Analysis of potentials of an HMI-concept concerning conditional automated driving for system-inexperienced vs. system-experienced users

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Abstract

Conditional automated driving (CAD) functions will be one of the key technologies promising comfort and efficiency in personal transportation. This work addresses the importance of a user-centered and variable Human-Machine-Interface (HMI) for CAD in consideration of different levels of trust. The question arises as to how the level of trust, presumably caused by system-experience with an automated system, modulates information needs. The variable HMI-concept was tested with a panel of 47 subjects in a driving simulator. Effects on system evaluation in terms of experience with a conditional automated system (between; system-inexperienced vs. system-experienced users) and the HMI (within; maximal-HMI with higher informational content vs. minimal-HMI with lower informational content) were examined. The gaze behaviour showed that the system-experienced users trusted the system more and monitored the system less frequently than the system-inexperienced users. System-experienced users focused on a non-driving-related task more often than system-inexperienced users. Even though, both user groups trusted the system more using the maximal-HMI than using the minimal-HMI, it is assumed, that long-term use will modulate the level of trust and the resulting information needs. This study supports the idea of adaptability of the HMI depending on the level of trust and the information needs.

Introduction

Besides the need for security (Benmimoun, Zlocki, Aust & Faber, 2011) and comfort, the wish for a flexible mobility rises. With technical progress in sensor technology as well as digitalization, a flexible mobility as promised by conditional automated driving will be possible in the near future (Federal ministry for traffic and digital infrastructure, 2015). When using such a new technology, it is unclear how the human and the machine will interact to prevent misunderstandings. Especially during initial contact, the HMI might adopt the role of a teacher, introducing the user into the system. The user has to become familiar with his task as some kind of a co-driver, trusting the system’s ability to safely perform the main driving task. Trust in automation (Lee & See, 2004) represents an important factor while interacting with the vehicle (Beggiato, Hartwich, Schleinitz, Krems, Othersen & Petermann-Stock, 2018).
This fact stresses the importance of a trustworthy human-machine-interface (HMI) (Bendewald, Stephan, Petermann-Stock & Glaser, 2015). The HMI should be user-orientated and therefore guarantee system transparency, predictability and comprehensibility for all upcoming manoeuvres (Beggiato et al., 2015). To match the users’ requirements, Nielsen (1993) recommends the distinction between two user groups: people, who have never interacted with a conditional automated system before (system-inexperienced users, SIUs) versus people, who have already got to know such a system (system-experienced users, SEUs). Using such an automated system requires trust in technology (Lee & See, 2004), while for trust in technical systems, system experience plays a major role (Muir, 1994). It is assumed that trust in the system is a result of system experience. Hergeth et al. (2016) observed that higher trust in the automated vehicle results in reduced control gazes while focusing on a non-driving-related task (NDRT). In general, system users tend to focus on a NDRT more often, if they trust the system (Beggiato et al., 2015). In contrast, SIUs are expected to have a higher need to monitor and control the system than SEUs. Results of a driving simulator study (Beggiato et al., 2015) demonstrated that this user type wishes to have detailed system relevant information especially while initially getting in contact with the system. If users are informed about any system decision, they are able to understand those decisions, match them with the environment and develop a system comprehension. To guarantee this transparency, detailed as well as redundant information concerning system decisions and manoeuvres should be available. It is assumed that the users will expect this information in the instrument cluster (FPK) and in the Head-up Display (HUD), which are seen as usual information sources to fulfil the main driving task.

In contrast to SIUs, SEUs are expected to already possess a developed system understanding. They might have less uncertainty trusting the system’s ability to safely perform the main driving task compared to SIUs. Beggiato et al. (2015) and Hergeth et al. (2016) claim that by the gain of trust in the automated system, the need to control is shrinking. Hence, SEUs do not want to monitor the system as strongly as SIUs. Concluding from the participants’ statements of the driving simulator study of Beggiato et al. (2015), users want to have the possibility to obtain system relevant information concerning system decisions, manoeuvres and status, but do not want to be confronted with these at any time. SEUs might use the chance to give away the main driving task to turn towards a NDRT, like the infotainment.

