# THE INFLUENCE OF A GAZE DIRECTION BASED ATTENTION REQUEST TO MAINTAIN MODE AWARENESS

**Dr. Christina Kurpiers**
BMW AG
Germany

**David Lechner**
BMW AG
Germany

**Dr. Florian Raisch**
BMW AG
Germany

Paper Number 19-0245

## ABSTRACT

Future vehicles will combine different levels of driving automation characterized by varying responsibilities for users. This development will intensify system complexity which poses the risk of confusing the driver. We hypothesize that the users' mode awareness suffers especially when changing from Level 3 "Conditional Automation" to Level 2 "Partial Automation". Therefore, automated systems need to be designed in a way that minimizes confusion with regard to the automation mode. The article describes the influence of a gaze direction based Attention Request (ATR) to avoid mode confusion with the aim of contributing to the reliable operation of different levels of automation in one vehicle.

Two similar studies were conducted. One took place in a dynamic driving simulator with 40 participants. Every participant drove for 10 minutes with a partially automated driving (PAD) (SAE level 2) system and conditionally automated driving (CAD) (SAE level 3) system in the order PAD/CAD/PAD. The second study was conducted on a German highway in a Wizard-of-Oz car. All 40 test persons drove in each PAD and CAD phase 8 minutes in the order of PAD/CAD/PAD/CAD/PAD/CAD. The CAD-system was in both studies a high performing Hands-Off Level 2 system that required no input of the driver. To promote the same mental model for all participants as it is a requirement to measure the differences in mode awareness, all persons became a detailed description of the Level 2 and 3 systems presented by video and text.

Both studies used a between-subject-design to measure the influence of an ATR. The ATR was based on the gaze direction of the driver and initiated by the investigator when the drivers gaze was not in the street AOI for longer than 4 seconds. Mode awareness was operationalized by the visual attention towards driving-relevant areas, a qualitative analysis of a questionnaire and followed by an interview.

The ATR was proven to be an effective action to maintain the mode awareness by using a level 2 and 3 system within one car. Specifically, the visual attention did not decrease by an intermitted CAD drive during PAD. Moreover, the visual attention to the road scene increased for the group with an ATR during PAD. This was indicated by the measurement of a significant interaction effect for the development of the visual attention to the road scene for the groups with and without ATR. Thus, the gaze direction based ATR was proven to be an effective measure to maintain mode awareness, if different levels of automation are combined in one vehicle. This result helps to take the next step for realizing such combined multilevel systems with tailored HMIs for advanced driver assistance systems.

Moreover, it has to be considered, that the studies put the emphasis on the first glance of the drivers, during their first contact with partly and conditionally automated systems. Further studies should investigate the long term effect of an ATR.

## INTRODUCTION

Technical advances in recent years lead to the presence of automated vehicles in road traffic within the next few years. As a result of progressive development towards full driving automation, future vehicles will combine different levels of driving automation modes. This development of combining different levels of automation in one car will intensify system complexity which poses the risk of confusing the driver [1, 2] as different levels of driving automation are characterized by varying responsibilities for their users.

The Society of Automotive Engineers (SAE) provides a taxonomy for motor vehicle driving automation systems that perform part or all of the dynamic driving task on a sustained basis and that range in level from no driving automation (level 0) to full driving automation (level 5) [3].

Recently released driving automation systems in production vehicles can be classified as Level 2 "Partial Automated Driving" (PAD). In Level 2, the automation performs both lateral and longitudinal vehicle guidance [3]. However, due to system limits and at system failures where the systems cannot cope, the user is considered to be the fallback level at all times and has to continuously monitor the vehicle behavior for fast and correct intervention. Common current limitations include restrictions in operating speed ranges; how much steering, braking and acceleration the system can apply; and limitations in lane and object detection. Thus, the driver has to supervise both, ongoing automation performance and detection of precrash conditions.

The next step is to temporarily release the driver from all driving-related responsibilities. On Level 3, "Conditional Automated Driving" (CAD), the system comprises the entire range of dynamic driving tasks when it is available, and thus the user can engage in non-driving-related task (NDRT). CAD recognizes its system limits and timely requests the driver to intervene if it becomes necessary [3]. With CAD, the user is considered to be the fallback level, which means he/she is expected to be receptive to the system's requests to intervene and to timely respond accordingly.

Thus, the main difference between Level 2 to Level 3 is that the driver has to continuously monitor the automation during PAD, whereas during CAD he/she is allowed to engage in NDRT.

### Trust in automation

Trust in automation is commonly described as an important factor for system use and acceptance. If drivers do not trust, thus undertrust the systems, they will not activate them. However, if drivers overtrust the functionalities, this may certainly lead to unsafe situations.

Lee and See [4] define trust as an "attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability" [4], p. 54. In this definition, an agent can be automation or another person that actively interacts with the environment on behalf of the person. Lee and See [4] specified calibration of trust as one of three components of appropriate trust and described calibration of trust as having accurate knowledge of the system's capabilities. Calibration is needed for a driver to know when human action is required. However, there is more to trust calibration than just avoiding overtrust and undertrust. Trust may be perfectly calibrated with a system that is very unreliable. In that case there is a very low level of trust, but well calibrated. One could even argue that undertrust is good for traffic safety since the driver will have a high level of attention and a high readiness to take back control. So although trust calibration is an important issue in automated driving, a minimum level of trust seems to be required to have comfort and safety benefits for the user [4]. Lee and See [4] conclude that overtrust is more dangerous than undertrust as drivers ignore a high level of attention and a high readiness to take back control.

Thus, the ability of people to effectively supervise automation is also clearly related to difficulties in achieving calibrated trust, in which the user's trust matches the automation capabilities [4, 5]. Higher levels of trust are associated with less eyes-on-road time and less monitoring [6]. Hancock et al. [7] determined in their meta-analysis that robot performance and attributes were found to be the most important influences of trust development. Therefore, a very reliable Level 2 system can lead to the risk of overtrust in Level 2 automation.

To conclude, overtrust is a very crucial factor for the usage and Human-Machine Interaction of automated systems that can lead to low situation awareness that will be explained in the next paragraph.

