Keeping drivers engaged in automated driving through maneuver control - effects on perceived control and responsibility

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Background

Highly automated driving is projected to change the global transportation system in the future, taking the human driver out of the control loop of vehicles [1]. However, systems employed today still require a human to monitor the automation, changing a driver's task from actively controlling the vehicle to a monitoring role [2]. Research shows that drivers frequently engage in secondary tasks and do not fulfil the required monitoring role [3][4]. This distraction from drivers' monitoring task leads to decreased detection of automation failures and a lack of situation awareness in takeover situations [5][6]. Vehicle manufacturers have implemented systems that aim to ensure continuous monitoring, e.g. through requiring the driver to have regular contact with the steering-wheel or through monitoring the driver's attention and turning of the automation if inattention is registered [7][8]. Existing safety systems penalize inattention, but do not increase drivers' engagement in the monitoring task.

A relatively new field of study in the area of automated driving has been the implementation of *shared control* or *maneuver control* [9][10][11]. Under this proposed control scheme, the basic driving task, i.e. control of speed and trajectory of the vehicle, is controlled by the automation. Advanced driving parameters, such as following distances, lane choice, and targeted maximum speed can be controlled by the driver through a human-machine interface (HMI). Shared control allows the driver to influence the driving style of the automation and to initiate driving maneuvers without taking over complete control of the vehicle. In theory, the concept encourages drivers to stay engaged in the driving task, although the vehicle automation is activated. A first implementation of this concept is Tesla's lane change assist, which allows drivers to initiate a lane change maneuver during highly automated driving [12].

In this driving simulator study, we investigated how the ability to adjust driving parameters and initiate driving maneuvers in highly automated driving influences the subjective experience of drivers when compared to driving a completely automated vehicle without maneuver control, and self-driving without any form of automation. We hypothesized that drivers' perceived level of control and perceived responsibility for potential crashes would be significantly increased through the implementation of maneuver control when compared to automated driving without maneuver control. We further hypothesized that drivers would use maneuver control to adjust the vehicle's following distances to a value that correlates with their preferred following distance in self-driving.

Method

A convenience sample of 42 participants (28 female) was recruited from the Leuphana University Lüneburg. Participants were on average M = 22.36 years old (SD = 3.36), had an average driving experience of M = 4.5 years (SD = 2.9) and had driven an average of M = 30,378 kilometers since acquiring their license. The study was conducted in a fixed-base driving simulator with a projected field of view of 110°x30° (3072x768 pixels), running version 1.4 of the SCANeR Studio driving simulator software from Oktal. A joystick with a 3D-printed top was installed in the center console of the simulator as the HMI that allowed participants to initiate maneuvers and adjust driving parameters.

In a within-subject repeated measures design, the level of control that participants had over the vehicle was varied threefold. Participants either had complete control over the vehicle (full control), were driving highly automated but could use the joystick to adjust driving parameters or initiate maneuvers (maneuver control), or had no control over the vehicle as it was driving fully automated (no control). Participants were presented with 18 traffic situations on city-, rural-, and highway-roads. 12 of these situations were designed to allow participants to either conduct a driving maneuver themselves (full control condition), initiate a maneuver through use of the joystick HMI, or monitor a driving maneuver conducted by the automation (no control). Driving maneuvers in these 12 situations consisted of lane changes and take-over maneuvers in different traffic environments. In 6 more situations, participants were following another vehicle and could either adjust their following distance through the use of the brake and gas pedal (full control), through using the joystick HMI (maneuver control), or monitor the following distance without the possibility to adjust it (no control). All 18 traffic situations were presented in one block for each condition (full control vs. maneuver control vs. no control), while the sequence of the blocks was randomized. After each block of 18 traffic situations, participants rated their subjective experience during the block on the disco-scale (Table 1) which measures discomfort in automated driving through 15 items on a 5-point Likert scale [13]. Furthermore, time headway following distances were registered for the full control and maneuver control block of the experiment. Time headway following distances in the no control condition were fixed to 3 seconds for all participants.