The question arises as to how a standardized HMI serves different types of users: a user, who has never interacted with an automated system before versus a user, who has. This paper focusses on a user-centered HMI-concept for conditional automated driving. The special feature of this HMI-concept is the scalability, which allows adjusting to the user’s level of trust and his need for information. Hence, the objective of the present research was to examine how the HMI meets users’ requirements best. Specifically, this driving simulator study addresses the control behaviour and the information needs of two different user groups driving conditionally automated. It is assumed that SIUs will monitor the system stronger as they have little trust in the system and therefore wish for detailed and redundant system information. SEUs, however, are expected to prefer reduced information and
a comfortable sitting position to enjoy NDRT since they trust the system more. This was realised by examining the effects on system evaluation in terms of experience with a conditional automated system and the HMI.

**Experimental user study**

**Experimental setup and design variations**

The experimental setup consisted of a static driving simulator with an AUDI mock-up of the Group Research of Volkswagen Aktiengesellschaft, equipped with an automatic gear and three projection screens 3.5 m in front of the mock-up. The projections screens’ width were 3.05m each and the resolution of the projector was 1920 x 1200 pixels. A field of view of 140° was covered. The simulation was implemented with the software Virtual Test Drive (VTD) and was projected onto three screens.

The study was conducted using a 2x2-mixed factors design with the factors system experience and HMI with two characteristics each. Participants differed in system experience (between-subjects factor): users, who had never interacted with a conditional automated system before (SIUs) versus users, who have already got to know such a system (SEUs). The SEUs took part in a previous study for conditional automated driving, where they learned how to activate and deactivate this automated system. Furthermore, they attended a separate training, where they received a detailed system description and practiced to operate the two HMIs. All participants tested two HMIs for conditional automated driving (within-subjects design) in randomized order, which were designed to fit the respective user group’s needs. There was the maximal-HMI with detailed as well as redundant system relevant information, which supports monitoring the system, potentially appropriate for the SIUs. In contrast to this, the minimal-HMI with rather reduced system relevant information, allowing the user to lean back due to moveable hardware elements. Effects of experience with a conditional automated system and the HMI on system evaluation were examined. For this evaluation, data of trust, control behaviour and information needs were gathered.

**User-centered HMI-concept for conditional automated driving**

To take the individual level of trust and the resulting information needs into account, the Volkswagen Group Research has developed a user-centered HMI-concept for conditional automated driving. The special feature of this human-machine-interface is the scalability, which allows adjusting to the user’s need by varying the amount of information in the different displays (see figure 1) and the sitting position while driving in conditional automation. The comfortable sitting position is realised with the movement of hardware elements: the steering wheel will move towards the instrument panel and the driver seat (inclusively the operating element for the infotainment) will move backwards for a bigger legroom. This concept is a further development of the HMI shown in the test vehicle Jack (Bendewald, Stephan, Petermann-Stock & Glaser, 2015). Concerning the HMI, this paper’s scope is on display content and the movement of hardware elements. The purpose of other HMI
elements is explained in a detailed potential analysis of this HMI-concept (Bauerfeind, 2016).

Since it is assumed that the needs of SIUs and SEUs differ, it was necessary to develop two different HMIs: The HMI for the SIUs (maximal-HMI, see figure 2, picture 1) and the one for the SEUs (minimal-HMI, see figure 2, picture 2). Each HMI contains a certain amount of system relevant information on different displays and the adjustment of scalable hardware.

The maximal-HMI, which potentially serves the need of the SIUs, contains detailed as well as redundant system information, especially located in the HUD and the FPK. Except for the steering wheel, the hardware elements will not move, enabling the user to stay in his driving position able to monitor the system. The movement of the steering wheel conveys the system status *automated driving*: By moving away from the driver, the system seems to announce the taking over of the main driving task. To remind the driver of taking back control, the steering wheel moves towards him. In contrast, the minimal-HMI, which should be appropriate for the SEUs, gives the chance to turn away from the main driving task to enjoy NDRTs. The user will be presented with reduced system relevant information. Since the user’s attention is expected to be on the infotainment in the centre console display, this user type might enjoy receiving system relevant information close to this area. This is why the rear mirror, as the nearest display to the infotainment, serves as an informing display. With moving hardware elements (driver seat and steering wheel) the SEUs are provided with a comfortable sitting position to enjoy NDRTs.
an HMI-concept for different users

Picture 1: maximal-HMI

![Maximal HMI Image](image1)

Picture 2: minimal-HMI

![Minimal HMI Image](image2)

Figure 2. System relevant information on three different displays (FPK, HUD and rear mirror) in the two HMIs: the maximal-HMI (with detailed and redundant information, picture 1) and the minimal-HMI (reduced information, picture 2). Other HMI elements are explained in the detailed HMI specification (Bendewald et al., 2015) and in the potential analysis (Bauerfeind, 2016).