**Situation Awareness and Mode Awareness**

It is first necessary to distinguish the term situation awareness, as a state of knowledge, from the processes used to achieve that state. Situation awareness is defined as the "perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." 8, p. 36. Thus, a person's situation awareness is formed by the perception of the relevant elements in the environment, as determined from system displays or directly by the senses.

Automation effects from aviation [1, 8–10] show that situation and mode awareness are vital criteria for take-over scenarios. The driver has to be aware of the surrounding scenery, traffic constellations, and the system mode at all times.

Mode awareness is defined as "the ability of a supervisor to track and anticipate the behavior of automated systems" [1], p. 7. A user can achieve mode awareness for a system, when he or she perceives system information, interprets the information correctly to have an understanding of the current state of the system and is able to project the future status of the system [1, 11, 12].

Sarter and Woods [1] stated that more complex automated systems might pose the risk of confusing drivers and therefore provoke erroneous behavior. Such incorrect driver behavior occurs when the driver is not aware of the currently activated automation mode and its functional capability or assumes that a different mode is currently activated [1], thus, if there is mode confusion. Bredereke and Lankenau [13] state that mode confusion occurs when the observed behavior of a technical system is out of sync with the behavior of the user's mental model of it.

By implementing different levels of automation modes into one vehicle that increases the complexity of the system, the automotive domain is facing challenges concerning mode awareness. In each automation mode, drivers have to be aware of the current state of the system and the environment and to keep in mind which tasks are taken over by the system and which they have to remain responsible for. While driving in PAD, the driver must monitor the system at all times, meaning that he/she has to verify that the vehicle is behaving as it is supposed to depending on the given situation.

Therefore, mode confusion and lack of mode awareness can be identified as risk factors for the safe operation of automated vehicles and need to be further examined [14].

Kolbig and Müller [11] showed in their model (see Figure 1) the connection of mode and situation awareness within the key components of driver, vehicle and environment. While the scope of information in mode awareness is limited to the system, situation awareness also includes all information about the current situation in which the system and the user are located [11].

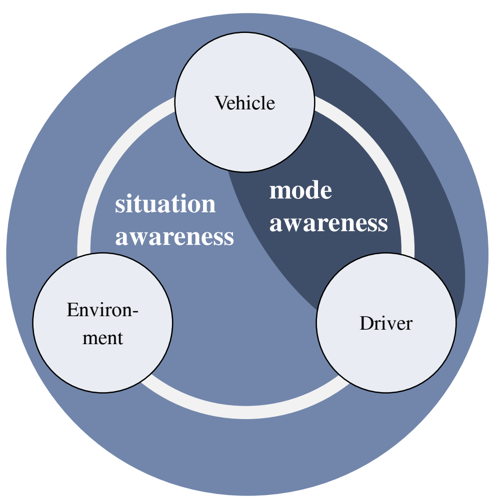



***Figure 1. Scope of information for situation and mode awareness (referring to 11, p. 3)***

**Mental Model**

According to Norman [15] mental models are naturally evolving models. Through interaction with a target system, people formulate mental models of that system. Humans use mental models when they interact with technical systems in general, and with automated systems in particular. A person, through interaction with the system, will continue to modify the mental model in order to get to a workable result [15]. Mental models will be constrained by such things as the user's technical background, previous experiences with similar systems, and the structure of the human information processing system. Thus, a mental model represents the user's knowledge about a technical system and it consists of a naive theory of the system's behavior.

Humans often have gaps and misconceptions in their mental models of automated systems due to their complexity. Consequently, operators are often surprised by the automation and they do not understand why it behaves in a certain manner or what it will do next [16]. It is necessary that a correct mental model of the system, along with the associated required driver behavior, is clearly described. Thus, it is very important to communicate system limitations, for example in level 2 automation, to avoid mental model misconceptions and consequently a lack of mode awareness. Therefore, central problems to address in further research are potential gaps and misconceptions in drivers' mental models and transparency of automated systems.

Kolbig and Müller [11] built by following the main findings from Endsley [8] and Norman [15] a model to address the development process of a mental model (see Figure 2). Thus, the development of a mental model is dependent on system knowledge or previous experience, system feedback and relevant system information in the environment.

For the correct execution of supervision during the usage of a level 2 system of automation a detailed mental model of the driver is necessary as this is a precondition for the mode awareness [11]. According to Kolbig and Müller [11] a mental model can mainly be formed by the system feedback. Thus, it can be assumed that in order to achieve mode awareness with increasing automation, an increasing scope of feedback is required. Figure 2 also shows the influence of an attention request as system feedback on the adjustment of the mental model in the case of misconduct of the driver.

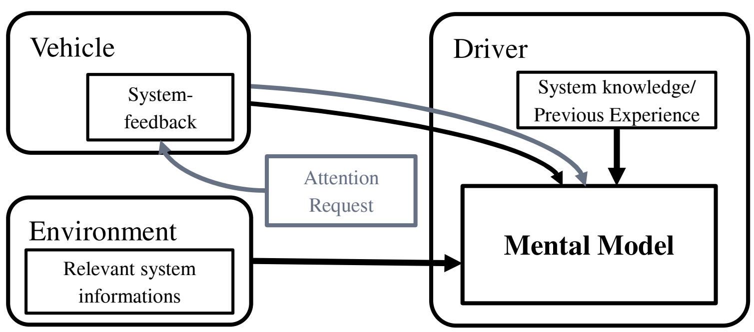



***Figure 2. Developing process of mental models according to 11 [11]***

**Aim of the paper**

Studies showed that humans tend to reduce their monitoring of highly reliable automation because of its ability to function properly for an extended period [16, 17]. Therefore, the question comes up how to prompt operators to pay attention to the roadway in level 2 driving and how to contribute to the reliable operation of different levels of automation in one vehicle.

Therefore, a paradigm of vehicle guidance has to be found in which both the automation system and the human can collaborate and mutually compensate the insufficiencies and failures of the other. With such a cooperative manner of vehicle driving the driver shall be kept active and in the loop of the shared driving task.

