Adjustable Automation and Manoeuvre Control in Automated Driving

Felix Wilhelm Siebert [1*], Fabian Radtke [2], Erin Kiyonaga [3], Rainer Höger [2]

[1] Department of Psychology and Ergonomics, Technische Universität Berlin, Berlin, Germany
[2] Institute of Experimental Industrial Psychology, Leuphana University Lüneburg, Lüneburg, Germany
[3] University of Calgary, Canada
[*] felix.siebert@tu-berlin.de

Abstract: Current implementations of automated driving rely on the driver to monitor the vehicle and be ready to assume control in situations that the automation cannot successfully manage. However, research has shown that drivers are not able to monitor an automated vehicle for longer periods of time, as the monotonous monitoring task leads to attention reallocation or fatigue. Driver involvement in the automated driving task promises to counter this effect. We researched how the implementation of a haptic human-vehicle interface, which allows the driver to adjust driving parameters and initiate manoeuvres, influences the subjective experience of drivers in automated vehicles. In a simulator study, we varied the level of control that drivers have over the vehicle, between manual driving, automated driving without the possibility to adjust the automation, as well as automated driving with the possibility to initiate manoeuvres and adjust driving parameters of the vehicle. Results show that drivers have a higher level of perceived control and perceived level of responsibility when they have the ability to interact with the automated vehicle through the haptic interface. We conclude that the possibility to interact with automated vehicles can be beneficial for driver experience and safety.

1. Introduction

Recent studies on automated vehicles have revealed a crucial barrier to their safe operation - the human drivers that are supposed to monitor them might not be up to the task [1]. Researchers have found that drivers engage in non-driving related secondary tasks, and do not always fulfil their designated monitoring role [2][3]. Researchers have further found that drivers' non-engagement during automated driving can lead to very low arousal states, fatigue, and in extreme cases has led to drivers falling asleep [4][5][6]. Levels of automation that require drivers to monitor the driving task, without having them engage in the control of the vehicle have subsequently been termed the *uncanny/unsafe valley of automation*, as they do not keep the driver in the loop through the necessity of control, while at the same time not allowing the driver to completely disengage from the driving task [7]. While manufacturers promise to bring systems to the market which can operate without human monitoring (so called *level 4 automation)*, today's systems require an always attentive human driver for their safe operation [8]. Manufacturers have attempted to approach the challenge of the *non-attentive human* by implementing systems that continuously monitor the driver's state. Some of these systems require the driver to periodically perform a task, such as touching the steering-wheel, while other systems monitor the drivers physical state, e.g. by tracking their head- and eye-movement [9][10]. Once a driver is found to be non-attentive, the automated vehicle prompts a take-over request, which forces the driver to take back complete control over the vehicle [11]. A drawback of these systems is that they are penalizing in nature, i.e. they do not attempt to keep the driver engaged, but merely punish inattention. They therefore do not address the fundamental challenge of keeping drivers engaged in monitoring the driving task.

A relatively new control scheme which takes a more constructive approach is the implementation of so called *shared control* or *manoeuvre control* [12][13][14]. In *manoeuvre control* systems, the fundamental driving task, i.e. velocity and trajectory control, is controlled by the automated vehicle. However, through the implementation of a human-machine interface (HMI) the driver has the ability to adjust higher level driving parameters, such as target speed, target headway, or preferred lane choice [15][16]. In some implementations, the HMI further allows the driver to initiate more complex driving manoeuvres which incorporate speed adjustments and lane changes, such as taking over another vehicle on a highway [17]. A first implementations of this functionality can be found in Tesla vehicles, which have an *auto lane change* function which can be triggered by the driver through the use of the turn indicator when driving automated [18]. Through these functions, *manoeuvre control* enables high level control of the automated vehicle through the driver. Through retention of the driver's actions, it is further possible to enable an individualized automation, which can converge a driver's driving related preferences with the automation's driving parameters.