Procedure

All participants were presented with the two HMIs in a randomized order. The driven interstate route of 25 km with other traffic was the same for both HMIs. The gaze behaviour was measured with an eye-tracking system from Ergoneers GmbH using the software Dikablis 2.5 (Ergoneers GmbH, 2016). After receiving the instruction how to activate and deactivate the system without getting further information about the content of the different displays, all participants fulfilled two short trainings. Before the main drive, participants were informed to have the possibility to watch videos on the infotainment display.

The participants were confronted with either a scenario that included an accident, which was the cause for a take-over request (TOR) or the TOR was triggered due to an obstacle on the street. It was randomly chosen which HMI was tested with
which scenario. The participants started driving manually to the interstate, where the system became available and could be activated to fulfil the complete driving task. Due to other road users, participants experienced lane changes done by the automated system. In the middle of a 15 minutes drive, the system asked for a take-over by the participant because it could not handle the upcoming situation on its own (obstacle on the street or an accident). This TOR consisted of visual information in the FPK and a voice output one minute and also 15 seconds prior to the take-over. Participants were told that they had to take over the driving task and exit the interstate manually in the end of each session. After testing each HMI, participants completed the questionnaire Trust in technical systems on a 4-point likert scale (Wiczorek, 2011). This questionnaire listed a total of 16 items and Cronbach’s Alpha was $\alpha=0.91$ for both HMIs. In the end of the study, the participants created their desired HMI for conditional automated driving. To facilitate this, a cockpit template was used that allowed participants to place cut-out pictures of system relevant information (system status, velocity, manoeuvre announcement, other vehicles, traffic lanes). By doing so, participants could personalise the cockpit, so they could demonstrate where they prefer to receive the different information. Furthermore, they indicated the desired movement of hardware elements. Choosing between the maximal- and the minimal-HMI, participants could also select their preferred HMI. They could also abstain from this decision.

Participants

The sample included 47 drivers, who were recruited from the test driver pool of Volkswagen Group Research. There were 24 SIUs (42% female) and 23 SEUs (44% female). The SIUs’ mean age was 37.7 years (SD = 11.9 years; min = 22, max = 59) and the SEUs’ mean age was 39.5 years (SD = 9.7 years; min = 22, max = 58). All participants were employees of the Volkswagen Aktiengesellschaft. The participants drove an average of 19298 km per year. Most of the participants had gained experience with an Adaptive Cruise Control (ACC), and a Cruise Control (CC) (see table 1). Most of the SIUs had not driven with Heading Control (HC).

Table 1. Percentages of user groups’ experience with the driver assistance systems “Adaptive Cruise Control” (ACC), “Cruise Control” (CC) and “Heading Control” (HC)

<table>
<thead>
<tr>
<th></th>
<th>ACC</th>
<th>CC</th>
<th>HC</th>
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</thead>
<tbody>
<tr>
<td>SIUs</td>
<td>67</td>
<td>71</td>
<td>42</td>
</tr>
<tr>
<td>SEUs</td>
<td>70</td>
<td>65</td>
<td>65</td>
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</tbody>
</table>

Results

Trust in the conditional automated system: subjective data

Subjective data of 47 participants were analysed using repeated measures Analysis of Variance (rmANOVA) to examine the effects of experience with a conditional automated system and the HMI on trust in the system. Data revealed that SEUs trusted the conditional automated system more than SIUs, $F(1, 45) = 8.47, p = .006,$
η_p^2 = .16. The system was rated as more trustworthy when participants drove with the maximal-HMI than with the minimal-HMI, F(1, 45) = 5.11, p = .029, η_p^2 = .10.

Control behaviour: gaze data

The aim was to investigate whether SIUs showed a stronger control behaviour than SEUs. Areas of interest had to be determined (see figure 3) to compute the participants’ percentage distribution of gazes.