Table 1 Disco-scale

Items (Answered on a 5-point Likert scale (“strongly disagree” “strongly agree”))
1. I can move unconcerned using the system.
2. I feel endangered by the system.
3. With more clearance distance my journey would be more comfortable.
4. I felt that I could always intervene in time.
5. Using the system is unpleasant.
6. The system relieves me as a driver.
7. I was always in control of the situation.
8. I felt safe during the drive.
9. I felt the situation was risky.
10. There was enough safety clearance to travel comfortable.
11. I found the driving situation to be uncomfortable.
12. If an accident happens I am responsible.
13. The system is an added burden.
14. In my opinion the system increases safety.
15. I perceive driving myself as less strenuous.

Results

While the disco-scale consists of 15 items, only the results on perceived ability to control the vehicle (item 7), ability to intervene in time (item 4), and potential responsibility in case of a crash (item 12) are presented in this extended abstract. When asked to rate their ability to control the vehicle on a 5-point Likert-scale (1 to 5), the full control condition was rated highest for controllability (M = 3.48, SD = 1.11), followed by the maneuver control condition (M = 2.50, SD = 1.33), and the no control condition (M = 1.52, SD = 0.94). A repeated measures ANOVA was calculated to test the effect of level of the independent variable on the perceived level of control. As Mauchly's Test revealed a violation of the assumption of sphericity for the main effect of control ($\chi^2(2) = 9.51$, $p <$ .01), Greenhouse-Geisser corrected degrees of freedom were used (ε = .83). Control conditions were rated as significantly different on the perceived control item ($F_{(1.65, 67.68)}$= 38.18; $p <$ .01; η_p^2 = .48). Post-hoc tests using Bonferroni correction for multiple comparisons revealed significant differences between all levels of control (all $p <$ .01).

Participants further rated if they thought they could intervene in time during the traffic situation. Perceived ability to intervene was again highest in the full control condition (M = 3.62, SD = 1.17), followed by rating in the maneuver control (M = 2.29, SD = 1.24), and no control condition (M = 1.76, SD = 1.27). A repeated measures ANOVA revealed significant differences between perceived ability to intervene ($F_{(2, 82)}$= 26.24; $p <$ .01; η_p^2 = .39) depending on the level of control. Bonferroni corrected post-hoc tests revealed that there is a significant difference in the level of perceived ability to intervene between the full control and the maneuver control condition ($p <$ .01), as well as the full control and the no control condition ($p <$ .01). There was no difference in perceived ability to intervene between the maneuver control and no control condition (p = .069).

When asked if they would feel responsible for a potential crash with the vehicle, participants felt most responsible in the full control condition (M = 3.45, SD = 1.12), followed by the maneuver control (M = 3.14, SD = 1.10), and no control condition (M = 2.12, SD = 1.31). A repeated measures ANOVA revealed significant differences between conditions $F_{(2, 82)}$= 20.51; $p <$ .01; η_p^2 = .33). Post-hoc test with Bonferroni correction revealed that perceived responsibility in case of a crash differs between the full control and the no control condition, as well as between the maneuver control and the no control condition (both $p <$ .01). There was no significant difference in perceived responsibility between the full control and maneuver control condition.

Time headways from traffic situations in which the following distance to a lead vehicle could be adjusted were found to correlate significantly between the full control and maneuver control conditions (r = .38 to .72, all $p <$ .05).

Conclusion

The ability to adjust driving parameters and initiate maneuvers in highly automated driving has positive effects on the subjective experience of drivers. Participants in this study felt more in control of the vehicle in driving situations with maneuver control when compared to highly automated driving without this ability. Furthermore, maneuver control increased the perceived level of responsibility in case of a crash, to levels that do not significantly differ from self-driving (full control condition). This high level of perceived responsibility could help to keep drivers of highly automated vehicles engaged in the driving task. While our results on drivers' perceived ability to intervene indicate that they do not perceive the joystick HMI as a tool to use in case of safety critical intervention, the

effect of maneuver control on take-over behavior needs to be researched in future studies. The results of a significant correlation between following distances in self-driving (full control) and adjusted following distances in maneuver control conditions indicates that drivers use the ability to adjust driving parameters to individualize the driving style of the automated vehicle to align with their own preference in self-driving.

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