To investigate how *manoeuvre control* influences driver experience and driver behaviour, we conducted a simulator study, comparing varying levels of control over the vehicle. Our implementation of *manoeuvre control* allows drivers to adjust the forward distance to lead vehicles (headway), change lanes, and initiate overtaking manoeuvres (passing another vehicle). To allow participants the initiation of all individual manoeuvres with a single interface, they were provided with a multi-directional haptic interface. Comparable interfaces have been proposed and tested in studies that explored concepts similar to manoeuvre control [15][17]. We register drivers subjective experience through three items of the Disco-Scale [19], assessing perceived control, ability to intervene, and perceived responsibility for potential accidents. We further investigate driver behaviour, by comparing headways assumed in *manual driving* to headways assumed under *manoeuvre control* driving conditions, building on research that has identified a high inter-individual variance in time headways [20][21] and a need for adjustable headways in highly automated driving [22]. Parts of this study have been reported in a previous paper [23].

2. Method

2.1. Participants

For this study, 42 participants (14 male, 28 female) were recruited as a convenience sample on the campus of the Leuphana University Lüneburg in Germany. Participants were contacted through a university-wide e-mailing list and a Facebook group for students of the university. The only prerequisite for participation was that all participants were required to have a driver's license. On average, participants were M = 22.36 years old (SD = 3.36), and had an average driving experience of M = 4.5 years (SD = 2.9). Participants had driven an average of M = 30,378 kilometres since they had acquired their driver's license and their average estimated yearly driving was *M* = 4,550 kilometres (*SD* = 8100.9). Only about one third (31%) of participants owned a car at the time of the experiment. For their participation in the experiment, participants were awarded 1.5 *study subject hours*, of which students need to collect 20 during their studies at the Leuphana University Lüneburg.

2.2. Hardware

The study was conducted in the driving simulator of the Institute of Experimental Industrial Psychology at the Leuphana University Lüneburg. The simulator consists of an open cabin with two seats, taken from a Volkswagen Golf 4 vehicle. The fixed-base driving simulator was positioned 2 metres from three projection planes, each measuring 1.4x1.4 metres (Fig. 1).

Fig. 1. *Driving simulator cabin and projection planes.*

The SCANeR Studio simulator software from Oktal was used to project the driving environment onto the three projection planes, resulting in a field of view of approximately 110° horizontally and 30° vertically, with a resolution of 3072x768 pixels. Between the two seats in the centre console, the haptic HMI was installed. It was built from the base of a Thrustmaster USB Joystick, used for flight-simulation. The handle of the joystick was replaced with a 3D-printed top, measuring 8 cm in width, 6 cm in length, and 2.5 cm in height (Fig. 2). The absolute height of the interface was 15 cm measured from the bottom of the joystick base to the top of the 3D-printed handle. The interface could be moved within the two dimensional space of two axes (left-right, forward-backward) for 3.5 cm in each direction from the centre position, resulting in a 7x7 cm space available for interface movement. Mechanical springs inside the joystick base applied very light pressure to move the interface to the centre position of the two axes, acting as a self-centring mechanism. The joystick base did not have any other type of force feedback. The haptic HMI was connected to the simulation PC by a USB interface. Simulation data as well as the position of the HMI was recorded with a frequency of 20Hz through a custom Python script.

Fig. 2. *Haptic HMI used in this study.*

2.3. Study Design

The level of control over the vehicle was varied threefold in this experiment in a within-subject design. In a *manual driving* condition, participants were asked to use the pedals and the steering wheel to control the car. In this condition, no automation was implemented in the simulation. In a *full automation* condition, the simulated car was driving automated, i.e. no input from the participants was necessary, and participants just monitored the drive. In the *manoeuvre control* condition, participants were able to interact with the automated vehicle by using the haptic HMI (Fig. 2). Participants were not specifically instructed in regard to the safety of the automated driving function in the *manoeuvre control* and *full automation* condition. They were only informed that the vehicle would drive by itself without the need for pedal or steering-wheel input.

For this experiment, 18 different traffic situations were programmed in city-, rural-, and highway-road environments. In each of these conditions, a pre-recorded audio message was played, informing participants of the appropriate driving manoeuvre for the situation. 12 of these situations were prototypical settings in which drivers usually conduct driving manoeuvres, such as lane-changes or overtaking (passing another vehicle). Of these 12 complex driving manoeuvre situations, 7 were lane change situations and 5 were overtaking situations. In lane change situations, participants were instructed to change either to the left or right lane, in city, country-road, and highway environments.