![Figure 3. Areas of interest for the investigation of gazes. For the analysis of control behaviour, just the gazes on the street and in the FPK are reported. Control gazes into mirrors are described in the detailed potential analysis (Bauerfeind, 2016).](image)

One participant had to be excluded from the gaze analysis due to technical issues. Thus, gaze data of 46 participants were analysed using t-tests for independent samples (Mann-Whitney-test in case of missing normal distribution) to examine whether SIUs showed a stronger control behaviour compared to SEUs. There is a tendency that SIUs monitored the FPK more than SEUs (see figure 4 & table 2). Furthermore, SIUs monitored the street significantly stronger than the SEUs, in case of driving with the minimal-HMI. There is no difference in gaze frequency between the two user groups when using the maximal-HMI.

Gaze data showed that SEUs watched the infotainment in the infotainment display more often than SIUs; especially while driving with the minimal-HMI (see table 2). This tendency could also be observed while driving with the maximal-HMI.
Figure 4. Average percentage distribution of gaze frequencies into different AOIs while driving in conditional automation for the two user groups and for the two HMIs. Control gazes into mirrors are described in the detailed potential analysis (Bauerfeind, 2016).

Table 2. Results regarding gaze frequencies for both user groups into different AOIs for the two HMIs.

<table>
<thead>
<tr>
<th></th>
<th>SIUs</th>
<th>SEUs</th>
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<th>U</th>
<th>z</th>
<th>p</th>
<th>r</th>
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<tbody>
<tr>
<td></td>
<td>M (SE)</td>
<td>M (SE)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Maximal-HMI</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>FPK</td>
<td>16.03 (1.85)</td>
<td>11.23 (1.15)</td>
<td>187.00</td>
<td>-1.69</td>
<td>.090</td>
<td>-25</td>
<td></td>
</tr>
<tr>
<td>Street</td>
<td>51.89 (2.78)</td>
<td>43.89 (4.36)</td>
<td>1.55</td>
<td>.131</td>
<td>.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IT</td>
<td>13.07 (2.54)</td>
<td>24.29 (4.41)</td>
<td>187.00</td>
<td>-1.69</td>
<td>.090</td>
<td>-25</td>
<td></td>
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<tr>
<td>Minimal-HMI</td>
<td></td>
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<tr>
<td>FPK</td>
<td>9.51 (1.05)</td>
<td>7.03 (0.92)</td>
<td>182.00</td>
<td>-1.80</td>
<td>.071</td>
<td>-27</td>
<td></td>
</tr>
<tr>
<td>Street</td>
<td>45.29 (2.94)</td>
<td>34.61 (3.96)</td>
<td>157.00</td>
<td>-2.35</td>
<td>.019</td>
<td>-35</td>
<td></td>
</tr>
<tr>
<td>IT</td>
<td>14.36 (2.20)</td>
<td>25.88 (3.51)</td>
<td>-2.83</td>
<td>.007</td>
<td>.42</td>
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</table>

Note. SIU = system-inexperienced users, SEU = system-experienced users, IT = infotainment, M (SE) = mean with standard error, t = t-tests for independent samples (in case of normal distribution), U = Mann-Whitney-test (in case of missing normal distribution), for a simplified comparison just the means are reported.
Desired HMI

The aim was to examine what the user groups’ ideal HMI would look like concerning system relevant information and the movement of hardware elements. Descriptive data analysis of the desired HMI revealed that both user groups had a similar need for information. Half of all participants asked for rather detailed system relevant information while driving in conditional automation: 50% of the SIUs and 52% of the SEUs wanted to be informed about the current driving environment (other vehicles, traffic lanes). In regard of redundancy, information about the system status should be available on several displays according to most of the participants (67% of the SIUs, 70% of the SEUs). 58% of the SIUs (30% of the SEUs) also asked for redundant information about the current velocity. 79% of the SIUs and 74% of the SEUs liked the rear mirror as an informing display, even though 63% of the SIUs asked for a free mirror half without any information. 52% of the SEUs could imagine the rear mirror to serve as a full display.