A review of several incidents and even accidents in the aviation sector caused by a lack of mode awareness revealed that the main reasons for the occurrence of mode confusion and the resulting erroneous behavior were poor system feedback, high complexity of the automated system, and insufficient mental models on the part of the pilots [1]. Thus, automated systems need to be designed in a way that minimizes confusion with regard to the automation

mode. Moreover, an adequate human-machine interface (HMI) is needed to ensure that the user is aware of the activated mode.
To contribute to the reliable operation of different levels of automation in one vehicle, the aim of this paper was to understand how to secure driver supervision engagement, thus how to influence the gaze behavior of the driver that he or she maintains the eyes on the road even though the mental model might not be exhaustive enough from beginning on or might be neglected over time due to arising overtrust.
Therefore, the influence of a gaze direction based Attention Request (ATR) during PAD was investigated to develop and adjust a correct mental model for the levels of automation, to maintain drivers' mode awareness and to avoid encouraging overtrust. The ATR should bring the drivers gaze back to the road scene ahead, if he/she stops monitoring the driving task or starts engaging in a NDRT during PAD.
The ATR was designed as a 3 step warning cascade with increasing urgency and is described in more detail below. The first stage of the ATR-cascade appeared after a continuous eyes-off time of 4 seconds and starts with a message in the instrument cluster behind the steering wheel for reminding them to supervise driving.

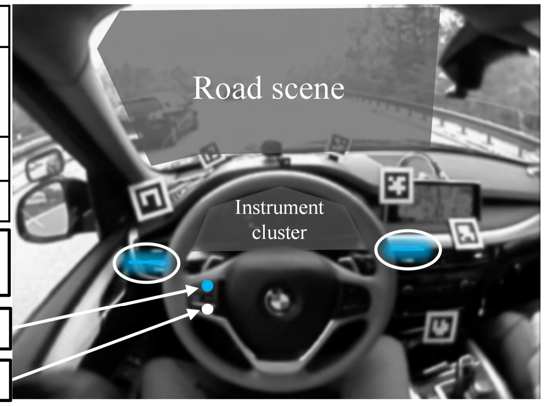
## METHODS

### Measure of mode awareness

To measure mode awareness and compare it between different drivers, it is necessary, that every driver has a comparable knowledge about the used levels of automation (compare Figure 2). The reason is, that the mental model is an underlying construct of mode awareness and is affected by the users' knowledge and previous experience with the used levels of automation [15]. Consequently, every participant was instructed with a detailed description of the different levels of automation by video and text. This description gave an overview of level 2 and 3, their system limits and put emphasis on the monitoring task of the driver during level 2. Moreover, it described that the driver is allowed to engage in non-driving-related-tasks (NDRT) during level 3. To ensure the correct understanding, the instructor controlled the participants' knowledge about the levels of automation. Therefore, they had to repeat the overview of the system functions and limits as well as their tasks. If a participant had an incorrect understanding, he or she had to read again the instruction until he or she achieved a correct and comparable knowledge about the automation levels experienced during the study. This step of a correct understanding is very important to measure the impact of different system designs on the drivers' mode awareness and his/her underlying mental model.
A level 2 and level 3 system can be designed in different ways. The system design of the automated system is an important influence factor for the users' mode awareness [1] and the worst-case scenario to achieve a sufficient mode awareness are two very similar systems as it is very difficult for the driver to distinguish between similar systems. Thus, a level 2 and a level 3 system, that are designed very similar make it more difficult for the user to have enough mode awareness and to behave correct during the use of each system. Therefore, a very similar PAD and CAD system were implemented in the two studies presented in this paper as this seems to be the most suitable method to investigate the impact of different system designs on the drivers' mode awareness. Both were Hands-Off systems and had the same functionality, meaning that the car automatically executed the lateral and longitudinal guidance, independently overtook slower cars and drove up to 130 km/h (80 mph). The driver was able to differentiate between PAD and CAD by the different visual design in the instrument cluster and by the color of the LED bars (see Figure 3). During PAD the LED bars lighted green and during CAD they lighted blue. Additionally, there was a simulated environmental model in the instrument cluster during CAD. Moreover, the user had to activate the systems and confirm the mode change from CAD to PAD by pressing a button. Consequently, the driver could differentiate between PAD and CAD even though the systems felt very similar due to their functionality. The characteristics of the PAD and CAD systems were exemplary systems.

| | Instrument cluster | LED-bars |
|---|---|---|
| **CAD** | Blue indication of CAD-state Model of the driving environment | Blue |
| **PAD** | Green indication of PAD-state | Green |
| **Manual** | Basic instrument cluster | Off |

**LED-bars** to display the system state (surrounded with a white circle and in blue as an example)




**Activation/ Deactivation CAD**

**Activation/ Deactivation PAD**

***Figure 3. Visual design of the human-machine-interface (field of view of the participant in the Wizard-of-Oz study) and area of interest "Road scene"***

Feldhütter et al. [2] showed, that changing between PAD and CAD impairs the drivers' monitoring behavior in PAD. Thus, the order of the PAD- and CAD-sequences is also important for measuring the mode awareness of the participants. Hence, the study started with a PAD-sequence as a baseline for the monitoring behavior during PAD and then alternated between PAD and CAD. To compare the monitoring behavior during PAD and CAD with the monitoring behavior during manual driving, a manual baseline was conducted before the first PAD-sequence.

To ensure a naturalistic behavior of the driver the NDRT should not have an additional extrinsic motivation. Therefore, the participants were instructed to engage in the NDRT, if it is allowed in their opinion and in relation to the actual driving situation. To generate a comparable intrinsic motivation, the drivers could choose between the usage of their own smartphone or of a study smartphone on which a quiz-game was installed. The drivers were allowed to run any application on their own smartphone only the voice-interaction or making a phone call was restricted to ensure a visual engagement in the NDRT.

To operationalize mode awareness and the underlying mental model of the participants with objective measures the definition of the driver behavior according to SAE International [3] was used. Thus, the driver is expected to monitor the driving environment while using a level 2 system, whereas the driver must stay receptive for alerts in level 3. The monitoring behavior of the participants was assessed by using the Dikablis Essentials head-mounted eye-tracking system (by Ergoneers GmbH), with a sampling frequency of 50 Hz. Consequently, the monitoring behavior was operationalized by the visual attention to the road scene ahead (see Figure 3). The attention ratio is representing the percentage of time that a participants' gaze direction is in the area of interest (AOI) in relation to the total duration of each driving phase [18]. The trust into the automated systems was operationalized by a questionnaire from Pöhler et al. (2016) and was therefore measured subjectively. For a more detailed view on the participants' mental model a questionnaire for the system understanding was used after the studies.