In overtaking situations, participants were asked to overtake a slow lead vehicle in their lane. Overtaking situations were also presented in all three driving environments. In the *manual driving* condition, participants were able to conduct these manoeuvres through the use of the pedals and the steering wheel. In the *manoeuvre control* condition, participants were able to initiate the manoeuvres through the use of the haptic HMI. Participants were instructed that the haptic interface would recognize specific movement types, which it would then translate into manoeuvres. However, unbeknownst to the participants, any movement of the HMI led to the initiation of the driving manoeuvre required in the driving situation. This was implemented in the following way, the interface was programmed to detect HMI movement and then initiate the manoeuvre necessary in the driving situation, once the HMI returned to its initial position. The interface therefore was functional, but any movement away from and subsequent return to the centre position of the interface would trigger the pre-planned vehicle manoeuvre. While non-movement of the haptic HMI would have resulted in no manoeuvre being initiated, all participants used the HMI in all *manoeuvre control* condition drives. In the *full automation* condition, participants were informed that a specific manoeuvre was going to be initiated by the automated vehicle. Since they had no control over the vehicle in this condition, they could only monitor the manoeuvre.

Apart from the 12 manoeuvre situations, 6 headway situations were programmed in which the following distance to a lead vehicle could be adjusted. In the *manual driving* condition, participants were able to adjust their time headway distance through using the pedals (time headway = distance between the front of two vehicles divided by the speed of the ego vehicle in metres per second). In the *manoeuvre control* condition drives with time headway adjustment, participants could push the haptic HMI forward to decrease time headway in 0.1 second increments or pull back the HMI to increase time headway in 0.1 second increments. I.e. in contrast to the *manoeuvre control* conditions in which a more complex driving manoeuvre would be initiated, the haptic interface required specific movements along its forward-backward axis to function in time headway conditions. Participants were specifically instructed on how to use the interface in headway adjustment conditions. In the *manual driving* as well as in the *manoeuvre control* condition, participants were instructed to adjust their headway until they felt comfortable with it, at which point the time headway was registered. In the *full automation* condition, the headway adjustment situations were not presented, since it was not possible to know how a headway would need to be adjusted by the automated vehicle to result in a comfortable headway for individual participants.

Manoeuvre and headway situations were combined to build an experimental block of 18 traffic situations. Each block was presented for each control condition (*manual driving* vs. *manoeuvre control* vs. *full automation*) with the sequence of the blocks balanced between participants. Following each block of one control condition, participants were asked to rate their subjective experience during the preceding driving situations on three items of disco-scale, which was developed to measure discomfort in automated driving. The items assessed perceived control ("I was always in control of the situation."), ability to intervene ("I felt that I could always intervene in time."), and perceived responsibility for accidents ("If an accident happens I am responsible."). Items were rated on a 5-point Likert-scale, ranging from "strongly disagree" to "strongly agree". For headway situations, time headway distances between the ego vehicle and the lead vehicle were registered. Since there were no headway situations in the *full automation* condition, time headway data is only available for the *manual driving* and the *manoeuvre control* conditions.

3. Results

Data on the *perceived control* over the vehicle is presented in Fig. 3. Participants rated their perceived control highest in the *manual driving* condition (M = 3.48, SD = 1.11). In the *manoeuvre control* condition, participants rated their perceived control over the vehicle lower, with a mean of M = 2.5 (SD = 1.32). Perceived control was lowest in the *full automation* condition (M = 1.52, SD = 0.95). A repeated measures ANOVA was calculated to test the effect of level of the experimental conditions on participants' perceived level of control. Since 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 ($\varepsilon = .83$). Control conditions were rated as significantly different on the perceived control item ($F_{(1.65,\ 67.68)}$= 38.18; $p < .01$; $\eta_p^2 = .48$). Post-hoc tests using Bonferroni correction for multiple comparisons revealed significant differences between all condition (all $p < .01$), i.e. participants' perceived control over the simulated vehicle differs significantly, depending on the experimental condition.

