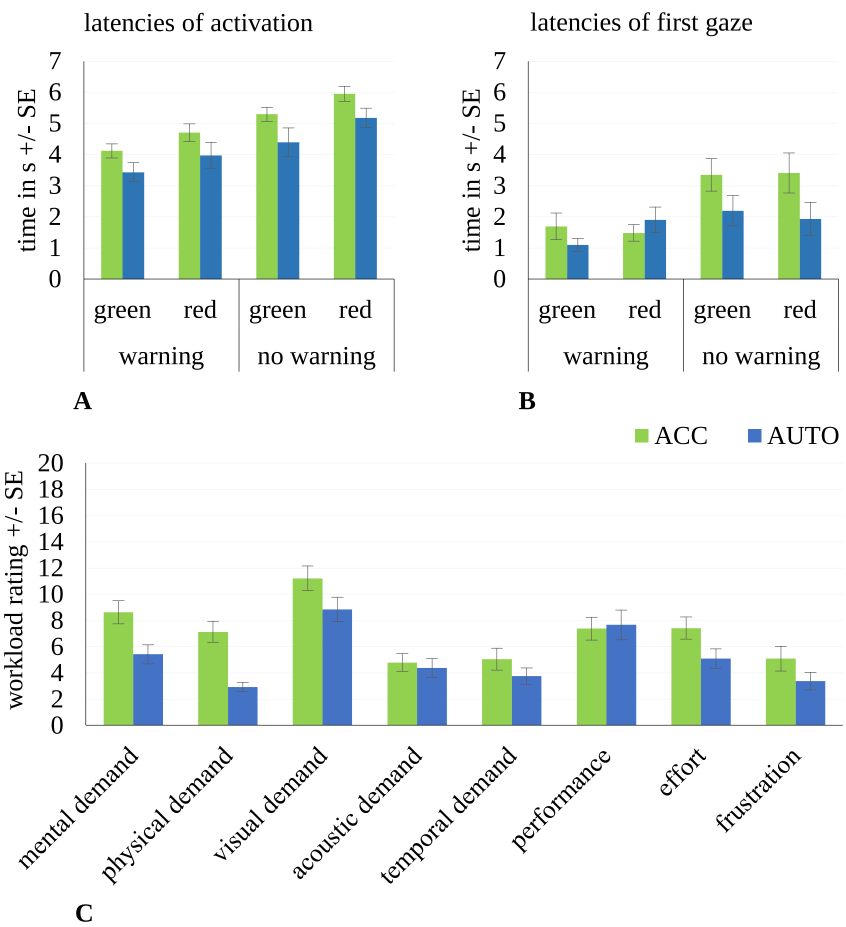

Figure 3. A - averaged latencies with regard to automation level (ACC and AUTOpilot), traffic light status (red or green) and the availability of warning cue. B – averaged latencies of first gaze towards the traffic light with regard to automation level (ACC and AUTOpilot), traffic light status (red and green) and the availability of warning cue. C – effect of automation level (ACC and AUTOpilot) on averaged results of subjective workload scales ranging from 1 – "very low" to 20 – "very high".

Gaze data could only be analysed for twelve participants due to technical inconveniences. Accordingly, non-parametric Wilcoxon signed-rank tests were calculated and Bonferroni corrections were applied. Figure 3B provides an overview of the latencies to first fixation to the traffic light. Warning cues decreased the duration of recognizing the traffic light (reduction overall of $M = 703$ ms), $Z = 2.51$, $p < .05$. This difference was mainly achieved due to the difference of warning in the ACC condition ($Z = 2.75$, $p < .05$) but not in the AUTOpilot condition ($Z = 1.33$, $p > .05$). Furthermore, participants saw the traffic light earlier when there was no warning in the AUTOpilot compared to ACC condition ($Z = 2.51$, $p < .05$). This means that a warning accelerated the recognition of the traffic light only for ACC but not for AUTOpilot. The status of the traffic light had no influence on the time to first fixation.

Subjective workload

The different subscales of NASA TLX and DALI were considered for every automation condition. Overall, increased workload while driving with ACC ($M = 7.08$) compared to AUTOpilot ($M = 5.18$) was observed ($t(23) = 5.12$, $p < .001$). However, the subjective workload was rather small (see Figure 3C.) The largest difference of automation level on workload was observed for physical demand, but also mental, visual demand and effort were larger for ACC compared to AUTOpilot ($p < .001$).

Discussion

The present research investigated the effect of automation level, cues and scope of action on the human capability of partial take-overs in a simple strategic manoeuvre. Individuals were able to manage this cooperative action with driver assistance and partial automation. The task was predominantly visually and mentally demanding, because drivers had to recognize the traffic light and decide for the correct action. Automated system behaviour was activated by pressing the STOP or GO button. Additional cues were observed to increase the recognition and activation of partial take-overs (in line with hypotheses II). Contrary to hypotheses I, results showed longer latencies of activation in the ACC compared to the AUTOpilot condition which can be explained by the additional task of steering and lane keeping while driving with ACC. Gaze data support this assumption: If participants were warned about an oncoming traffic light they were as fast in ACC as in AUTOpilot condition in recognizing the target. But they still showed slower reactions due to manual steering activity. If there were no warning cues drivers kept their attention on the street and recognized the target later in ACC condition.

These results showed that higher level of automation does not necessarily decrease driving performance in case of a partial take-over as it was observed in full take-over situations (e.g. Strand et al., 2014). However, the participants of this study were not confronted with a critical situation and the intervention was not on a control but rather manoeuvring level.

The scope of action was varied by the status of the traffic light to ensure that participants observed the target. Surprisingly, participants reacted faster when the traffic light was green, but there were no differences in gaze behaviour. It allows for drawing the conclusion that participants were aware that the car would always stop at the traffic light. Consequently, there was an increased requirement to react when the light was green in order to prevent braking and ensure smooth continuation. The time and space for reaction was smaller for green compared to red traffic light. Therefore, it is of prime importance to provide the relevant information about the operating principles of the automated car and consequences of the own action to ensure appropriate behaviour within the scope of driver-vehicle interaction.

Overall it can be stated, that people are able to manage partial take-overs or can deal with external triggered adaption of level 1 and 2 automation in a simple scenario on the decision stage. Even with a rather small sample size, the effect of warning cue and scope of action could be observed on a behavioural level. Restrictively it must be considered that the traffic light scenario is a rather simple task with regard to information acquisition and analysis. Complexity by increased traffic density was shown to have a negative effect on driving performance in take-over situations (Gold, Körber, Lechner, & Bengler, 2016). The evaluation of more complex and varying scenarios with increased difficulty is necessary to further evaluate the concept of cooperative partial take-overs.

Furthermore, participants were not distracted while driving. Thus, they observed the automation and the external environment attentively all the time. It can therefore be assumed, that the drivers were in the loop while being temporarily chauffeured, as it is supposed to be. Further research should focus on longer driving durations or interleaved non-target-tasks (i.e. navigation task) to gain insights in partial take-over performance with reduced situational awareness. In relation to that, insights in level 3 of automated driving should be provided when drivers are allowed to turn attention to other tasks. Within that case it is of utmost importance to develop appropriate partial take-over situations in line with the cooperative driving framework. The situation specific dynamic adaptive automation might be the foundation of capable, safe and comfortable handling of future mobility. Further research should in addition focus on acceptance and trust of cooperative adaptive automation, which is pivotal for the dissemination of automated vehicles.

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