**Attention Request to correct the mental model**

The corrective measure to increase the mode awareness and the underlying mental model of the participants is the gaze direction based attention request during PAD. The ATR should bring the drivers gaze back to the road scene ahead, if he/she stops monitoring the driving task or starts engaging in NDRTs. According to Klauer, Dingus, Neale, Sudweeks, and Ramsey [19] a safety-based time duration to allow the driver to take his or her eyes off the road is two seconds, as they showed that an eyes-off time from the road scene longer than two seconds increases the probability of an accident during manual driving [19]. An earlier investigation of an attention prompt during PAD showed, that an allowed eyes-off time of two seconds leads to habituation-effects and the participants start to ignore the prompts [20]. In accordance to the findings of Groves and Thompson [21] concerning habituation of warnings a trade-off between short eyes-off times with frequent warnings and extended eyes-off times with high acceptance of the driver is necessary. Therefore, the first stage of the ATR-cascade was executed after a continuous eyes-off time of 4 seconds to minimize the risk of ignoring the ATR. In the first stage the driver was requested to look back at the driving scene by an indication sound, green flashing LED-bars and a pop-up message in the instrument cluster. The ATR consisted of three stages and the urgency of the warning increased by changing from green to red color and

using an alert-sound after stage 1. The detailed description of the ATR-cascade is shown in Figure 4. The cascade started to count after the driver took his/her eyes off of the defined AOI road scene (see Figure 3). The driver was then classified as "inattentive" by the investigator, who tracked the gaze direction of the participant during the simulator study on a computer in the control center and during the Wizard-of-Oz study on a tablet at the passenger's seat. The driver was classified as "attentive" again and the ATR-cascade stopped in stage 1 and stage 2, when he/she looked back at the road scene ahead. In stage 3 the driver had to make an active intervention of the vehicle guidance to stop the cascade.

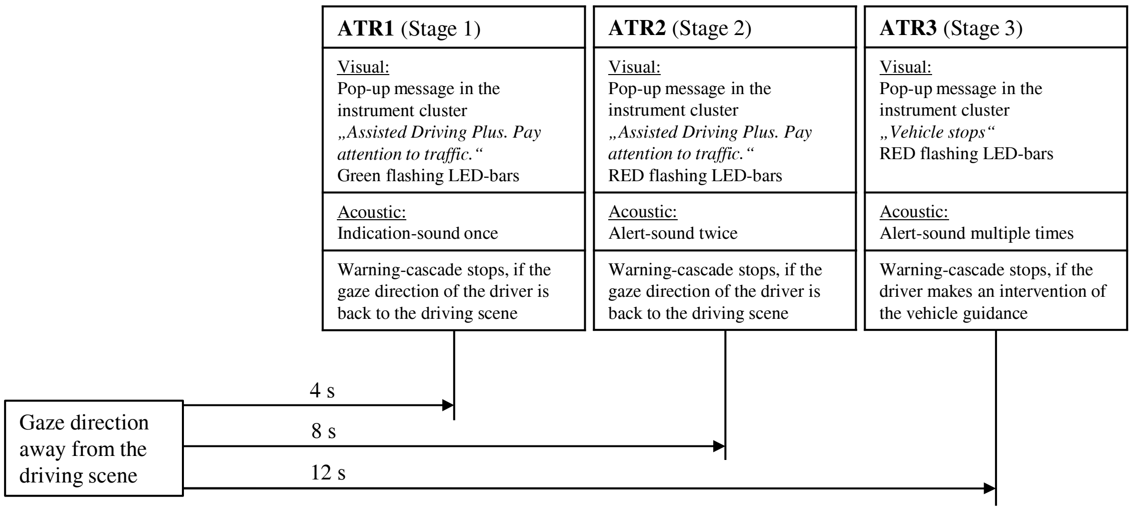



*Figure 4. ATR-cascade*

**Experimental design of the two studies**

To investigate the effect of an ATR during PAD two similar studies were conducted. The first took place in a dynamic driving simulator and the second on a public highway in Germany with a Wizard-of-Oz car. The method Wizard-of-Oz is described in the section of Study 2 below. Both studies had a similar design. The independent variable was PAD with and without an ATR and a between-subject-design was used to measure the influence of the ATR. Consequently, half of the participants became an ATR during PAD and the second half of the participants did not became an ATR during PAD. The level auf automation was varied in a within-subject, meaning that every participant experienced PAD and CAD. The two studies shared a similar general methodology according to the explanations for measuring mode awareness as stated above and are explained in detail below.

**Study 1 - Dynamic driving simulator** The first study was conducted in a dynamic driving simulator at the BMW Research and Innovation Center. A complete 5-series mock-up was mounted in the dome on a hexapod system for motion simulation. The visual simulation in the dome is accomplished with projectors and generates a 360 degrees field of view for the participant. The engine sound, driving and ambient noises are also simulated with the help of speakers in the dome. The dynamic driving simulator was additionally equipped with active steering. The automation modes PAD and CAD were implemented as described above. The virtual driving scenario was a standard three-lane highway with surrounding traffic. In both PAD phases, the test track and the surrounding traffic were designed in such a way that overtaking maneuvers were not necessary. The procedure of the first study and the duration of each phase is shown in Figure 5. The durations of continuous monitoring as it is required during PAD were chosen to be shorter than 15 minutes, to avoid vigilance effects on the monitoring behavior [12, 22]. The duration of 10 minutes should be long enough to develop enough trust in CAD and measure a realistic behavior of the participants. At the beginning of each study, participants became a detailed description of the automation modes presented by video and text. Afterwards they were familiarized with the simulator and the use of the level 2 and level 3 automated systems. The group with ATR neither became any instructions regarding the ATR, nor experienced an ATR during the familiarization-phase. As baseline for the monitoring behavior of the participants, the test drive started with a manual drive. During that baseline drive participants got the instruction not to exceed 130 km/h (80 mph) for a better comparison with the following PAD and CAD-phases, because the maximum speed

of the automated systems also was 130 km/h (80 mph). Afterwards, the participants started with the first PAD-phase (PAD1). During that level 2 phase, people in the "ATR group" became an ATR, if they took their eyes off the road longer than 4 seconds. The mode change from PAD to CAD and back to PAD was not interrupted by a manual drive; the only action from the participants was to activate CAD by pressing the CAD-button (white) and to confirm the mode change to PAD by pressing the PAD-button (blue) another button. The study concluded with a questionnaire and an interview at the end of the study. To obey the ethical guidelines people were debriefed after the study.