Results made clear, that in comparison with SIUs, SEUs were more open for the movement of hardware elements while driving in conditional automation. The majority of all participants asked for the movement of the steering wheel (58% of the SIUs, 78% of the SEUs). Concerning the driver seat’s flexibility (including operating element) the two user groups had different demands. In contrast to the 33% of SIUs who were against it, 61% of the SEUs asked for this movement to have a comfortable sitting position while driving in conditional automation. In the end of the study, participants could choose their preferred HMI. They could also abstain from this decision. Results revealed that the majority of the SIUs (75%) liked the maximal-HMI most. In contrast, there was no tendency for the SEUs: 39% of this user group preferred the minimal-HMI and 43% chose the maximal-HMI.

Discussion and conclusions

The aim of this research was to investigate the effects on system evaluation in terms of experience with a conditional automated system and the HMI. This driving simulator study addresses the control behaviour, presumably caused by a lower level of trust and the information needs of two different user groups driving conditionally automated.

With regard to trust, SEUs trusted the conditional automated system more than the SIUs. Hence, these results support the findings of Muir (1994), who states that system experience plays a major role concerning trust in a technical system. The maximal-HMI with detailed system relevant information was rated as more trustworthy and more transparent as the minimal-HMI. It needs to be taken into account that in this study system experience was obtained by participating in a previous study based on this HMI, a separate training, and a detailed system description. Therefore, SEUs did not have long-time experience with this system. The question is whether SEUs’ evaluation will change after having driven the minimal-HMI for a longer time. They might prefer the minimal-HMI, because detailed and redundant information might not be seen as transparent and clear anymore, but rather as annoying (Beggiato et al., 2015). This can only be explored in long-term studies. In general, it has to be considered that participants might rate
the system more trustworthy while driving in a simulator rather than driving in a real car. They might feel more secure driving in a simulation than being exposed to a real traffic situation.

Concerning the control behaviour, SIUs were looking at the FPK more often than SEUs to monitor the system. This behaviour was shown for both HMI. Concerning gazes to the street, just the minimal-HMI made a difference: SEUs watched the street driving with this HMI much rarer than SIUs. One reason could be that SIUs observed the street since there were minimal information on the displays. Another explanation is that the minimal-HMIs aim to convey the possibility of turning away from the driving task to a NDRT succeeded. The SEUs accepted this HMI and made use of this option. These results are consistent with the findings of Hergeth et al. (2016), who declares that higher trust in the automated vehicle leads to reduced control gazes while focusing on a NDRT.

In general, SEUs trusted the system more and showed a weaker control behaviour than the other user group. Nevertheless, all participants had similar information needs in this study. Both user groups asked for system transparency, predictability and comprehensibility. Information about the system status should be available on several displays according to most of the participants. Half of all participants preferred rather detailed system relevant information, which is requested for the initial contact with the system (Beggiato et al., 2015). It has to be discussed whether these results might be attributable to the user training applied to the members of the SEU group. This training might have been too short to gain a sufficient level of system experience, which has to be taken into account when interpreting these results. Nevertheless, the user groups’ statements concerning the movement of hardware elements differed: SEUs were more open for the movement of hardware elements while driving in conditional automation compared to SIUs. An explanation might be that SIUs associate this movement with a loss of control. Instead of enjoying a comfortable sitting position while driving in conditional automation, SIUs might feel less secure by taking back the driving task while sitting leaned back. Thus, this training applied to the SEUs already had an impact on users’ demands. Descriptive data analysis showed that in contrast to the SIUs, who preferred the maximal-HMI, the SEUs did not show such a tendency. They rather wished for an HMI individually customized. The SIUs enjoyed to be led by the maximal-HMI, which had proved to be a suitable introduction for using a conditional automated system for the first time.

With regard to the methodology, one of the advantages of this experimental setup with a driving simulator is the high level of situation standardization. It could be guaranteed, that every participant experienced similar conditions. Furthermore, the implementation of a prototypical HMI-concept is easier to realise in a mock-up than in a test vehicle.

These results help to understand differences concerning the interaction between different user types and an automated system. Especially during initial contact, the HMI should be transparent in system decisions, which allows the user to gain trust in the technology. Overall, this study recommends the distinction between user
groups with different levels of system experience while developing an HMI for conditional automated driving. Furthermore, the idea of adaptability of the HMI depending on the level of trust and the need for information is suggested.

References