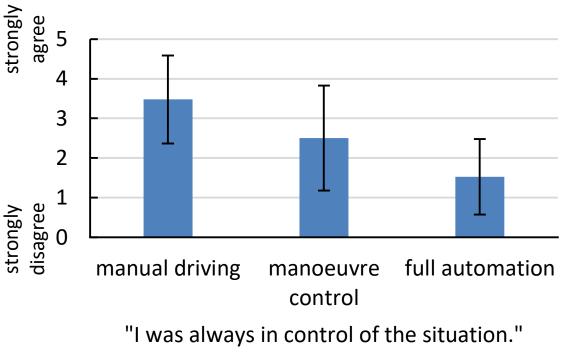

Fig. 3. *Average perceived control in the three experimental conditions (bars show standard deviation).*

The perceived ability of participants to *intervene in time* is presented in Fig. 4. The average ability to intervene in time is highest in the *manual driving* condition (M = 3.62, SD = 1.15), followed by the *manoeuvre control* condition (M = 2.29, SD = 1.23), and the *full automation* condition (M = 1.76, SD = 1.27). A repeated measures ANOVA revealed significant differences between participants' perceived ability to intervene ($F_{(2,\ 82)}$= 26.24; $p < .01$; η_p^2 = .39), depending on the experimental condition. Bonferroni corrected post-hoc tests revealed a significant difference in the level of perceived ability to intervene between the *manual driving* and the *manoeuvre control* condition ($p < .01$), as well as the *manual driving* and the *full automation* condition ($p < .01$). There was no difference in perceived ability to intervene between the *manoeuvre control* and *full automation* condition ($p = .069$).

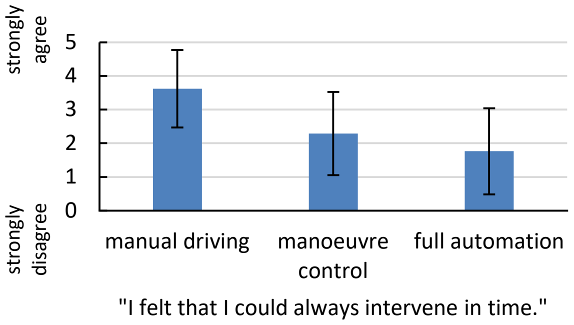

Fig. 4. *Average perceived ability to intervene in the three experimental conditions (bars show standard deviation).*

Participants were further asked if they would feel responsible if an accident were to happen. Average ratings for this question are presented in Fig. 5 for the three experimental conditions. Perceived responsibility for a potential accident was highest in the *manual driving* condition ($M = 3.45$, $SD = 1.18$), followed by the *manoeuvre control* condition ($M = 3.14$, $SD = 1.10$), and the *full automation* condition ($M = 2.12$, $SD = 1.33$). A repeated measures ANOVA revealed significant differences between the experimental conditions ($F_{(2,\ 82)} = 20.51$; $p < .01$; $\eta_p^2 = .33$). Bonferroni corrected post-hoc tests revealed that perceived responsibility in case of a crash differs between the *manual driving* and the *full automation* condition, as well as between the *manoeuvre control* and the *full automation* condition (both $p < .01$). There was no significant difference in perceived responsibility between the *manual driving* and *manoeuvre control* condition.

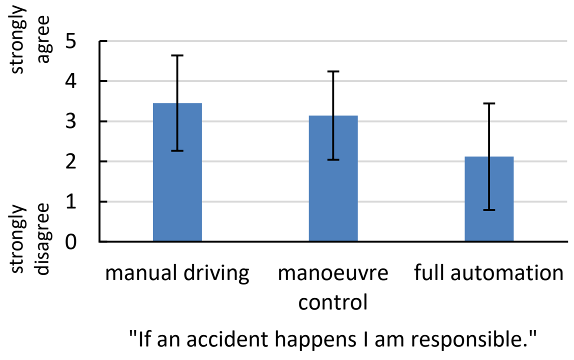

Fig. 5. *Average perceived responsibility for accidents in the three experimental conditions (bars show standard deviation).*