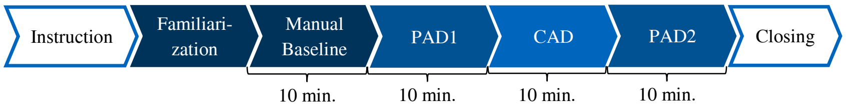



***Figure 5. Procedure of the driving simulator study***

**<u>Study 2 - Wizard-of-Oz study on public highway</u>** The second study was conducted on a public highway in Germany to investigate the monitoring behavior and the influence of a gaze direction based ATR in real traffic. The BMW AG modified a BMW X5 xDrive50i to allow a Wizard-of-Oz configuration that was used for this study as test vehicle. The Wizard-of-Oz method allows to imitate a complex automated system by a human driver and the participant believes to interact with the automated system [23]. In this study, the wizard imitated both the PAD and CAD system with an additional steering wheel and pedals. The participant did not see the wizard during the whole study and believed to interact with an automated system. This method was chosen to allow us to investigate our research-questions in a safe study in a real traffic environment and to avoid risk for the participant when he or she is not monitoring the systems correctly. The study was conducted on the German highway A92, which is a two-lane, limited access highway. It took place during off-peak hours (late morning and early afternoon) to ensure middle traffic density. The procedure of the second study and the duration of each phase is shown in Figure 6. At the beginning of each study, participants became the same description of the automation modes presented by video and text as in the simulator study. Afterwards, they were familiarized with the test vehicle and the study started due to the environmental conditions with a manual baseline. This was also used as baseline for the participants' monitoring behavior and once again it was not allowed to exceed 130 km/h (80 mph) for a better comparison with the following PAD and CAD-phases because the maximum speed of the automated systems was also 130 km/h (80 mph). The instructor was sitting on the passenger seat during the test drive and the participants were told not to talk with him to create a more realistic scenario. The manual baseline was followed by a familiarization-phase for getting used to the use of the level 2 and level 3 automated systems. The group with ATR neither became any instructions regarding the ATR, nor experienced an ATR during the familiarization-phase. The test drive started with the first PAD-phase and the participants in the "ATR group" became an ATR, if they took their eyes off the road longer than 4 seconds during PAD. The participants had to active PAD by pressing the PAD-button and confirmed the mode change from CAD to PAD by pressing the CAD-button. The mode changes were not interrupted by a manual drive, except the change from PAD2 to CAD2 due to a necessary change of the driving direction and a consequently intermittent manual drive. The participants had to confirm the mode change from CAD to PAD by pressing the CAD-button. In this study, an additional trust questionnaire was conducted before and after the test drive, because the results of the simulator study indicated an influence of the ATR on trust of automation. The study concluded with a questionnaire and an interview at the end of the study. To obey the ethical guidelines people were debriefed after the study and the Wizard-of-Oz method was explained to them.

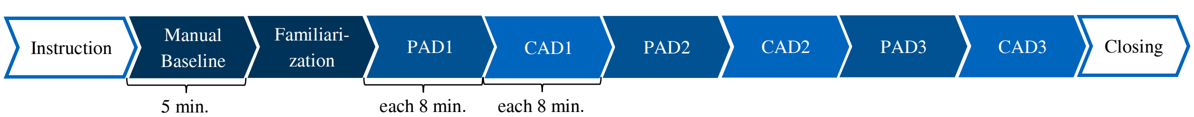



***Figure 6. Procedure of the Wizard-of-Oz study***

## RESULTS

The results of the dynamic driving simulator and the Wizard-of-Oz study will be explained separately and in a chronological order below.

### Study 1 - Dynamic driving simulator

38 participants were recruited in cooperation with a market research institute and received an appropriate monetary incentive. The participants did not work in the automotive industry and did not participate in an autonomous driving study 12 month prior to the study. $N = 5$ participants were excluded from the analysis due to a low understanding of the system. The low system understanding was determined in the questionnaire and the interview after the study and it was decided to exclude these participants due to defined requirement of a comparable mental model. Another $n = 3$ participants were excluded from the analysis because they refused to engage in the NDRT and consequently the visual attention to the road scene was not an appropriate objective measure for them. This resulted in a sample size of 30 participants. The 21 male and 9 female participants that were considered for the analysis were between the ages of 28 and 67 ($M = 46.27$ years, $SD = 11.38$). The participants were split into two groups, one without ATR ($n_{None\ ATR} = 16$) and the second with ATR during PAD ($n_{ATR} = 14$).

The monitoring behavior was assessed by the visual attention towards the road scene ahead in the different driving phases (BASELINE, PAD1, CAD and PAD2) and for the different PAD conditions with and without ATR. The left side displays with a boxplot diagram the mean values of the drivers' attention ratio to the road scene during the different driving phases. The mean value of the attention ratio to the road scene ahead is in PAD1 compared to the manual BASELINE for the group without ATR about 24.28 % and for the group with ATR about 31.82 % lower. In PAD1 no major effect of the ATR is visible, but the group with ATR shows a higher interquartile range (IQR) and the Median is lower than the 1st Quartile of the group without ATR. The monitoring behavior between PAD1 and CAD is distinguishable for both groups. The IQR increases for both groups from PAD1 to PAD2. The 1st Quartile for the group without ATR decreases from PAD1 (48.44 %) to PAD2 (36.68 %). This shows a decreasing monitoring behavior of the participants without ATR. Contrarily to this, the 3rd Quartile of the participants with ATR increases from PAD1 (60.46 %) to PAD2 (71.23 %) and represents an increasing monitoring behavior.

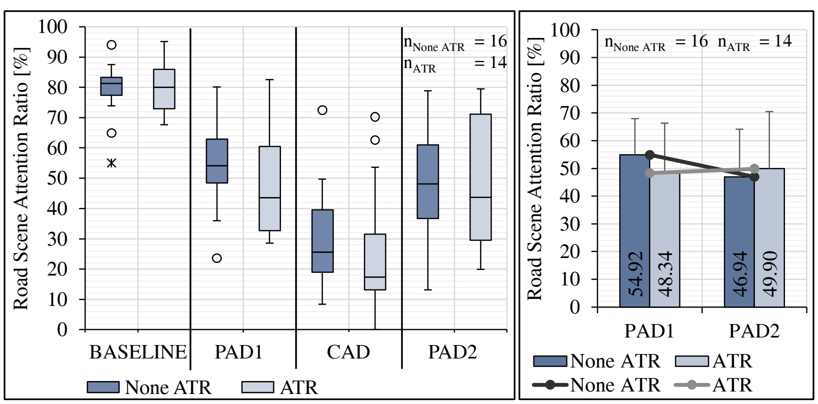



***Figure 7. Boxplots for the percentage of glance time at the road scene ahead separated by condition for the simulator study. Whiskers represent upper/lower hinges ± 1.5*IQR. 1st Quartile represents, that 25 % of the values are lower. 3rd Quartile represents, that 75 % of the values are lower. Right: Development of the percentage of glance time at the road scene separated by condition for the simulator study.***

The influence of the ATR on the visual attention to the road scene was also statistically analyzed. The two groups for PAD with and without ATR were the between-subject-factor and the measuring points PAD1 and PAD2 were the within-subject-factors, leading to a 2 x 2 analysis of variance. The development of the averages for both groups from PAD1 to PAD2 is shown in Figure 7 on the right side. The interaction effect for group and time of measure is significant ($F(1, 28) = 4.67$, $p = .039$). According to the development of the averages from PAD1 to PAD2 for both groups in the right diagram of Figure 7, this significant interaction effect shows, that the visual attention towards the road scene developed significantly different in dependence of the PAD-design with or without an ATR. The

averages also show that the visual attention for the group with ATR increases from PAD1 to PAD2 and decreases from PAD1 to PAD2 for the group without ATR.

**Study 2 - Wizard-of-Oz study on public highway**

49 participants were recruited in cooperation with a market research institute and received an appropriate monetary incentive. The participants did not work in the automotive industry and did not participate in an autonomous driving study 12 month prior to the study. $N = 7$ participants had to be excluded from the analysis due to technical problems with Dikablis. Another $n = 3$ participants were excluded from the analysis because variations of the surrounding traffic influenced the trust and the behavior of the participants essential, like for example cars that pass very close to the test vehicle. This resulted in a sample size of 39. The 21 male and 18 female participants considered for analysis were between the ages of 28 and 60 ($M = 45.15$ years, $SD = 9.30$). On average, they owned a driver's license for 26.74 years (SD = 9.32). The participants were split into two groups, one without ATR ($n_{None\ ATR} = 19$) and the second one with ATR during PAD ($n_{ATR} = 20$).

The monitoring behavior was assessed by the visual attention towards the road scene ahead in the different driving phases and for the different PAD conditions with and without ATR. The left side of Figure 8 displays with a boxplot diagram the mean values of the drivers' attention ratio to the road scene during the different driving phases. The mean values in PAD1 are for both groups approximately 9 % lower compared with the manual BASELINE. In PAD1 no major effect of the ATR is visible, however the group without ATR shows two outliers with very low attention ratio during PAD1. The IQR is increasing for the group without ATR from PAD1 (16.56) to PAD3 (29.64), also the minimum decreases to PAD3 (9.97 %). Contrary, the IQR for the group with ATR decreases from PAD1 (18.05) to PAD3 (12.64) and the minimum increases to PAD3 (59.97). The increase of the IQR for the participants without ATR shows a different monitoring behavior of the participants, due to some participants that monitored as good as the participants with ATR. However, in PAD3 at least 25 % of the participants without ATR showed a lower visual attention to the road scene than the minimum of the group with an ATR. The small IQR and absentee of outliers in PAD3 for the group with ATR shows, that there is a low variation in the monitoring behavior of the participants with an ATR. The monitoring behavior for both groups between PAD1 and CAD1 can be distinguished visually. Contrary to this is the difference between PAD3 and CAD3. For the group with ATR it can be clearly distinguished between the monitoring behavior for PAD3 and CAD3, due to no overlaps of the displayed boxplots. The participants without ATR show more similarities in the monitoring behavior for PAD3 and CAD3.

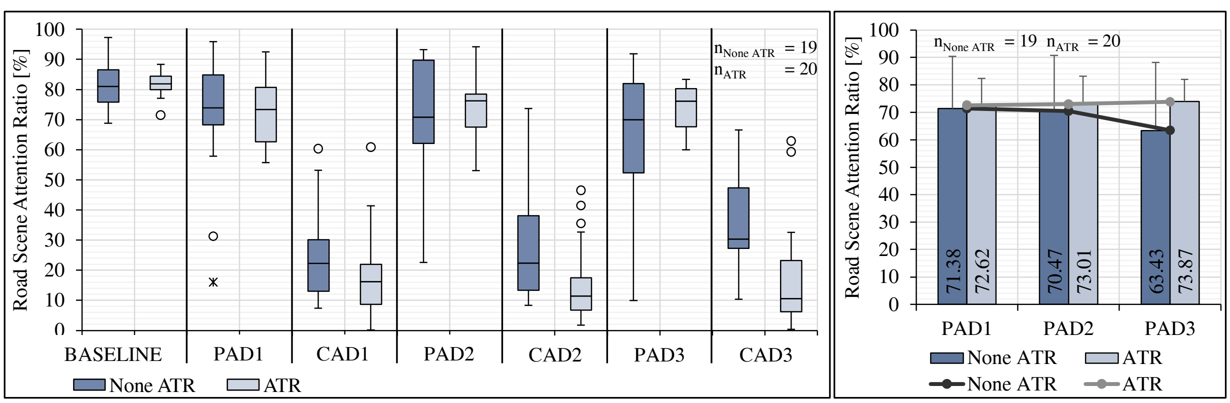



***Figure 8. Boxplots for the percentage of glance time at the road scene ahead separated by condition for the Wizard of Oz study. Whiskers represent upper/lower hinges ± 1.5*IQR. 1st Quartile represents, that 25 % of the values are lower. 3rd Quartile represents, that 75 % of the values are lower. Right: Development of the percentage of glance time at the road scene separated by condition for the Wizard of Oz study.***