Time headways, registered during headway adjustment drives in the *manual driving* and *manoeuvre control* conditions are plotted in Fig. 6. Each data point represents an individual participant's time headway, with time headways of a given driving environment for both control conditions presented in the same vertical space. All drives are presented in ascending order for their time headway value averaged between the *manoeuvre control* and *manual driving* condition of a given driving environment. Time headways larger than 6 seconds were excluded from Fig. 6 and further analysis as they are not considered following distances in the literature [24]. 13 time headways in the *manual driving* condition, and one time headway in the *manoeuvre control* condition were excluded, resulting in 126 drives. It can be observed that time headways vary widely, i.e. given the ability to adjust their following distance, participants took the opportunity to use it. Time headways in the *manual driving* and *manoeuvre control* condition correlated significantly ($r = .25$, $p < .01$), i.e. participants prefer similar time headways in different experimental conditions. A repeated measures ANOVA revealed that time headways in the *manoeuvre control* condition were significantly lower than in the *manual driving* condition ($F_{(2,\ 82)} = 40.4$; $p < .01$; $\eta_p^2 = .56$).

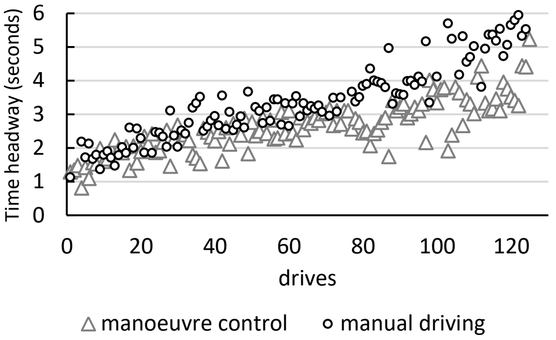

Fig. 6. *Participants' individual time headways in the manual driving and manoeuvre control conditions, ordered in ascending order for average time headway.*

4. Discussion and Conclusion

The aim of this study was to investigate the effects of manoeuvre control in automated driving on the experience and behaviour of drivers. Perceived control, ability to intervene, and responsibility for accidents were compared at different levels of control over the simulated vehicle. Participants in this study felt significantly more in control of an automated vehicle when they were given the ability to initiate manoeuvres through a haptic HMI (Fig. 3). Still, there was a significant difference between this *manoeuvre control* condition and the *manual driving* condition, in which participants were driving without any form of assistant system or automation. Since the haptic HMI only allows drivers to initiate specific manoeuvres, it does not offer the full range of control over the vehicle that is present in manual driving (i.e. the *manual driving* condition). In this light, the results on perceived control over the vehicle are coherent. A potentially negative effect of an increase in the perceived controllability of automated vehicles through the use of haptic HMI could be the erroneous use of the HMI in emergency situations. If drivers perceive the HMI as a means to initiate, e.g. evasive manoeuvres, the implementation of such an HMI could have adverse effects on safety.

Our results on participants' perceived ability to "intervene in time" suggest that, in this study, participants did not regard the haptic HMI as a means of direct intervention in emergency situations. Participants' ratings of intervention ability were highest in the *manual driving* condition, where they had control of the steering wheel and the gas- and brake-pedal. The *manoeuvre control* and the *full automation* condition did not show a significant difference on this subjective variable, suggesting that while participants see the HMI as a means of increased control, they do not perceive it as a means for direct intervention in the driving task.

When asked if they would feel responsible for a potential accident with the vehicle, perceived responsibility was highest in the *manual driving* condition. Surprisingly, this level of perceived responsibility did not differ significantly when compared to the *manoeuvre control* condition. Generally, providing any means to control the vehicle (*manual driving* and *manoeuvre control* condition) led to a significant increase of perceived responsibility for accidents compared to driving in an automated vehicle with no means of control (*full automation* condition). This finding is interesting, in that it appears participants' perceived responsibility for accidents (Fig. 5) is influenced through their perceived ability to generally control the vehicle (Fig. 3), but not through their ability to intervene in time (Fig. 4).