The influence of the ATR on the visual attention to the road scene was also analyzed statistically. The two groups for PAD with and without ATR were the between-subject-factor and the measuring points PAD1, PAD2 and PAD3 were the within-subject-factors, that leads to a 2 x 3 analysis of variance. The development of the averages for both groups from PAD1 to PAD3 is shown in Figure 8 on the right side. The interaction effect for group and time of measure is significant ($F(1.47, 54.33) = 3.91$, $p = .038$). Mauchly's test indicated a violation of sphericity and a

Greenhouse-Geisser correction was applied. According to the development of the averages from PAD1 to PAD3 for both groups in the right diagram of Figure 8, this significant interaction effect shows, that the visual attention towards the road scene developed significantly different in dependence of the PAD-design with or without an ATR. The averages also show, that the visual attention to the rad scene increases for the group with ATR from PAD1 to PAD3 and decreases from PAD1 to PAD3 for the group without ATR.
The trust of the participants was assessed with a questionnaire (5-point-likert scale) prior to and after the test drive for each automation level with nine items from the standardized trust-questionnaire from Pöhler, Heine, and Deml [24]. Two participants from the group with ATR became no ATR during PAD, because they never took their eyes off the road for longer than 4 seconds during PAD. Consequently, for the evaluation of trust they are considered in the group without ATR, because the effect of the ATR should be investigated and they did not experience an ATR. The data was not normal distributed and therefore, statistically analyzed with a Mann-Whitney-U-Test for independent samples. There was no significant difference of trust in PAD prior to the test drive between the groups with and without ATR ($z = -0.28$, $p = .777$). After the test drive, the difference was investigated with a one-sided test as the hypothesis was directed. A significant different trust-level in PAD was found between the groups with and without ATR ($z = -1.66$, $p = .049$). According to the average values for the trust-level in Table 1, the participants with ATR had after the test drive a significant lower trust level in PAD than the participants without ATR.

***Table 1.***
***Trust in automation: 5-point-likert scale from -2 (no trust) to 2 (high trust) questionnaire from Pöhler et al. (2016).***

| | | Trust in automation | | | |
|---|---|---|---|---|---|
| | | *M* | *SD* | *α* | *N* |
| Prior to the test drive | $PAD_{None\ ATR}$ | 0.99 | 0.55 | .936 | 21 |
| | $PAD_{ATR}$ | 0.98 | 0.41 | .721 | 18 |
| | $CAD_{None\ ATR}$ | 1.12 | 0.52 | .815 | 21 |
| | $CAD_{ATR}$ | 0.97 | 0.54 | .815 | 18 |
| Following the test drive | $PAD_{None\ ATR}$ | 1.66 | 0.40 | .936 | 21 |
| | $PAD_{ATR}$ | 1.49 | 0.35 | .931 | 18 |
| | $CAD_{None\ ATR}$ | 1.68 | 0.55 | .911 | 21 |
| | $CAD_{ATR}$ | 1.70 | 0.29 | .849 | 18 |

*Note.* Average (*M*); Standard Deviation (*SD*); Cronbachs Alpha (*α*); Participants (*N*)

## DISCUSSION

To contribute to the reliable operation of level 2 and 3 automation in one vehicle, the aim of this paper was to understand how to secure driver supervision engagement during PAD, while intermittent CAD-phases. The question was how to influence the gaze behavior of the driver that he or she maintains the eyes on the road and that the supervision task will not be neglected over time due to for example arising overtrust. During PAD it is necessary that the driver has to unmistakably understand that it is an assistance system that needs an active driver to lead and share control. Therefore, we investigated the question how to prompt operators of a car with different levels of automation to pay attention to the roadway during PAD if they neglect their supervision task and how to differentiate between different levels of automation in one vehicle.
In a dynamic driving simulator study and a Wizard-of-Oz study in real traffic the influence of a gaze direction based ATR during PAD was investigated to develop and adjust a correct mental model for the levels of automation, to maintain drivers' mode awareness and to avoid arising overtrust. The ATR should bring the drivers gaze back to the road scene ahead, if he/she stops monitoring the driving task or starts engaging in a NDRT during PAD.

In both studies a worst-case approach concerning the two different levels of automation was used meaning that PAD and CAD were both Hands-Off systems and had the same functionality. This worst-case approach is most suitable to investigate differences in mode awareness from a safety in use perspective as in that case it is very difficult for the driver to distinguish between similar levels of automation.

As we wanted to measure mode awareness and compare it between different drivers, it is necessary, that every driver has a comparable knowledge about the used levels of automation due to the fact that the mental model is an underlying construct of mode awareness and is affected by the users' knowledge and previous experience with the used levels of automation [15]. Consequently, in both studies every participant was instructed with a detailed description of the different levels of automation by video and text and the participants' knowledge about the levels of automation was controlled by the investigator.

We investigated the influence of the ATR on the visual attention to the road scene during PAD, on the change of the visual attention during the course of alternating PAD and CAD and on the trust in automation.

The results of the simulator study showed that the ATR can reduce the negative influence of an intermediating CAD phase and can help the driver to develop a more correct monitoring behavior during PAD. However, in PAD 1 no major effect of ATR was measured. We found that the group without ATR during PAD1 showed a slightly higher, but not significantly relevant visual attention to the road scene, compared to the group with ATR. This difference in PAD1 can have various reasons. One reason might be the individual driving-related risk-taking of the participants. One can conclude that the random classification of the participants in the groups with and without ATR is a worst-case approach, because it looks like that there are more people with higher driving-related risk-taking or a faster increasing overtrust in PAD in the group with ATR than in the group without ATR, hampering to find significant results.

However, the visual attention increased for the group with ATR from PAD1 to PAD2 and decreased for the group without ATR. The significant interaction effect shows that the ATR increased the visual attention to the road scene from PAD1 to PAD2 in spite of an intermittent CAD-phase.

Also in the Wizard-of-Oz study for the development of the visual attention to the road scene from PAD1 to PAD3 a significant interaction effect of the ATR was measured. Thus, the supervision behavior for the group with ATR increased whereas for the group without ATR it decreased. Consequently, the ATR influenced the development of the monitoring behavior during PAD and was improving it. The visual attention towards the road scene was similar in PAD1 for both groups, except of two outliers in the group without an ATR that showed a very low monitoring behavior during PAD1. From PAD1 to PAD3 more participants in the group without ATR showed a very low monitoring behavior, consequently the lower whiskers of the boxplot (1.5*IQR) included the outliers in PAD2 and PAD3. Contrary to this, there were no outliers during the PAD-phases for the group with ATR and the minimal visual attention to the road scene ahead was 59.97 % in PAD3, whereas the minimal attention ratio for the group without ATR was 9.97 %. For the group without ATR more than 25 % of the participants showed a low monitoring behavior during PAD3, whereas for the group with ATR the drivers showed a very high monitoring behavior in PAD3.

This shows, that also in the Wizard-of-Oz study the ATR helped to prompt drivers not to neglect their monitoring task. Moreover, the group without ATR showed an increasing IQR from PAD1 to PAD3 whereas the group without ATR had a decreasing IQR. Consequently, the ATR was able to counterbalance the negative influence of intermittent CAD-phases.

Furthermore, both studies showed that the ATR helped the drivers to distinguish between level 2 and level 3. The visual attention to the road scene showed that drivers with ATR could better distinguish between level 2 where they had to monitor the driving task and level 3 where they were allowed to engage in NDRT and where it was therefore not necessary to apply a high monitoring behavior. Especially, in the Wizard-of-Oz study in which drivers had due to the design of the study more frequent changes from PAD to CAD the effect of distinctiveness it can be clearly seen.

The monitoring behavior for the group with and without ATR between PAD1 and CAD1 can be distinguished visually. Contrary to this is the difference between PAD3 and CAD3. For the group with ATR it can clearly be distinguished between the monitoring behavior for PAD3 and CAD3, due to no overlaps of the displayed boxplots. The participants without ATR showed more similarities in the monitoring behavior for PAD3 and CAD3 as for them the borders became blurred. The results show that over time it became more and more difficult for the drivers do

distinguish between level 2 and 3 without any feedback of the system when they didn`t behave correctly. Whereas, for the drivers with ATR even after a while of driving in level 2 and level 3 automation mode PAD3 and CAD3 were still clearly distinguishable.
Thus, the ATR can help drivers to establish distinctiveness between level 2 and 3. The ATR can bring the drivers gaze back to the road scene ahead, if he/she stops monitoring the driving task or starts engaging in a NDRT during level 2.
Even though the mental model might not be exhaustive enough from beginning on or might be neglected over time the ATR can help the driver to develop and adjust a correct mental model for the levels of automation, to maintain drivers' mode awareness and to avoid arising overtrust.
Moreover, in the Wizard-of-Oz study participants' trust into the automated systems was conducted before and after the test drive by a questionnaire from Pöhler et al. (2016). The trust level in PAD and CAD before the test drive was similar for the group with and without ATR. By experiencing the PAD- and CAD-system during the test drive the trust level increased for both groups in PAD and in CAD. However, the participants that were in the group with ATR had a significant lower trust level in PAD after the test drive compared to the group without ATR. Thus, the ATR can help to calibrate an adequate trust level in PAD like it is required for the safe use of automated systems [4].

**Conclusion**

In two different study environments (dynamic driving simulator and real traffic) the gaze direction based ATR was proven to be an effective measure that can calibrate an adequate trust level and maintain mode awareness, if SAE level 2 systems (PAD) and SAE level 3 systems (CAD) are combined in one vehicle.
Hereby, the development of the visual attention towards the road scene during PAD increased in both studies for the group with ATR after an intermittent CAD-phase and decreased for the group without ATR. This difference in the development of the visual attention between the groups with and without ATR was significant.
This result helps to take the next step in the implementation of such combined multilevel systems for advanced driver assistance.

**Limitations and Implications for Further Research**

Despite the promising results, it has to be considered that the studies are only a first glance on the behaviors of the drivers, during their first contact with level 2 and level 3 systems. Further studies should investigate the long term effect of an ATR to evaluate whether it is effective in the long run.
Moreover, further research concerning the characteristics of the ATR is necessary. It might be for example helpful to introduce a stage before the investigated first stage of the ATR where a pop-up message appears in the instrument cluster, the LED-bars start to flash green and the indication sound chimes to increase the visual attention during level 2. One solution might be an additional silent announcement in the instrument cluster for example after 2 seconds eyes-off time that can encourage drivers to continuously monitor a level 2 automation system and helps to bring the drivers gaze more quickly back to the road scene. Furthermore, the ATR is based on purely visual distraction. However, another key component of driver engagement that should be investigated is the cognitive distraction. Attention and understanding are often implicitly mixed together in descriptions of monitoring. However, it might for example be possible that the driver looks at the road scene but can't act as he or she is cognitively distracted.
Moreover, in both studies every participant was instructed with a detailed description of the level 2 and 3 systems by video and text and the correct understanding was controlled by the instructor. This approach was necessary as we wanted that every driver has a comparable mental model about the used levels of automation to measure mode awareness and compare it between different drivers. But, further studies are necessary that investigate the effectiveness of the ATR without such a detailed instruction of the system.
Furthermore, in both studies PAD was implemented with a high reliability that was close to ideal and there were no situations during the PAD phases that would have reminded the drivers about their monitoring task. This worst case was chosen to investigate participants' behavior in full width, but it could also have caused the development of overreliance. Therefore, future studies should investigate whether overreliance also occurs in a more realistic system design.

**ACKNOWLEDGEMENT**

We thank Anna Feldhütter from the Chair of Ergonomics of the Technical University of Munich for the scientific support and the helpful amendments concerning the Wizard of Oz study that was conducted within a Master's thesis.

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