In this experiment, participants had the ability to adjust the following distance between their vehicle and another vehicle driving in front of them. Results for the *manual driving* condition mirror earlier findings from manual driving [20][21] that show drivers have a preference for specific time headways when following other vehicles. As such, time headways registered for different participants differ by a wide margin (Fig. 6). This broad range of time headways assumed in *manual driving* was also found in the *manoeuvre control* condition, in which participants used the haptic HMI to adjust their time headway. Our results on high variation in individual time headways show the importance of giving drivers in automated vehicles the means to adjust their time headways individually.

We found that time headways in the *manoeuvre control* condition were significantly lower than in the *manual driving* condition. This result is an unexpected result, since earlier research suggests that time headways do not differ significantly between *manual driving* and assisted-driving [21], which can be viewed as similar to driving an automated vehicle with the ability to adjust the automation (*manoeuvre control* condition). A possible explanation for this results lies in differences in the process of time headway adjustment between the *manual driving* and *manoeuvre control* condition in this experiment. In headway adjustment situations in the *manual driving* condition, participants use the gas- and brake pedal to adjust their velocity, thereby also adjusting their distance to the lead vehicle (i.e. time headway). Although this process is familiar from real-life driving, maladjusted braking can lead to large headway gaps. Since deceleration through braking is higher than acceleration through the use of the gas pedal, maladjusted braking can lead to relatively large headways in a short amount of time. Since participants were instructed to adjust their time headway until it was comfortable, there was no motivation to seek a *just-comfortable* time headway, a time headway that is close to the threshold of being uncomfortable [20][21]. In the *manoeuvre control* condition, time headway adjustment was very granular, i.e. participants could use the haptic HMI to adjust exact time headways with a precision of 0.1 seconds. Therefore, participants might have adjusted time headways that are closer to their comfort thresholds, i.e. closer to their *just comfortable* time headway.

This study has multiple limitations. Since it was conducted in a driving simulator, the subjective experience of drivers differs starkly from real-life driving. The perceived responsibility for accidents might be assessed much differently once there is a real risk of injury, which is absent in a driving simulator. Furthermore, our implementation of *manoeuvre control* did not include the possibility to initiate potentially dangerous driving manoeuvres. A real-world implementation of *manoeuvre control* / *shared control* would need to incorporate a feedback mechanism that acts either through the haptic HMI or another channel, to inform drivers of the impracticability of driving manoeuvres. As discussed, future research into headway adjustments needs to take into account differences in the regulation of headway between *manoeuvre control* and *manual driving*. As participants in this study were young and relatively unexperienced drivers, the results are not readily generalizable to the general public.

In this study, participants were told that the vehicle was able to distinguish between different HMI movements to trigger specific manoeuvres, although in reality, any movement would trigger the required driving manoeuvre. Future studies will need to assess whether participants truly believed in the ability of the vehicle to distinguish between HMI movements, or if some participants realized that any movement would trigger the required manoeuvre.

While we found that drivers actively engage in the driving task when asked to use the haptic HMI, it is unclear how frequently drivers would use the haptic HMI in real-life driving. Future studies will need to investigate, how the actual engagement of drivers changes through the availability of the haptic HMI, when its use is not prompted. Furthermore, engagement with the HMI cannot be equated with awareness of the driving environment. Future studies should therefore include situation awareness measures to assess whether an increased engagement with the automated vehicle translates to an increase in situation awareness.

The concept of manoeuvre control breaks with the dichotomy of established function allocation structures such as the SAE levels of automation. Since first manoeuvre control functions are already implemented in today's vehicles (e.g. with the Tesla lane change assist), existing taxonomies for automated driving will need to timely incorporate these new control structures.

To conclude, we found that the ability to use a haptic HMI lead to a number of positive effects, increasing perceived control and responsibility, while not leading to an erroneous misconception of the haptic HMI as a means of intervention on a situational level. Despite these early findings on the positive effects of a haptic HMI for automation adjustment and manoeuvre control, more research is necessary to investigate potential negative effects in situation where control over the vehicle is transferred from the automation to the driver.

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